NUMERO: 2367A

ANNO: 2018

A P P U N T I

STUDENTE: Sobrero Giovanni

MATERIA: Materials for Mechanical Industries - Prof. Ubertalli

Materials for Mechanical Industries (MMI) (6 cfu)

Professor

MMI: Prof. Graziano Ubertalli

Giovanni Sobrero's Schemes

A.A. 2017 – 2018

2017 – 2018 Program

Powder metallurgy technology. Powders (types and properties), compacting pressing (materials classes, types of dies, methods), sintering (furnaces, atmospheres, operating conditions, mechanism) post-treatments, products.
Corrosion. Anodic and cathodic behavior. Oxygen, temperature and solution concentration influences. Galvanic corrosion coupling different materials or in case of different phases. Active and passive behavior of stainless steels. The different types of corrosion. Protection methods of metallic materials.
Stainless steels. Schaeffler and De Long diagram. Stainless steels classes and designation. Heat treatment, welding, deformability and tool work-ability. Surface finishing. Sanification. Metallic ions release.
Tool steels. Cold and hot working classes. Heat treatments and tempering parameter. High speed steels.
Deep drawing steels and aluminum alloys for "Body in White" car components.
Surface coating technologies and materials.
Titanium alloys. Grades, alloying elements, phase diagrams, properties, heat treatments, influence of microstructure. Applications and products.
Metallic materials microstructure and failure analysis: fracture modes and morphologies.

Criteria, rules and procedures for the exam

During the exercises practice in teams, the professor helps in the development of the exercise and verifies the level of student learning.
The exam is written (exercises, open and multiple responses) with, eventually, an oral colloquium.
Any materials and forms will be provided by the teachers
The final mark is assigned considering the score obtained in the written test and the level of knowledge of subjects in the subject.

MATERIALS FOR MECHANICAL INDUSTRIES

ENGLISH - ITALIAN

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GIOVANNI SOBRERO 'S SCHEMES

A.A. 2017 - 2018

MAIN TOPICS

0. REVISION
1. POWDER METALLURGY TECHNOLOGY
2. CORROSION
3. STAINLESS STEELS
4. TOOL STEELS
5. TITANIUM ALLOYS
6. METALLIC MATERIALS MICROSTRUCTURE AND FAILURE ANALYSIS.

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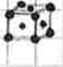
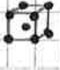
0. REVISION : INTRODUCTION OF METALLIC MATERIALS

GENERAL FEATERS OF METALLIC MATERIALS (6)

- METALLIC BONDS (LEGAMI METALLICI)
- HIGH PLASTIC STRAIN (ELEVATA DEFORMAZIONE PLASTICA)
- HARDENED AFTER WORK HARDENING
- THE MAIN ALLOYS ARE DUCTILE
- THEY ARE COMPOSITE METALLIC MATERIALS (COMPOSITE agg = A STRUTTURA MISTA)
- THEY SHOW A WIDE RANGE OF CHEMICAL , PHYSICAL AND TECHNOLOGICAL PROPERTIES.

LATTICE STRUCTURES OF METALLIC MATERIALS (STRUTTURE RETICOLARI)

- **FCC** : FACE CUBIC CENTERED 

  (IRON 907 - 1400 °C , COPPER , SILVER , GOLD , NICKEL , ALUMINIUM , LEAD (PIOMBO) , PLATINUM)
- **BCC** : BODY CUBIC CENTERED 

  (IRON < 907 °C , > 1400 °C , TUNGSTEN , VANADIUM , MOLYBDENUM , CHROMIUM , ALCALINE METALS)
- **HCP** : COMPACT HEXAGONAL 

  (ZINC , MAGNESIUM , TITANIUM , ZIRCONIUM , BERYLION , CADMIUM , COBALT)

THEY ARE HIGH PACKING STRUCTURES : METAL ATOMS HAVE THEIR MINIMUM FREE ENERGY WHEN THEY ARE VERY CLOSE TO EACH OTHER.

(LATTICE/RETICULAR STRUCTURES)

- **BCC : BODY CUBIC CENTERED** 

(IRON < 907°C, >1400°C, TUNGSTEN, VANADIUM, MOLYBDENUM, CHROMIUM, ALCALINE METALS (Na, K))

IT IS A UNITARY CUBIC CELL IN WHICH THERE IS A CENTRAL ATOM AND AN ATOM AT EACH VERTEX OF THE CUBE.

- n OF ATOMS PER CELL = $\left(8 \cdot \frac{1}{8} + 1\right) = \textcircled{2}$
- COORDINATION NUMBER = NUMBER OF ATOMS NEAR WHICH AN ATOM IS BOUND = $\textcircled{8}$

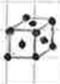
(I PUT MYSELF IN THE ROLE OF AN ATOM AND I SEE HOW MANY ATOMS THERE ARE NEAR)

- APF : ATOMIC PACKING FACTOR (FATTORE DI COMPATTAZIONE ATOMICA)

$$\boxed{APF = \frac{n \text{ OF ATOMS PER CELL} \cdot \text{SINGLE ATOM VOLUME}}{\text{CELL VOLUME}}} = \frac{2 \cdot \frac{4}{3}\pi R^3}{a^3} = \frac{2 \cdot \frac{4}{3}\pi\left(\frac{\sqrt{3}}{4}a\right)^3}{a^3} = \textcircled{0.68}$$

$\left(4R = \sqrt{3}\,a \Rightarrow R = \frac{\sqrt{3}}{4}a\right)$

- THE DIRECTION WITH THE HIGHEST PACKING IN THE LATTICE BCC IS THE $\langle 111 \rangle$ (LINEAR DENSITY = 100%)
- THE PLAN WITH THE HIGHEST PACKING IN THE LATTICE BCC IS THE $\{110\}$ (PLANAR DENSITY = 88%)

- **FCC : FACE CUBIC CENTERED** 

(IRON 907-1400°C, COPPER, SILVER, GOLD, NICKEL, ALUMINIUM, LEAD, PLATINUM)

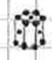
IT CONSISTS OF A UNITARY CUBIC CELL WITH ATOMS ARRANGED AT THE VERTICES OF THE CUBE AND AT THE CENTER OF EACH FACE.

- n OF ATOMS PER CELL = $\left(8 \cdot \frac{1}{8} + 6 \cdot \frac{1}{2}\right) = \textcircled{4}$
- COORDINATION NUMBER = $\textcircled{12}$
- $APF = \frac{n \text{ OF ATOMS PER CELL} \cdot \text{SINGLE ATOM VOLUME}}{\text{CELL VOLUME}} = \frac{4 \cdot \frac{4}{3}\pi R^3}{a^3} = \frac{4 \cdot \frac{4}{3}\pi\left(\frac{a}{2\sqrt{2}}\right)^3}{a^3} = \textcircled{0,74}$

$\left(a = 4R \cdot \cos 45 = 4R\frac{\sqrt{2}}{2} \Rightarrow R = \frac{a}{2\sqrt{2}}\right)$

- THE DIRECTION WITH THE HIGHEST PACKING IN THE LATTICE FCC IS THE $\langle 110 \rangle$ (LINEAR DENSITY = 100%)
- THE PLAN WITH THE HIGHEST PACKING IN THE LATTICE FCC IS THE $\{111\}$ (PLANAR DENSITY = $\textcircled{90.7\%}$)

(NB!: FCC LENDS ITSELF MORE TO PLASTIC DEFORMATION)

- **HCP : COMPACT HEXAGONAL**  (OR HEXC)

(ZINC, MAGNESIUM, TITANIUM, ZIRCONIUM, BERYLIUM, CADMIUM, COBALT)

UPPER AND LOWER FACES: SIX ATOMS FORM A REGULAR HEXAGON CONTAINING AN ATOM IN THE CENTER.
+ AN INTERMEDIATE PLANE CONSISTING OF THREE ATOMS.

- n OF ATOMS PER CELL = $\textcircled{6}$
- COORDINATION NUMBER = $\textcircled{12}$
- APF = $\textcircled{0.74}$

	n PER CELL	COORDIN. n	APF
BCC	2	8	0.68
FCC	4	12	0.74
HCP	6	12	0.74

IT IS A VERY DENSE STRUCTURE SIMILAR TO LATTICE FCC (SAME $n_{COORD} = 12$, APF = 0.74)

FCC AND HCP CAN BE DESCRIBED AS TWO VARIANTS OF THE SAME LATTICE (/RETICULAR) STRUCTURE.

REMEMBER: [xyz] FOR A SPECIFIC DIRECTION ; <xyz> FOR THE CRYSTALLOGRAPHICALLY EQUIVALENT DIRECTIONS. (hkl) FOR A SPECIFIC CRISTALLOGRAPHIC PLAN ; {hkl} FOR THE CRYSTALLOGRAPHICALLY EQUIVALENT (= PARALLEL) PLANS. (hkl) = MILLER INDICES : $(hkl) = \left(\frac{1}{x}\frac{1}{y}\frac{1}{z}\right)$; $\{hkl\} = \left\{\frac{1}{h}\frac{1}{k}\frac{1}{l}\right\}$

LATTICE DEFECTS

1) PUNCTUAL:

- VACANCIES
- INTERSTITIAL ATOMS
- SUBSTITUTIVE ATOMS

2) LINEAR:

- DISLOCATIONS

3) PLAIN: (DIFETTI DI AREA)

- GRAIN BOUNDARIES (BORDI DI GRANO)

4) VOLUME:

- STACKING FAULTS ("ERRORI" DI IMPILAMENTO)

(MANCANZA)
VACANCY = LACK OF AN ATOM IN THE LATTICE

ARRHENIUS LAW : $\boxed{N_v = N\,\mathrm{EXP}\left(-\frac{Q_v}{kT}\right)}$ = NUMBER OF VACANCIES

N = TOTAL NUMBER OF ATOMIC SITES

Q_v = ENERGY REQUIRED FOR THE FORMATION OF ONE VACANCY

T = ABSOLUTE TEMPERATURE [K]

k = BOLTZMAN CONSTANT

VACANCIES JUSTIFY THE MOTION OF CHEMICAL ELEMENTS IN THE LATTICE:

$\boxed{D = D_0\,\mathrm{EXP}\left(-\frac{Q}{RT}\right)}$: EXPRESSES THE MOBILITY OF CHEMICAL SPECIES IN RELATION TO TEMPERATURE.

DISLOCATIONS: THEY ARE LATTICE IMPERFECTIONS THAT EXTEND ALONG ONE DIRECTION. OBSERVED AT HIGH MAGNIFICATIONS, THEY APPEAR AS IRREGULARLY SHAPED LINES.

- ANGULAR DISLOCATIONS (DISLOCAZIONI A SPIGOLO)
- SCREW DISLOCATIONS (DISLOCAZIONI A VITE) OR PROPELLER DISLOCATIONS (A ELICA)
- DISLOCATIONS OF MIXED TYPE

DISLOCATIONS AND FORCES - SCHMIDT'S LAW

WHAT CAUSES THE DISLOCATIONS TO MOVE ARE THE CUTTING FORCES ACTING ON THE PLANE ON WHICH THE DISLOCATIONS MOVE: SLIP PLANE.

THE TANGENTIAL STRESS τ WHICH WORKS (ON THE INCLINED AREA $A_s = A/\cos\varphi$) IS:

$\boxed{\tau = \sigma\cos\lambda\cos\varphi}$, $\sigma = \frac{F}{A}$ (τ = SHEAR STRESS = SFORZO DI TAGLIO)

φ = ANGLE BETWEEN THE NORMAL TO THE SLIP PLANE AND THE DIRECTION OF F.

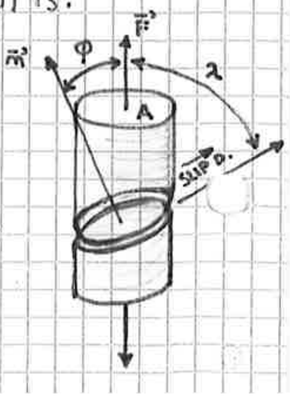
λ = ANGLE BETWEEN THE SLIP DIRECTION AND THE DIRECTION OF F.

THIS EQUATION EVIDENCES THAT THE MAXIMA SHEAR STRESSES ARE OBTAINED FOR:

$\varphi = (90° - \lambda) = 45°$ ($\Rightarrow \lambda = 45°$; $\varphi = 45°$)

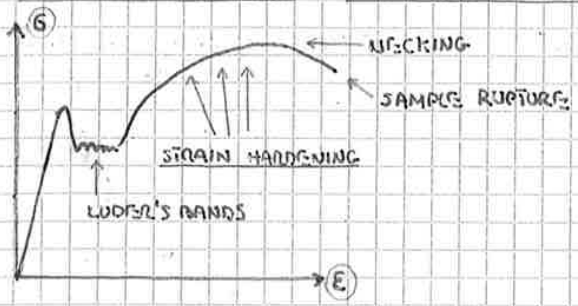
WHICH GIVES:

$\tau = 0.5\,\sigma = 0.5\,(F/A)$

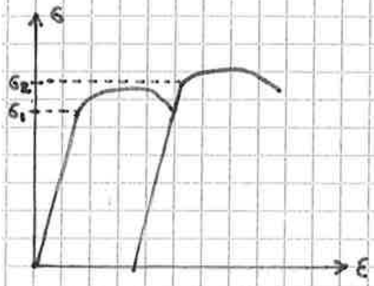


c) STRAIN HARDENING (INCRUDIMENTO)

PLASTIC DEFORMATION → INCREASE OF DISLOCATIONS DENSITY → BLOCK OF MOVEMENT OF DISLOCATIONS



A METAL ALREADY DEFORMED IS LESS EASILY DEFORMABLE : WORK/STRAIN HARDENING



AT σ_1 : SUFFICIENT STRENGTH TO START THE FIRST DISLOCATIONS.

THE DISLOCATIONS MOVE AND MULTIPLY.

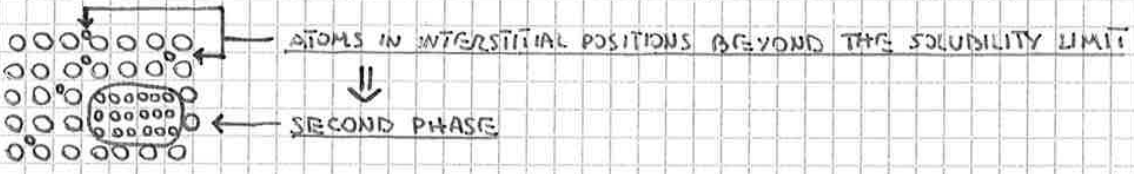
REMOVED THE LOAD, AN ELASTIC RECOVERY FOLLOWS.

(INNESCARE)

WE CAN DO THIS MANY TIMES. AT EACH CYCLE THE LOAD NECESSARY TO TRIGGER THE PLASTIC DEFORMATION INCREASES.

d) PRECIPITATION OF A SECOND PHASE (CHEMICAL METHOD)

ALLOY ELEMENTS ARE INSERTED BEYOND THE SOLUBILITY LIMIT. → PRECIPITATION OF A SECOND PHASE. THE DISLOCATIONS MOVE HARDLY IN THE SECOND PHASE.



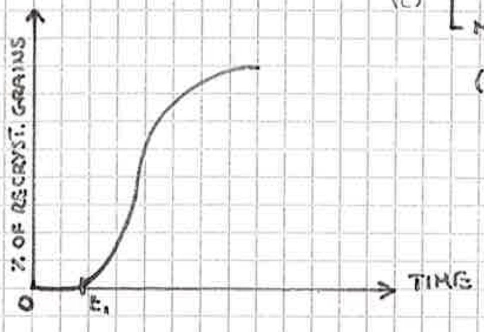
THIS IS THE STARTING POINT FOR THE NUCLEATION OF NEW CRYSTALLINE GRAINS WITH A LOW CONTENT OF DISLOCATIONS INSIDE THEM (MATERIAL NO LONGER HARDENED).

AT WHAT TEMPERATURE? HOW LONG? IF T IS HIGH ⇒ LESS TIME.

RECRYSTALLIZATION (HARDENING + HEATING)

(ε) (T)

MEANS: RECRYSTALLIZATION ENERGY = WORK-HARDENING ENERGY (OR ENERGY OF THE STRAIN) + HEATING ENERGY



$(0-t_1)$: RECOVERY: THERE IS NO CHANGE OF THE PRE-EXISTING CRYSTALLINE GRAINS.

(t_1): NUCLEATION: THE FIRST NEW CRYSTALS WITH A LOW CONTENT OF DISLOCATIONS ARE BORN.

IN THE END, AFTER A CERTAIN TIME, WE WILL HAVE COMPLETE RECRYSTALLIZATION.

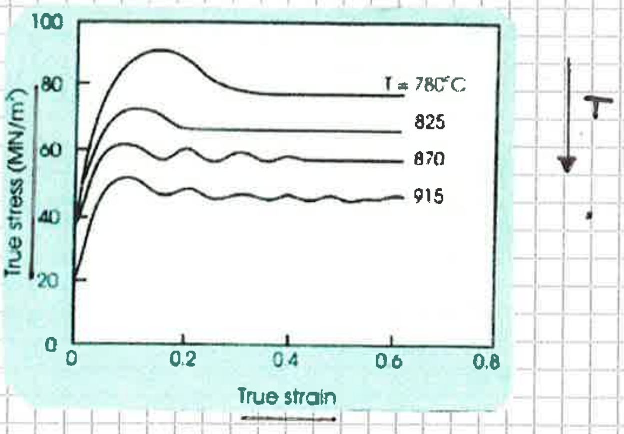
IT IS A KINETIC PROCESS WITH A NUCLEATION TIME AND A TIME OF MANIFESTATION.

TIME DEPENDS ON TEMPERATURE; TEMPERATURE MUST BE BETWEEN:

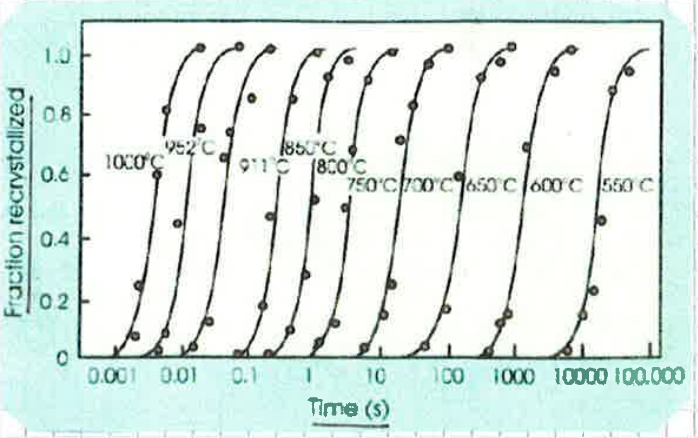
$$\boxed{\frac{T_M}{3} < T < \frac{T_M}{2}}$$

NOTE: IF $T > \frac{T_M}{2}$ THE MATERIAL RECRYSTALLIZES EVEN IF IT HAS NOT BEEN DEFORMED.

SUPERPLASTICITY PHENOMENON



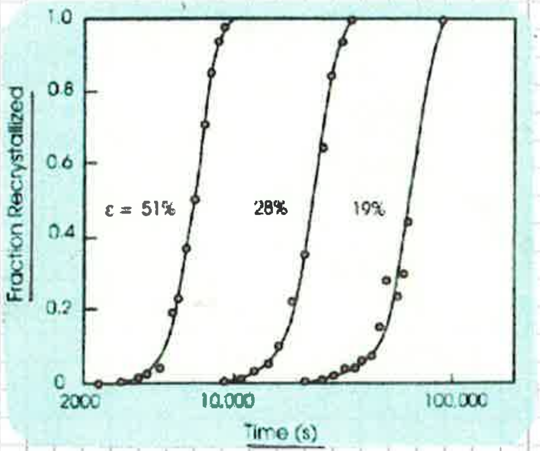
INFLUENCE OF TEMPERATURE [T]



← REFERRED TO A Fe - 3,5%Si DEFORMED WITH $\varepsilon = 60\%$

$\boxed{T \nearrow \Rightarrow t \searrow}$

INFLUENCE OF THE STRAIN [ε]

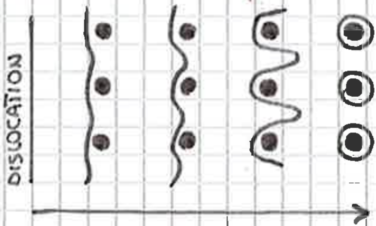


← REFERRED TO A Al-ALLOY HEATED AT 350[°C]

RECRYSTALLIZATION, IF THE MATERIAL HAS A GREATER ENERGY LINKED TO THE CONTRIBUTION OF PLASTIC DEFORMATION, MANIFESTS BEFORE AND ENDS EARLIER.

$\boxed{\varepsilon \nearrow \Rightarrow t \searrow}$

DEEPENING - DISLOCATIONS: OROWAN THEORY (HARDENING MECHANISM)



THE SECOND PHASE PRECIPITATES ARE "CROWNED" BY THE DISLOCATIONS AND GET LARGER.

=> THE NEXT DISLOCATIONS WILL FIND LARGER OBSTACLES AND WILL NEED MORE ENERGY TO TRANSPASS.

=> THE MORE A MATERIAL IS DEFORMED ($\varepsilon \nearrow$) THE HIGHER ENERGY TO DEFORM IT AGAIN. (HARDENING MECHANISM).

A POWDER CAN BE DEFINED AS A FINELY DIVIDED SOLID PARTICULATES.

ENGIGNEERING POWDERS INCLUDE METALS AND CERAMICS.

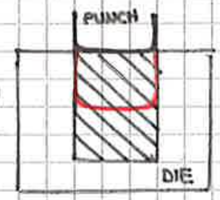
1.2 COMPLETE CYCLE OF PRODUCTION

1) POWDER PREPARATION Ⓐ Ⓑ Ⓒ

2) MIXING: IF THE MIX PROCESS IS NOT WELL DONE, BIGGEST PARTICLES TEND TO GO TO THE BOTTOM OF THE SHAPE

3) FORMING: TO CREATE A PHISICAL BOND BETWEEN THE PARTICLES Ⓐ Ⓑ Ⓒ Ⓓ

4) SINTERING: HEATING AT T BELOW THE MELTING POINT INTO A FORNACE



5) SECONDARY OPERATIONS
- 5.1 REPRESSING
- 5.2 SIZING
- 5.3 COINING
- 5.4 MACHINING

6) JOINING AND WELDING

7) HEAT AND/OR THERMOCHEMICAL TREATMENTS

8) FINAL PRODUCT ←

1) POWDER PREPARATION

THE MAIN PREPARATION METHODS ARE:

Ⓐ ATOMIZATION

Ⓑ CHEMICAL METHOD

Ⓒ MECHANICAL METHOD

Ⓐ ATOMIZATION

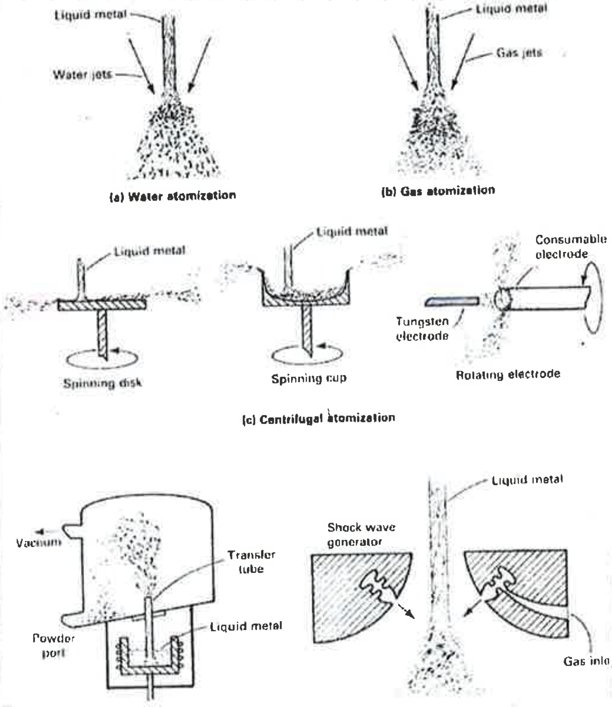
ⓐ WATER ATOMIZATION

ⓑ GAS ATOMIZATION

ⓒ CENTRIFUGAL ATOMIZATION

ⓓ VACUUM ATOMIZATION

ⓔ ULTRASONIC GAS ATOMIZATION



(a) Water atomization

(b) Gas atomization

(c) Centrifugal atomization

(d) Vacuum (soluble gas) atomization

(e) Ultrasonic gas atomization

Ⓑ CHEMICAL METHOD

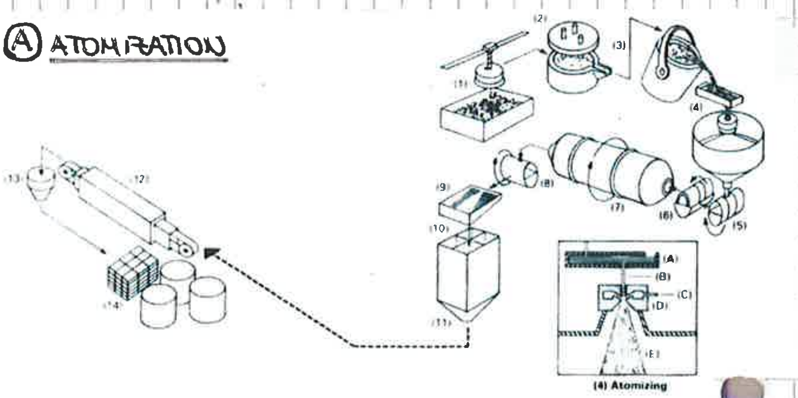
ⓐ OXIDES REDUCTION

ⓑ PRECIPITATION FROM SOLUTION

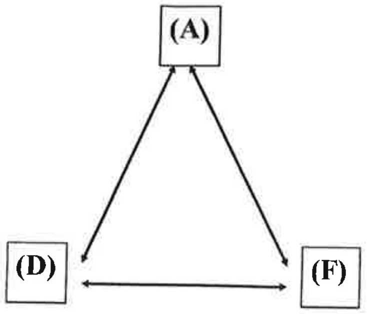
ⓒ THERMAL DECOMPOSITION

Ⓒ MECHANICAL METHOD ⇨

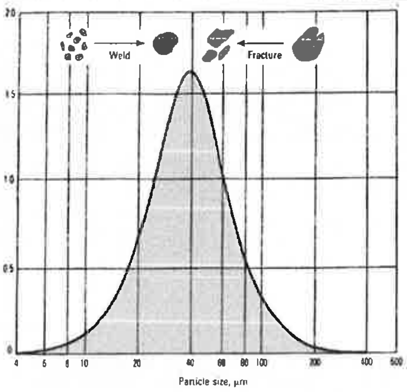
Ⓐ ATOMIZATION



(1) Iron wrecks selection. (2) Arc furnace. (3) Melted steel. (4) Atomization: (A) ladle, (B) liquid steel, (C) high pressure water, (D) nozzle, (E) atomized iron powder. (5) Wet magnetic separation. (6) Water elimination. (7) Dry rotating. (8) Magnetic separation. (9) Selection. (10) Homogenization. (11) Automatic packaging. (12) Continuous furnace annealing at 800-900 °C. (13) Homogenization. (14) Packaging.

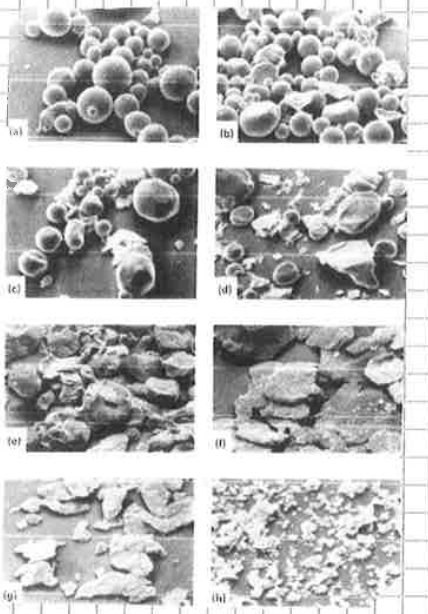


(A) Agglomeration
(F) Fracture
(D) Plastic deformation



Particle size distribution of powder produced *with* mechanical methods.

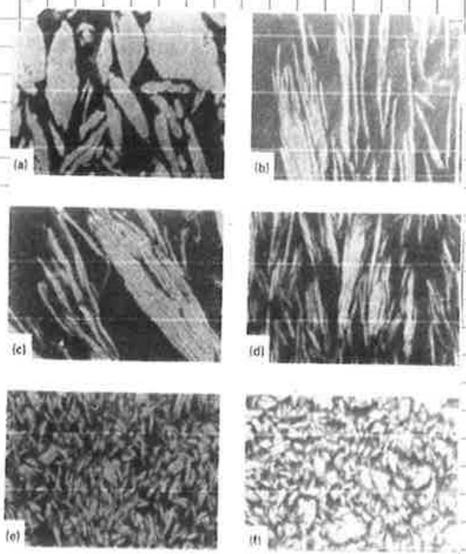
EXAMPLE: COBALT



Cobalt base alloy – spherical particles - mechanical method.
(a) As received ,
(b) after 1 hour,
(c) after 2 hours,
(d) after 4 hours,
(e) after 8 hours,
(f) after 16 hours,
(g) after 32 hours,
(h) after 64 hours.

EXAMPLE:

ELECTROLYTIC IRON



Electrolytic Iron – transversal section.
(a) As received,
(b) after 4 hours,
(c) after 8 hours,
(d) after 16 hours,
(e) after 32 hours,
(f) after 64 hours.

POWDER PROPERTIES:

- POWDER CLEANING

2) MIXING

(([illegible] OF MIXING; OBJECTIVE (TO OBTAIN...); MIX PROCESS (HOW IS MIX DONE))

TO HAVE A OMOGENEOUS POWDER ! I NEED TO PRODUCE THOUSAND OF THE SAME ITEM WITH THE SAME CHARACTERISTICS.

- EXPLOSIVITY: THE RATE OF OXIDATION COULD BE TOO HIGH THAT THE POWDER COULD EXPLODE

  MOSTLY FOR POWDERS OF Zr, Mg, Al, Li, Na : THOSE POWDERS REQUIRE A LOW O CONTENT (<3%) DUE TO THE LOW BURNING T (< 600[°C])

  HIGH: (Zr, Mg, Al, Li, Na) 20-50 [g/m³] of O? REQUIRED TO EXPLOSION

  MEDIUM: (Zn, Fe) 100-500 [g/m³] REQUIRED TO EXPLOSION

  LOW: (Mo, Co) POWDERS WITH BURNING T ≈ 700 [°C]

  SELF BURNING POWDER: POWDERS CAN SELF BURN; DEPEND ON $\frac{\text{SURFACE}}{\text{VOLUME}}$ RATIO

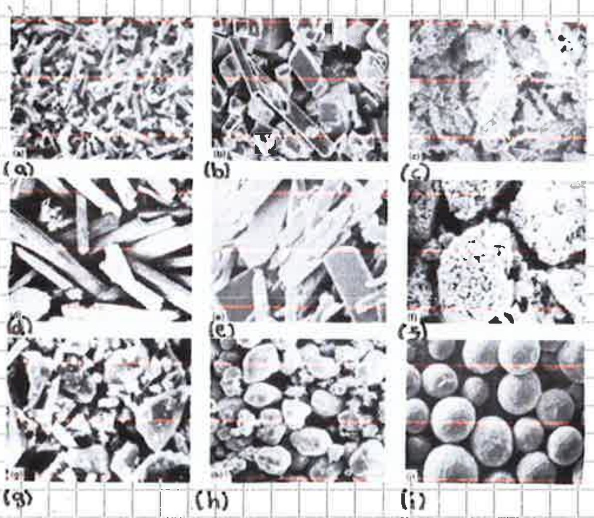
- TOXITY
- LUBRICANTS

CHARACTERIZATION:

MESH NUMBER ↗	MICROMETERS ↘
80	177
400	37

POWDER PARTICLES SHAPE:

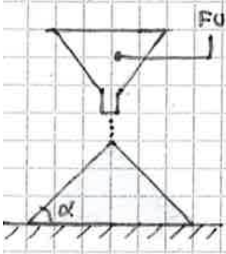
(a) NEEDLE LIKE PARTICLES (AGHIFORMI)
(b) ANGULAR PARTICLES
(c) DENDRITIC PARTICLES
(d) FIBROUS PARTICLES
(e) FLAT PARTICLES
(f) GRANULAR PARTICLES
(g) IRREGULAR PARTICLES
(h) NODULAR PARTICLES
(i) SFERICAL PARTICLES



INTERPARTICLE FRICTION AND FLOW CHARACTERISTICS (ANALYSIS)

FRICTION BETWEEN PARTICLES AFFECTS ABILITY OF A POWDER TO FLOW READILY (PRONTAMENTE) AND PACK TIGHTLY.

A COMMON TEST OF INTERPARTICLE FRICTION IS THE ANGLE OF REPOSE (α), WHICH IS THE ANGLE FORMED BY A PILE OF POWDERS AS THEY ARE POURED (VERSATI) FROM A NARROW (STRETTO) FUNNEL (IMBUTO).

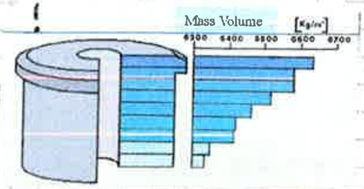


α = ANGLE OF REPOSE

- SMALLER PARTICLE SIZES GENERALLY SHOW GREATER FRICTION AND A STEEPER ANGLE OF REPOSE.
- SPHERICAL SHAPES HAVE THE LOWEST INTERPARTICLE FRICTION

⇒ AS SHAPE DEVIATES FROM SPHERICAL, FRICTION BETWEEN PARTICLES TENDS TO INCREASE; SO THE α RESULTS STEEPER.

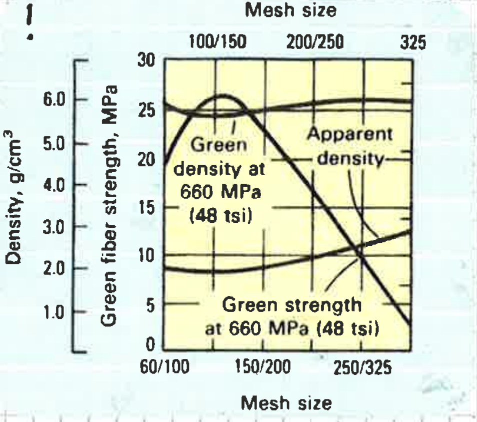
!



A GRADIENT IN THE DENSINTY IS EVIDENT. (IN THE PRESSING DIRECTION)

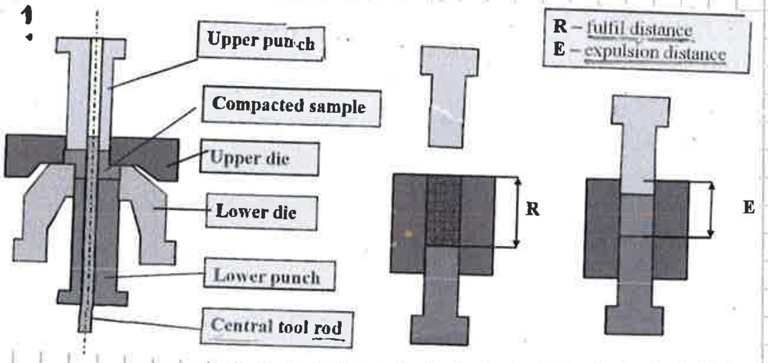
INFLUENCE OF PARTICLES DIMENSION ⇒ "GREEN STRENGTH"

!



SCHEME OF A RIGID DIE AND THE TYPICAL VERTICAL MOVEMENT IN PRESSING

!



COMPONENT CLASSES

CLASS I : COMPONENTS WITH A SINGLE THICKNESS AND ONLY ONE SIDE PRESSED ; THEY COULD HAVE A CHANGE OF DENSITY IN THE PRESSING DIRECTION.

CLASS II : COMPONENTS WITH A SINGLE THICKNESS AND PRESSED FROM TWO OPPOSITE SIDES.

CLASS III : COMPONENTS WITH TWO THICKNESS AND PRESSED FROM TWO SIDES

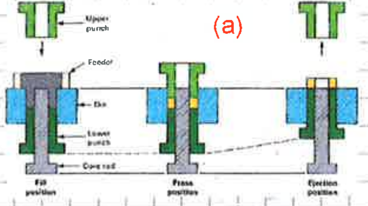
CLASS IV : COMPONENTS WITH MORE THAN TWO THICKNESS AND PRESSED FROM TWO SIDES.

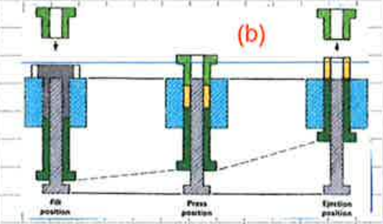
TYPES OF DIE

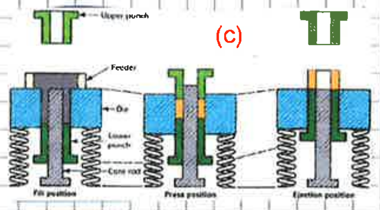
(a) SIMPLE EFFECT DIE

(b) DOUBLE EFFECT DIE

(c) FLOATING DIE

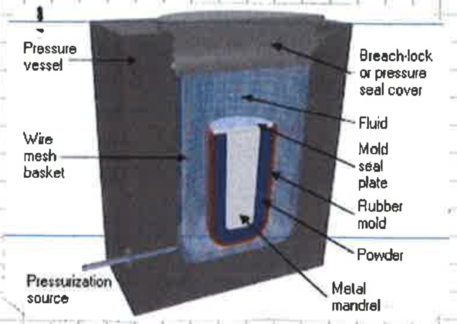






Ⓑ ISOSTATIC PRESSING OF POWDER IN FLEXIBLE DIES

IN THE ISOSTATIC COMPRESSING THE POWDERS ARE INSERTED IN AN ELASTIC DEFORMABLE DIE AND UNDERGO A ISOSTATIC PRESSURE.

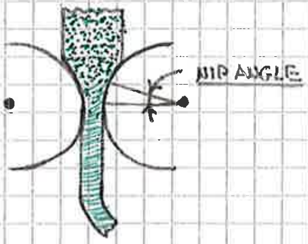


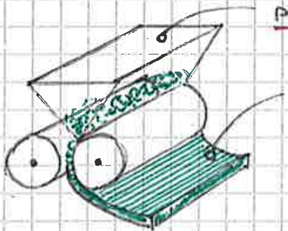
- COLD ISOSTATIC PRESSING (CIP): THE DIE IS A POLYMERIC MATERIAL AND THE FLUID ADOPTED TO TRANSMIT PRESSURE IS WATER.
- HOT ISOSTATIC PRESSING (HIP): THE DIE IS METALLIC AND THE FLUID IS A GAS.

- OMOGENEUS DENSITY BUT LOW PRODUCTIVITY => HIGH COST

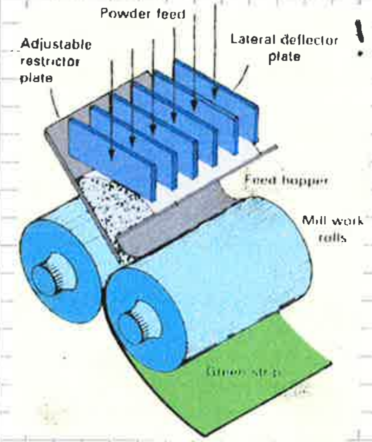
Ⓒ ROLLING COMPACTING (FOR RIBBONS (NASTRI) AND SHEETS (FOGLI))

- VARIABLES: { NIP ANGLE (ANGOLO DI AGGANCIO) 7÷8 % ; DIAMETER OF ROLLS }





(STRIP = "STRISCIA / FASCIA")



- THE "GREEN" PRODUCT IS ALWAYS A TWO-DIMENSIONAL STRIP
- EASY TECHNOLOGY USED TO PRODUCE LARGE AMOUNT OF STRIP
- LOW PRICE

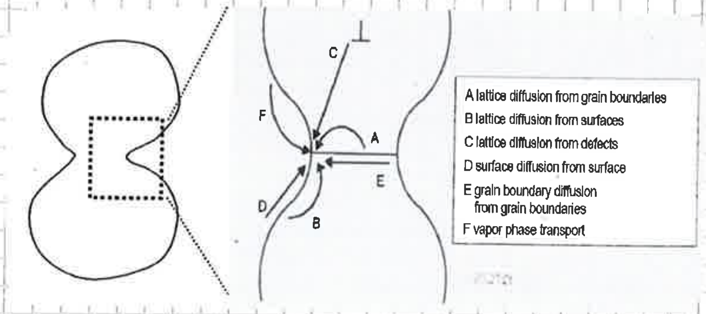
Ⓓ POWDER INJECTION MOULDING (STAMPAGGIO A INIEZIONE)

- THE TECHNOLOGY FOR PLASTIC MATERIALS MOULDING IS ADOPTED
- METALLIC, CERAMIC AND METAL-CERAMIC POWDERS ARE COMPACTED
- FINER AND MORE ROUNDED POWDERS MUST BE ADOPTED
- A HIGH PERCENTAGE OF THERMOPLASTIC FILLER IS USED (POWDER + THERMOPLASTIC MATERIAL)
- THE DIE IS FILLED (RIEMPITO) AT LOW PRESSURE AND VERY SLOWLY
- A HIGH SHRINKAGE (RESTRINGIMENTO) IS DETECTED DURING SINTERING PROCESS

(24-48 HOURS INTO FURNACE)

MASS TRANSPORT PHENOMENA

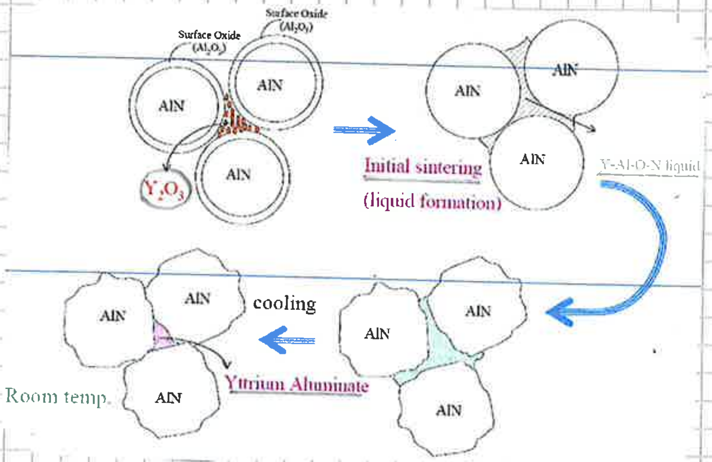
MASS TRANSPORT BY DIFFUSION



NOTES (FROM "TYPICAL QUESTIONS")

- DISSOCIATED AMMONIA IS THE MOST COMMONLY USED SINTERING PROCESS.
- THE Cu ENHANCES SINTERING PROCESS OF STEEL COMPONENTS.

LIQUID PHASE SINTERING OF ALUMINUM NITRIDE (AlN)

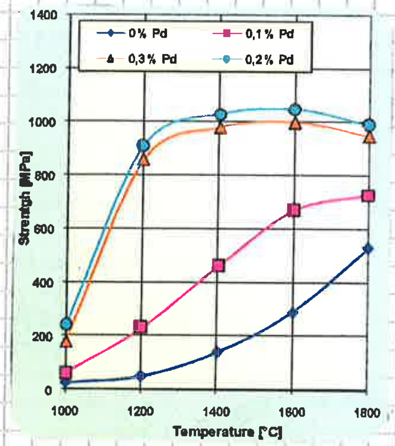


THE YTTRIUM ALLUMINATE INCREASE DIFFUSION BETWEEN AlN

AFTER THE SINTERING YTTRIUM ENTERS INTO THE SOLUTION

EFFECT OF PALLADIUM (Pd)

SINTERING PROCESS CAN BE ACTIVED WITH PALLADIUM

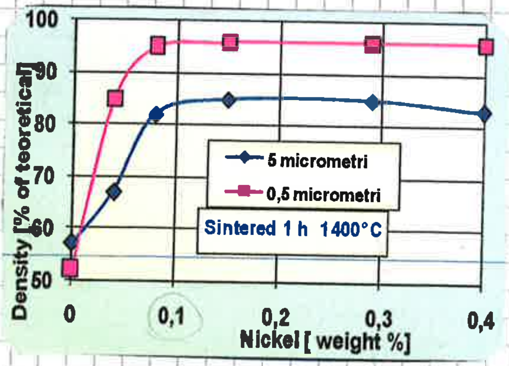


← INFLUENCE OF ACTIVATION WITH PALLADIUM DURING SINTERING PROCESS OF TUNGSTEN (W) BASE ALLOY.

THE PALLADIUM (Pd) INCREASES THE STRENGTH OF THE ALLOY

PURE W

EFFECT OF NICKEL (Ni)

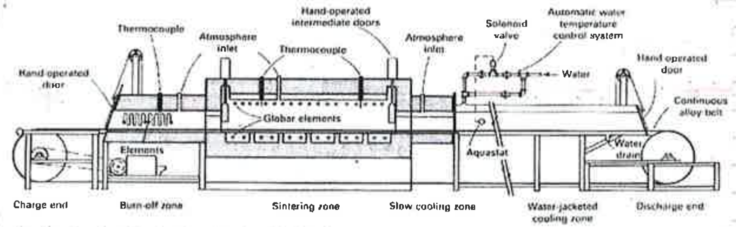


THE NICKEL (Ni) IS USED TO INCREASE DENSITY DURING SINTERING PROCESS SO IT DECREASES THE POROSITY.

(SINTERING 1h 1400°C)

← INFLUENCE OF POWDER DIMENSION AND Ni% ON SINTERING PROCESS OF TUNGSTEN (W) BASE ALLOYS.

EXAMPLE OF INDUSTRIAL PLANT (STABILIMENTO INDUSTRIALE)



CONTINUOUS PLANT OF SINTERING REPRESENTED WITH THE DIFFERENT DEVICES (DISPOSITIVI).

DESIGN GUIDELINES FOR PM PARTS

1 - ECONOMICS USUALLY REQUIRE LARGE QUANTITIES TO JUSTIFY COST OF EQUIPMENT AND SPECIAL TOOLING. SO MINIMUM QUANTITIES OF UNITS ARE SUGGESTED/REQUIRED.

2 - PM IS UNIQUE IN ITS CAPABILITY (CAPACITA') TO FABRICATE PARTS WITH A CONTROLLED LEVEL OF POROSITY.

3 - PM CAN BE USED TO MAKE PARTS OUT OF UNUSUAL METALS AND ALLOYS - MATERIALS THAT WOULD BE DIFFICULT IF NOT POSSIBLE TO PRODUCE BY OTHER MEANS. (EX.: $Cu + C_{GRAFITE}$)

4 - THE PART GEOMETRY MUST PERMIT EJECTION FROM DIE AFTER PRESSING:

  4.1 - **THE PART MUST HAVE VERTICAL OR NEAR VERTICAL SIDES**, ALTHOUGH STEPS ARE ALLOWED

  4.2 - DESIGN FEATURES SUCH AS UNDERCUTS (SOTTOSQUADRI) AND HOLES ON THE PART SIDES MUST BE AVOIDED (EVITATI).

  4.3 - VERTICAL UNDERCUTS AND HOLES ARE PERMISSIBLE BECAUSE THEY DO NOT INTERFER WITH EJECTION.

  4.4 - VERTICAL HOLES CAN BE OF CROSS-SECTIONAL SHAPES OTHER THAN ROUND WITHOUT SIGNIFICANT DIFFICULTY.

MECH. PROP.

5) SECONDARY OPERATIONS

THEY ARE PERFORMED TO INCREASE DENSITY (↑), IMPROVE ACCURANCY (↑) OR ACCOMPLISH ADDITIONAL SHAPING OF THE SINTERED PART.

5.1 REPRESSING: PRESSING THE SINTERED PART IN A CLOSED DIE TO INCREASE DENSITY AND IMPROVE PROPERTIES.

5.2 SIZING: PRESSING A SINTERED PART TO IMPROVE DIMENSIONAL ACCURACY.

5.3 COINING: PRESS WORKING OPERATION ON A SINTERED PART TO PRESS DETAILS INTO ITS SURFACE

5.4 MACHINING: CREATING GEOMETRIC FEATURES THAT CANNOT BE ACHIEVED BY PRESSING, SUCH AS THREADS (FILETTATURE), SIDE HOLES, AND OTHER DETAILS.

6) JOINING AND WELDING

7) HEAT AND/OR THERMOCHEMICAL TREATMENTS

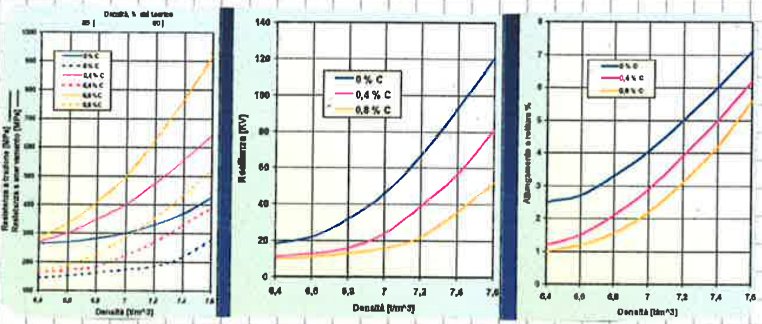
8) FINAL PRODUCT

1.5 MECHANICAL PROPERTIES

THE MECHANICAL PROPERTIES OF SINTERED COMPONENTS ARE MAINLY INFLUENCED FROM POROSITY AND SECONDARILY FROM CHEMICAL COMPOSITION, SINTERING CONDITIONS, ETC.

SOME RELATIONS FOR IRON SINTERED (EXPERIMENTALLY DETERMINED) ARE REPORTED.

- $\lambda = \lambda_0 (1 - 2\varepsilon)$ THERMAL CONDUCTIVITY (λ) ($\varepsilon < 20\%$)
- $B_{MAX} = a - b\varepsilon$ SATURATION INDUCTION (B_{MAX})
- $\sigma_m = \sigma_{m_0} \exp(-4.3\varepsilon)$ TENSILE STRENGTH (σ_m) (RESISTENZA A TRAZIONE)
- $\sigma_Y = \sigma_{Y_0} \exp(-4.3\varepsilon)$ YIELD STRENGTH (σ_Y) (TENSIONE DI SNERVAMENTO) FOR NOT ALLOYED STEELS
- $\sigma_Y = \sigma_{Y_0} + b\varepsilon + c(1-\varepsilon)$ YIELD STRENGTH (σ_Y) (TENSIONE DI SNERVAMENTO) FOR ALLOYED STEELS
- $E = E_0 (1-\varepsilon)^{3.4}$ LONGITUDINAL ELASTIC/YOUNG MODULUS ($\varepsilon < 50\%$)
- $\nu = \nu_0 \exp[1.372(1-\varepsilon)]$ POISSON RATIO (RAPPORTO DI POISSON) ($5\% < \varepsilon < 35\%$)
- $\lambda_0 = \dfrac{(1-\varepsilon)}{C_0}$ QUENCH ABILITY, C_0 = THERMAL PROPERTIES OF MATERIALS

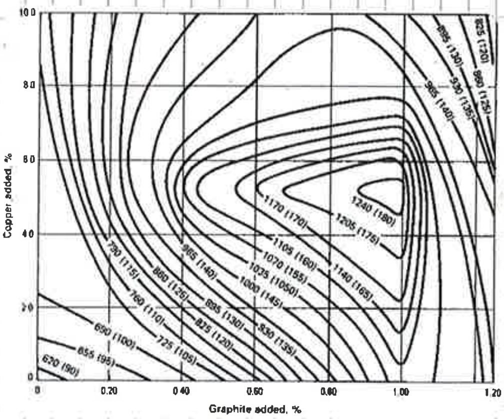


← AVERAGE VALUE OF SOME MECHANICAL PROPERTIES DETECTED ON IRON BASE SINTERED COMPONENTS WITH 4 WEIGHT % OF Ni. AN INCREASE OF MECHANICAL PROPERTIES WITH DENSITY INCREASING IS EVIDENT, ESPECIALLY FOR IMPACT TESTS.

TRASVERSAL TENSILE STRENGHT OF IRON PM COMPONENTS → (MASS VOLUME = DENSITY = 6.800 [Kg/m³]), SINTERED IN ENDOGAS ATMOSPHERE.

THE LINES INDICATE THE FIELD OF COMPOSITION WITH ALMOST THE SAME TENSILE STRENGHT IN [MPa] (KSI).

C IN STEEL IS ABOUT 80% OF ADDED GRAPHITE.



+APPLICATIONS

EXAMPLE: FILAMENT OF INCANDESCENCE LAMPS

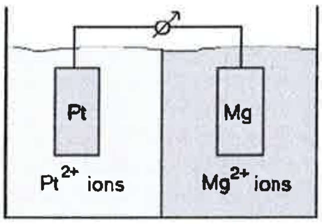
IN ORDER TO INCREASE THE LIFE OF SUCH FILAMENTS OF TUNGSTEN (W), IT IS NECESSARY TO CONTROL THE RECRYSTALLIZING STRUCTURE USING POTASSIUM (K), THAT ALLOWS TO OBTAIN COARSE GRAINS (GRANA GROSSA), RESISTANT TO THE BENDING (CURVATURA) INSTEAD OF A EQUIAXED MICROSTRUCTURE.

1.6 COMPARISON; MICROSTRUCTURE; FRACTOGRAFY ⇒

2. CORROSION

2.1 BRIEF REVIEW - ELECTROCHEMICAL SERIES AND GALVANIC SERIES

$Pt^{2+} + 2e^- \rightarrow Pt$ $\boxed{+1.2V}$
$Mg^{2+} + 2e^- \rightarrow Mg$ $\boxed{-2.363V}$
Actual
$Mg \rightarrow Mg^{2+} + 2e^-$ (oxidation) ?V
$Pt^{2+} + 2e^- \rightarrow Pt$ +1.2V
Total
$Mg + Pt^{2+} \rightarrow Mg^{2+} + Pt$?...V
(+) Potential means rxn will proceed as written.
(-) Potential means opposite rxn occurs.
The more positive rxn will proceed as written



ELECTROCHEMICAL CELL - CONDITION OF CHEMICAL AND ELECTRICAL EQUILIBRIUM

- CONCENTRATION (ONE NORMAL) OF Pt
- CONCENTRATION (ONE NORMAL) OF Mg

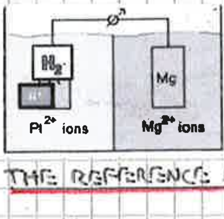
SEPARATED BY A POROUS SEPTUM (IT DOES NOT ALLOW THE IONS$^+$ OF Pt AND Mg RESPECTIVELY TO MIX WHILE THE NEGATIVE IONS$^-$ CAN BE MIXED SO AS NOT TO CHANGE THE CONCENTRATION OF THE SOLUTION EXCESSIVELY.)

THEN WE HAVE A CLOSED ELECTRICAL CIRCUIT AND A POTENTIAL METER THAT DOES NOT LET THE CURRENT FLOW, SO IT KEEPS THE DIFFERENCES IN POTENTIAL.

→ A METALLIC COMPONENT OF Mg IS PUT IN SOLUTION IN AN ACQUOUS LIQUID IN WHICH WE HAVE A CONCENTRATION (ONE NORMAL) OF IONS$^+$ Mg^+. A CHEMICAL EQUILIBRIUM IS ESTABLISHED BETWEEN THE POSITIVE IONS$^+$ OF THE SOLUTION AND THE ELECTRONS e^- PRESENT ON THE METAL COMPONENT ($Mg \rightarrow Mg^{2+} + 2e^-$) AND A CERTAIN POTENTIAL DIFFERENCE (ΔV) IS ESTABLISHED.

ELECTROCHEMICAL SERIES

Li/Li+	-3,045	Al/Al3+	-1,66	Co/Co2+	-0,30
K/K+	-2,925	Ti/Ti2+	-1,63	Ni/Ni2+	-0,25
Sr/Sr2+	-2,89	Zr/Zr4+	-1,53	Mo/Mo3+	-0,20
Ca/Ca2+	-2,87	Mn/Mn2+	-1,19	Sn/Sn2+	-0,140
Na/Na+	-2,713	Zn/Zn2+	-0,763	Pb/Pb2+	-0,126
Mg/Mg2+	-2,37	Cr/Cr3+	-0,74	Cu/Cu2+	+0,337
Be/Be2+	-1,85	Fe/Fe2+	-0,44	Ag/Ag2+	+0,800



③ TO OBTAIN THESE POTENTIAL VALUES IT IS NECESSARY THAT THE ANALYZED MATERIAL BE REFERENCED TO ANOTHER MATERIAL. THE REFERENCE MATERIAL IS HYDROGEN (H) WHICH BY CONVENTION IS ASSUMED TO BE AT ZERO POTENTIAL.

⇒ RELATIVE VALUES.

GALVANIC SERIES

① THE GALVANIC SERIES EVIDENCES THE TENDENCY OF A METAL TO BE CORRODED.

② [ANODIC SIDE]: HIGH (ΔV-) => HIGH DISSOLUTION ($Me \rightarrow Me^+ + e^-$) => HIGH CORROSION

[CATHODIC SIDE]: (ΔV+): MATERIALS THAT DON'T MANIFEST THIS DISSOLUTION => NO CORR.

(DISSOLUTION = TENDENCY OF METAL ATOMS (Me) TO BECOME IONS$^+$ (Me^+) ACCORDING TO THE ENVIRONMENT IN WHICH THEY ARE LOCATED)

③ ALL METALLIC MATERIALS UNDERGOES A DISSOLUTION OVER TIME. FOR SOME SHORTER TIMES [THOSE OF ANODIC SIDE] ARE REQUIRED, FOR OTHER LONGER TIMES [THOSE OF CATODIC SIDE]

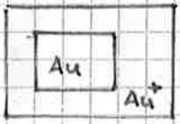
(TO MEMORIZE)

!

Anodic side
Magnesium
Zinc
Aluminium
Carbon steels
Alloyed steels
Cast iron
Martensitic stainless steels (active)
Ferritic stainless steels (active)
Austenitic stainless steels (active)
Brass
Bronze
Copper
Cupronichel
Nickel
Inconel
Martensitic stainless steels (passive)
Ferritic stainless steels (passive)
Austenitic stainless steels (passive)
Titanium
Silver
Gold
Platinum
Catodic side

↑ (GALVANIC SERIES OF SOME METALS AND ALLOYS IN SEA WATER)

EXAMPLE: GOLD (Au)



MODEST DISSOLUTION ($Cu \rightarrow Cu^{++} + 2e^-$ THEN $Cu^{++} + \frac{1}{2}O_2 \rightarrow CuO$)

DISSOLUTIO ≠ CORROSION ONLY BECAUSE OF TIME.

WHAT WE NEED THE GALVANIC SERIES FOR?

WE DON'T USE PURE ELEMENTS → WE USE ALLOYS.

④ THE GALVANIC SERIES IS USED TO SHOW TENDENCY TO CORRODE: $Me \rightarrow Me^+$ IN A SPECIFIC ENVIRONMENT

⑥ WHEN TWO METALS ARE COUPLED, IN SEAWATER FOR EXAMPLE, THE LOWER ONE IN THE COHERENT GALVANIC SERIES WILL TEND TO CORRODE.

→ ⑤ IT SERVES TO IDENTIFY WHICH METALLIC MATERIAL WILL BE THE FIRST TO DISSOLVE

! + Nernst equation (?)

$$E = E_0 - \frac{RT}{zF} \ln \frac{a_{red}}{a_{ox}}$$

where

- E is the half-cell reduction potential at the temperature of interest
- E_0 is the *standard* half-cell reduction potential
- R is the universal gas constant: R = 8.314 472(15) J K^{-1} mol^{-1}
- T is the absolute temperature
- a is the chemical activity for the relevant species, where a_{Red} is the reductant and a_{Ox} is the oxidant. $a_X = \gamma_X c_X$, where γ_X is the activity coefficient of species X. (Since activity coefficients tend to unity at low concentrations, activities in the Nernst equation are frequently replaced by simple concentrations.)
- F is the Faraday constant, the number of coulombs per mole of electrons: F = 9.648 533 99(24)×10^4 C mol^{-1}
- z is the number of moles of electrons transferred in the cell reaction or half-reaction

4

2.3.0 WET CORROSION – REACTIONS

- $Me \Rightarrow Me^{n+} + ne^-$ (1)
- $Me^{n+} + ne^- \Rightarrow Me$ (2)
- $2H^+ + 2e^- \Rightarrow 2H \Rightarrow H_2$ → BUBBLE OF H_2 (3)
- $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$ (acid solutions)- (4)
- $O_2 + 2H_2O + 4e^- \Rightarrow 4OH^-$ (neutral or basic solutions) (5)
- $Me^{3+} + e^- \Rightarrow Me^{2+}$ (6)

In water environment, in contact with air, the most common cathodes reactions are those of reaction (5).

IN SOLUTION WE CAN FIND: Me^+, H^+, O_2 (IF THE SOLUTION IS AERATED)

- IONS H^+ REACT WITH e^- OF Me TO GIVE RISE TO BUBBLES OF H_2 WHICH THEN GO AWAY
- IONS H^+ + OXYGEN (O_2) DISSOLVED IN WATER + e^- ⇒ WE OBTAIN WATER MOLECOLES (H_2O)

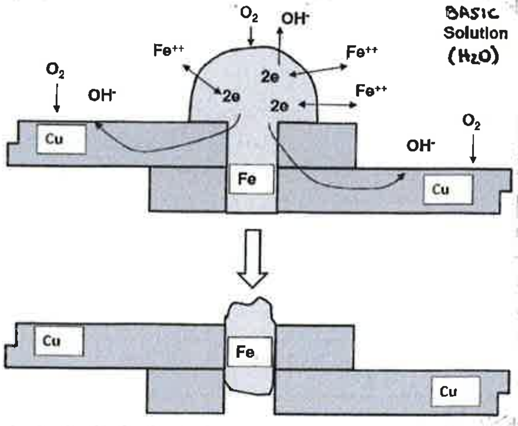
ALSO THIS REACTION MAKES CHARGES e^- DISAPPEAR AND THIS IS USEFUL FOR ACHIEVING BALANCE. (ACID SOLUTION)

- WATER (H_2O) + OXYGEN (O_2) + e^- ⇒ FORMATION OF HYDROXYL IONS (OH^-) WHICH MAKE THE SOLUTION BASIC (BASIC SOLUTION)

2.3.1 GALVANIC CORROSION

- THE GALVANIC CORROSION OCCURS WHEN CERTAIN AREAS ALWAYS ACT AS ANODES AND OTHERS ONLY AS CATHODES.
- MOST COMMONLY WHEN DISSIMILAR METALS (WITH DIFFERENT ELECTROCHEMICAL POTENTIALS) ARE IN ELECTRICAL CONTACT AND ARE EXPOSED TO AN ELECTROLYTE
- THE LESS NOBLE METAL (MORE REACTIVE) ACTS AS ANODE AND SO IT CORRODES
- RATE OF CORROSION DEPENDS ON SURFACE AREAS OF ANODE AND CATHODE. FOR SIMILAR CATHOD SIZE, SMALL ANODE WILL CORRODE FASTER THAN LARGE ANODE.
- ALSO WITHIN STEEL: TWO PHASES: (FERRITE = ANODIC) + (CEMENTITE = CATHODIC) ⇒ CORROSION OF FERRITE IN CELLS
- SO WHEN TWO METALS ARE COOPLED IN SEAWATER, THE LOWER ONE IN THE GALVANIC SERIES REFERRED TO SEA WATER (THE ONE MORE REACTIVE) WILL ACT AS AN ANODE AND THEN IT WILL CORRODE.

TYPICAL EXAMPLE: IRON (Fe) NAIL THAT CONNECT TWO COPPER SHEETS IN A SEAWATER SOLUTION



Cathodes reduction of oxygen on iron and copper, with dissolution of the iron alone.

It is a typical example of galvanic corrosion with a component constituted with a iron nail that connect two copper sheets.

IN THE GALVANIC SERIES THE IRON (Fe) PRECEDES THE COPPER (Cu) SO THE IRON ACTS AS AN ANODE AND IT CORRODES. LETS ANALYZE THE REACTIONS:

- $Fe \rightarrow Fe^{++} + 2e^-$ (LEFT ON THE NAIL)

THERE IS ELECTRICAL CONTACT BETWEEN THE NAIL AND THE TWO SHEETS ⇒ MIGRATION OF e^-

- $O_2 + 2H_2O + 4e^- \Rightarrow 4OH^-$ (5) [BASIC SOLUCTION]

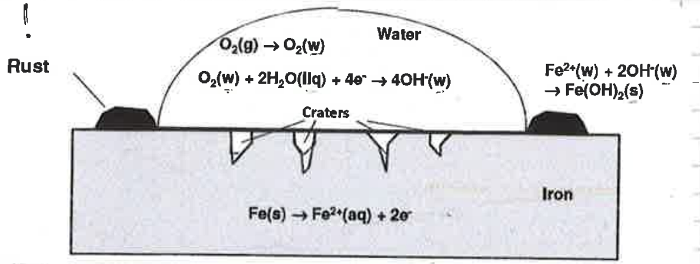
THE HYDROXYL IONS GO AWAY, CAUSING THE ELECTRONS e^- TO DISAPPEAR.

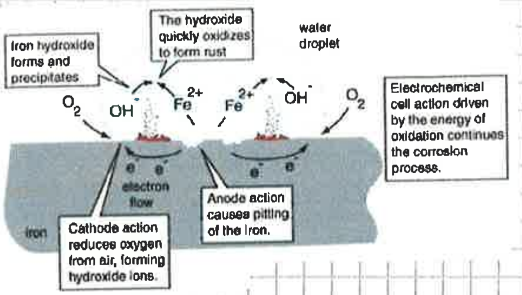
WET CORROSION - RUST FORMATION

BASIC SOLUTION : $O_{2(aq)} + 2H_2O_{(aq)} + 4e^- \Rightarrow 4OH^-_{(aq)}$ $4OH^-_{(aq)} + 2Fe^+_{(aq)} \Rightarrow 2Fe(OH)_{2\,(s)}$ (RUST!)
(PRESENCE OF H_2O)

ACID SOLUTION : $2H^+ + 2e^- \Rightarrow \boxed{H_2}$
(PRESENCE OF $\boxed{H^+}$) $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$ $O_2 + H_2O + 4e^- \Rightarrow 4OH^-$ $4OH^- + 2Fe^+ \Rightarrow 2Fe(OH)_2$

!

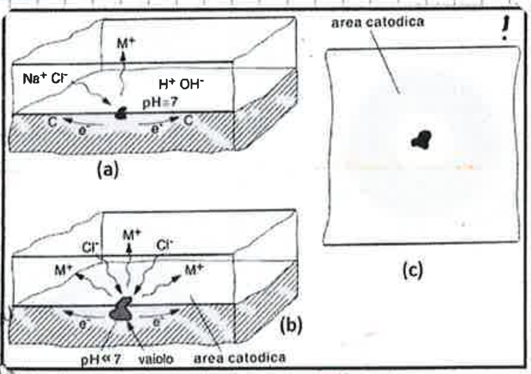




- IRON CORROSION CAUSED BY A WATER DROP
- THE PHENOMENON STARTS WHEN OXYGEN SOLVED IN WATER REACTS WITH THE METAL, FORMING SOME CRATERS THAT PROGRESSIVELY GROW AND BECAME DEEPER.
- THE RUST, $Fe(OH)_2$, GENERALLY FORMS ON DROP BOUNDARY WHERE DISSOLVED OXYGEN CONCENTRATION IS HIGHER AND WHERE THE FORMATION OF IRON IDROXIDE IS EASY.
  ($\neq$ HYDROXYS IONS (OH^-))

2.3.2 PITTING CORROSION (LOCALIZED CORROSION)

- THE PITTING CORROSION IS A LOCALIZED ATTACK WICH FORMS SMALL HOLES OR PITS (VAIOLI).
- THEY CAN BE VERY DEEP AND PENETRATE THROUGH SHEET WITHOUT MUCH WARNING / INDICATION.
- IT IS SIMILAR TO THE "CREVICE CORROSION".



- INITIATION MAY BE AT SURFACE SCRATCHES (GRAFFI), DEFETS, ETC.
- PITS USUALLY GROW DOWNWARD DUE TO GRAVITY: THE SOLUTION ENTERS INTO A PIT MAKING IT GROW.

(a) NUCLEATION PHASE. THE PITTING CORROSION STARTS FROM A DEFECT. THE METAL STARTS TO DISSOLVES. $Me \rightarrow Me^+ + e^-$

(b) THE ELECTRONS MOVE AROOUND THE PITTING ZONE THROUGH THE CATHODIC AREA. WITHIN THE PIT, THE SOLUTION (INITIALLY NEUTRAL), DUE TO THE INCREASING PRESENCE OF IONS, REACHES ph ACIC VALUES ($pH \ll 7$). THEREFORE IT WILL INCREASE THE DISSOLUTION IN A LOCALIZED WAY.

HOW CAN WE REDUCE THE PITTING CORROSION?

→ POLISHING (LEVIGARE) HELPS (TO) REDUCE PITTING.

→ STAINLESS STEELS ARE SUSCEPTIBLE BUT ALLOYING WITH 2% MOLYBDENUM GREATLY INCREASES RESISTANCE (2% Mo)

← ON THIS PLATE, WHICH WAS IMMERSED IN SEAWATER, CREVICE CORROSION HAS OCCURRED AT THE REGIONS THAT WERE COVERED BY WASHERS (RONDELLE).

CORROSION ENVIRONMENTS

- INCLUDES: ATMOSPHERE, ACQUEOUS SOLUTIONS, SOILS (SUOLI), ACIDS, BASES, SOLVENTS, MOLTEN SALTS (SALI FUSI), LIQUID METALS, BODY FLUIDS...
- MOST PREVALENT IS MOIST (UMIDA) AIR CONTAINING DISSOLVED OXYGEN.

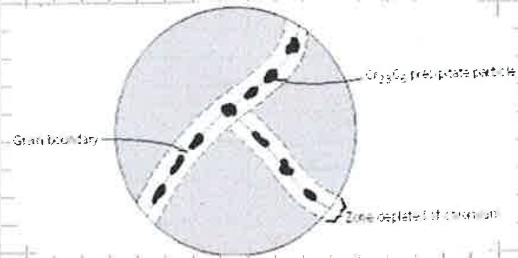
  \+ SALT → "SEA AIR"

  \+ ACID → "ACID RAIN"
- SEA WATER (3.5% SALT) IS MORE CORROSIVE THAN FRESH WATER. SALT INCREASES CONDUCTIVITY OF SOLUTION SO INCREASES CORROSION.

→ CAST IRON, STEEL, ALUMINUM, COPPER, BRASS, STAINLESS STEELS USED FOR FRESH WATER.

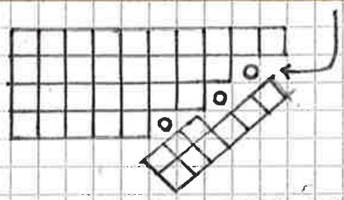
→ TITATIUM, BRONZE, Cu-Ni ALLOYS, Ni-Cr-Mo ALLOYS HAVE GOOD RESISTANCE IN SEAWATER.

2.3.6 INTERGRANULAR CORROSION



e.g.: in 304 (18/8) stainless steel, (0.08C, 19Cr, 9Ni, 2.0Mn), Cr carbides may form if heated at 500-800°C for some time (*sensitisation).*
Cr → $Cr_{23}C_6$ (ppts)
(Cr normally protects Fe from corrosion) so now get corrosion of Crdepleted zones- grains fall out or cracks run down GB's.

- THE INTERGRANULAR CORROSION CONSISTS IN A LOCALIZED ATTACK AT/NEAR TO GRAIN BOUNDARIES OF ALLOYS. IT MAKES COMPONENT DISINTEGRATE ALONG GRAIN BOUNDARIES. IT'S VERY COMMON IN SOME STAINLESS STEELS. (MOSTLY CARBIDES)
- SOMETIMES PRECIPITATES FORM IN/NEAR GRAIN BOUNDARIES WHICH MAKE GB VERY SENSITIVE (OR PRONE (INCLINE)) TO ATTACK.
- THE CORROSION TAKES PLACE IN THOSE SITES WHERE THERE IS NO SPACE FOR NEW GRAINS.



- IT CAN OCCUR DURING WELDING OF STAINLESS STEELS: WELD DECAY

  THE MATERIAL REACHES MELTING TEMPERATURE AND THE SORROUND AREA REACHES HIGH TEMPERATURE THAT CAN INDUCE NEW PHASE FORMATION. RECRESTALIZATION CAN HAPPEN IN THE SOURRONDING AREA, SITE WHERE WE CAN HAVE INTERGRANULAR CORROSION.

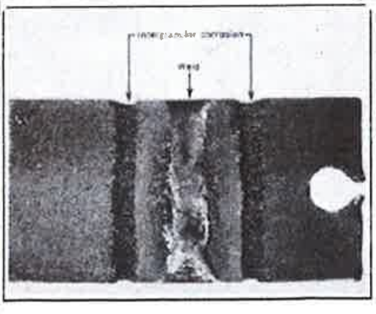


***FIGURE 18.19 Weld decay in a stainless steel.** The regions along which the grooves have formed were sensitized as the weld cooled.*

PREVENTION TO INTERGRANULAR CORROSION: (3)

→ PROPER (APPROPRIATO) HEAT TREATMENT (REDISSOLVE CARBIDES AT HIGH T)

→ LOW CARBON (C) CONTENT TO PREVENT THE FORMATION OF CARBIDES (< 0.03 wt% C) OR:

→ ADD NIOBIUM (Nb) OR TITANIUM (Ti) TO FORM STABLE CARBIDES

2.3.8 HYDROGEN EMBRITTLEMENT (INFRAGILIMENTO)

FOR SOME METAL ALLOYS (SPECIFICALLY STEELS) IF ATOMIC HYDROGEN (H) GETS INTO STRUCTURE. ⇒ STAINLESS STEELS IN CONTACT WITH ACID SOLUTIONS: H COMING INSIDE MATERIAL CAN INDUCE A SPONTANEOUS CRACK; H IS TINY (MINUSCOLO) SO IT CAN ENTERS INSIDE THE LATTICE AND CAN MOVE AND CONCENTRATE; H CREATES H_2 BUBBLES ACCUMULATING AND PUSHING ON THE MATERIAL BRINGING IT TO CRACK.

- CRACKING (CREP.) AND BRITTLE FRACTURE (ROTTURA FRAGILE) OCCURS UNDER TENSIL STRESS (SIMILAR TO SCC)
- ESPECIALLY FOR HIGHER STRENGTH STEELS (STAINLESS STEELS).
- IT REQUIRES SOURCE OF ATOMIC HYDROGEN (H):
  - ACID SOLUTIONS (SOLPHURIC ACID IN STEEL PICKLING, ELECTROPLATING OF PARTS)
  - WATER VAPOR AT HIGH TEMP. (WELDING, HEAT-TREATING)
  - "POISONS" - (H_2S) SUCH AS IN PETROLEUM INDUSTRY

TO REDUCE THE LIKELIHOOD (PROBABILITA') OF HYDROGEN EMBRITTLEMENT:

→ ANNEALING (RICOTTURA) (SOFTENING = RAMMOLLIMENTO).

→ REMOVING HYDROGEN SOURCE.

→ "BAKING" (COTTURA AL FORNO) COMPONENT TO REMOVE DISSOLVED HYDROGEN.

→ SUBSTITUTE MORE RESISTANT ALLOY (TYPICAL STEEL: BCC: HYDROGEN CAN CONCENTRATE AND MOVE ⇒ CHANGE ALLOY: FCC).

2.4 CORROSION PREVENTION⑤

- CHOOSE APPROPRIATE MATERIAL FOR WORKING CONDITIONS → STAINLESS STEEL (ACCIAIO INOSSIDABILE) [WITH %Cr]
- CHANGE ENVIRONMENTS (REDUCTION OF: T, FLUID VELOCITY; CHANGE OF CONCENTRATION)
- USE INHIBITORS: WHEN ADDED TO ELECTROLYTE THEY MIGRATE TO ELECTRODES AND REDUCE REACTIONS (POLARISATION). SPECIFIC INHIBITORS FOR ALLOYS AND ELECTROLYTES.

  EX.: CHROMATE SALTS IN CAR RADIATORS
- DESIGN TO ALLOW COMPLETE DRAINAGE, AND EASY WASHING.
- COATING: USED TO ISOLATE ANODES AND CATHODES TO PREVENT GALVANIZATION

  IF THE COATING DAMAGED THEN ANODE FORMS AND CORROSION OCCURS. (A SCRATCH THROUGHT TO THE STEEL CAUSES A SMALL ANODE WHICH CORRODES RAPIDLY).

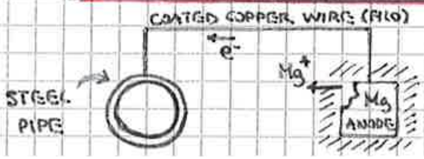
CATHODIC PROTECTION③

→ MAKE THE METAL (THAT WE WANT TO PROTECT) A CATHODE RATHER THAN AN ANODE

(1) • STEEL SHEETS (PIASTRE) (~ COATING) OF A MORE REACTIVE METAL SUCH Zn FOR Fe.

Zn SHEET: Zn, BEING ANODIC WITH RESPECT OF Fe, STARTS TO DISSOLVE, FIRST.

(2) • CONNECTION WITH A SACRIFICIAL ANODE (SO A METAL WITH A HIGHER |ELECTROCHEMICAL POTENTIAL|)



$$\begin{cases} Fe = -0.44\ V \\ Mg = -2.37\ V \end{cases}$$ ⇐ ANODE

3. STAINLESS STEELS (SS) (ACCIAI INOSSIDABILI)

3.1 STAINLESS STEELS - GENERALITY

- PRIMARY FACTOR: CORROSION RESISTANCE IS DUE TO AT LEAST 11 WEIGHT % CHROMIUM ADDITION.

$Cr \geqslant 11\%$ $\quad$ $4Cr + 3O_2 \rightarrow 2Cr_2O_3$ $\quad$ [MIXED Fe - Cr OXIDES: $(Fe,Cr)_2O_3$]

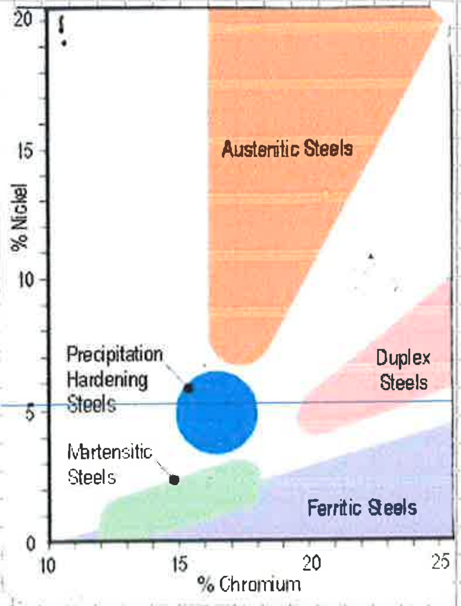
THIS THIN (SOTTILE) SURFACE OXIDE PROTECTS THE METAL UNDERNEATH (SOTTOSTANTE).

- Ni IS ANOTHER ALLOYING INGREDIENT IN CERTAIN SS TO INCREASE CORROSION PROTECTION.
- C IS USED TO STRENGTHEN SS, BUT %C ↗ RESISTANCE TO CORROSION ↘ ; CHROMIUM CARBIDES FORM REDUCING THE AVAILABLE FREE Cr.
- SS ARE NOTED FOR THEIR COMBINATION OF **STRENGTH AND DUCTILITY**: THESE PROPERTIES GENERALLY MAKE SS DIFFICULT TO WORK IN MANUFACTURING.
- SS ARE **MORE EXPENSIVE** THAN PLAIN (SEMPLICI) C OR LOW ALLOY STEELS.

NOTE: Ni IS A $\overset{\text{(FCC LATTICE)}}{\gamma}$ STABILIZER ELEMENT: IF WE HAVE $\%Ni > 7\%$ WE CAN HAVE AUSTENITIC ALLOY AT ROOM TEMPERATURE.

ALSO Mn IS A γ STABILIZER.

3.3 TYPES OF SS :



3.3.1 AUSTENITIC SS (304, 316L, 904L)

- WITH CR-Ni
- WITH CR-Mn-Ni

3.3.2 FERRITIC SS (409, 446)

- WITH CR(10.5 ÷ 20%) + C(0.08 ÷ 0.2%) + Ni + Mo

3.3.3 MARTENSITIC SS

- WITH CR(11 ÷ 18 %) + C (0.08 ÷ 1.2%) + Ni (MAX 2.5 %)

3.3.4 DUPLEX SS

- WITH CR (18 ÷ 28 %) + Ni(4 ÷ 6%) + Mo(1.5 ÷ 3 %)

3.3.5 PRECIPITATION HARDENING SS

- WITH CR + Ni + OTHER ELEMENTS (Mo, Cu, Ti, Al, N, P, V, Nb, Ta)

3.3.1 AUSTENITIC SS

1 • THIS GROUP CONTAINS AT LEAST 16% CR AND 6% Ni ;

2 • ADDITIONAL IMPORTANT ELEMENTS : Mo, Ti, Cu : TO IMPROVE THE RESISTANCE TO CORROSION;

3 • SUITABLE FOR LOW T APPLICATIONS SUCH AS CRYOGENIC APPLICATIONS BECAUSE THE EFFECT OF THE NICKEL (Ni) CONTENT IN MAKING THE STEEL AUSTENITIC AVOIDS THE PROBLEMS OF BRITTLENESS AT LOW TEMPERATURE, WHICH IS A CHARACTERISTIC OF OTHER TYPES OF STEEL; Ni (AND Mn) IS γ STABILIZER (FCC LATTICE);

4 • EXCELLENT FORMABILITY AND DUCTILITY, COLD-WORKING, NO DBTT;

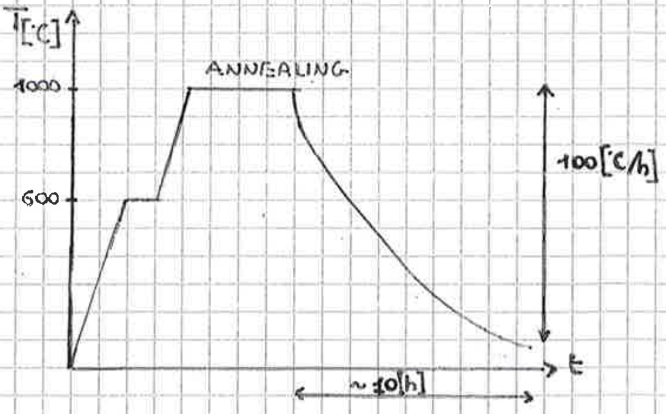
5 • NOT FERROMAGNETIC;

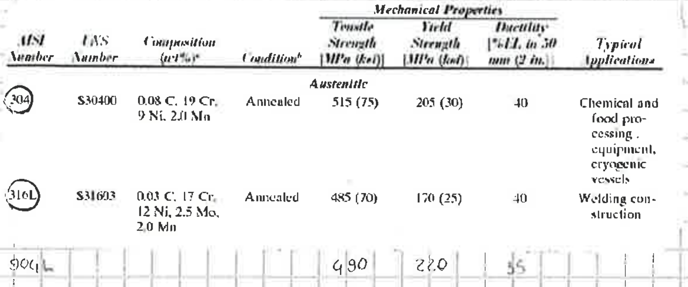
6 • RELATIVELY EXPENSIVE (80% WORLD PRODUCTION);

(0.08 % C) 0.03 % C

7 • 304 (BASIC GRADE; 18/8 = 18% CR AND 8% Ni) AND 316L (+ 2% Mo): ANNEALED (RICOTTO) AT 1000[°C] TO BE SURE OF LATTICE RECRYSTALLIZATION;

8 • 904L : SUPER AUSTENITICS (% Ni > 20%);





AISI Number	UNS Number	Composition (wt%)	Condition	Mechanical Properties Tensile Strength [MPa (ksi)]	Mechanical Properties Yield Strength [MPa (ksi)]	Mechanical Properties Ductility [%EL in 50 mm (2 in.)]	Typical Applications
			Austenitic				
304	S30400	0.08 C, 19 Cr, 9 Ni, 2.0 Mn	Annealed	515 (75)	205 (30)	40	Chemical and food processing equipment, cryogenic vessels
316L	S31603	0.03 C, 17 Cr, 12 Ni, 2.5 Mo, 2.0 Mn	Annealed	485 (70)	170 (25)	40	Welding construction
904L				490	220	35	

AISI : POSSIBLE APPLICATIONS :

304 CRYOGENIC VESSELS (RECIPIENTI);

316L WELDING CONSTRUCTIONS (SALDATURA);

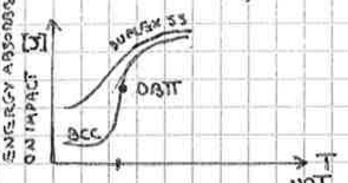
REVIEW : NOMENCLATURE OF SS

X 5 CR Ni Mo 17-12-2 17% CR ; 12 % Ni ; 2% Mo

ALLOYING ELEMEN (%C) = 5/100 = 0.05 % C (NW!)

3.3.4 DUPLEX SS [$Cr(18 \div 28\%) + Ni(4 \div 6\%) + Mo(1.5 \div 3\%)$]

- CONTEMPORARY PRESENCE OF 2 PHASES: AUSTENITE (γ) AND FERRITE (α);
- DENOMINATION: 2304 => 23% CR AND 4% Ni ; 2205 => 22% CR AND 5% Ni ;
- RESISTENT TO STRESS CORROSION CRACKING (NOT QUITE LIKE FERRITICS);
- GOOD TOUGHNESS ($\overset{\text{TENACIA}}{\text{DUREZZA}}$) (GREATER THAN THAT OF FERRITICS BUT LESS THAN THAT AUSTENITICS);
- HIGHT STRENGTH (2X AUSTENITIC STRENGHT);
- REDUCED TOUGHNESS BELOW DBTT (DUCTILE-BRITTLE TRANSITION TEMPERATURE) (≃ -50 [°C]) AND ABOVE 300 [°C];



POSSIBLE APPLICATIONS:
- CHEMICAL TANKERS;
- PRESSURE VESSELS;
- PROCESS EQUIPMENT;

- +LOW % Ni; (Ni IS NOT EXPENSIVE) -> LESS COST ;

↕

- PROBABLY THE USE OF DUPLEX SS WILL INCREASE: NOW COMPANIES ARE STILL NOT SURE OF THE REAL BEHAVIOUR OF THIS CLASS => PRICE OF DUPLEX ↑ BECAUSE JUST FEW COMPANIES PRODUCE IT;

3.3.5 PRECIPITATION HARDENING SS

- THIS GROUP CONTAINS **Cr** AND **Ni** TO INCREASE THE CORROSION RESISTANCE;
- OTHER ELEMENTS ARE ADDED: **Cu** AND **Nb** ADDED TO INCREASE MECHANICAL RESISTANCE;
- THE MOST COMMON PH SS IS: **17-4 PH SS** (ALSO KNOWN AS GRADE **630**): 17% Cr - 4% Ni - 4% Cu - 0.3% Nb
- THEY CAN BE SUPPLIED IN THE "**SOLUTION TREATED CONDITION**": HEATING - MANTEINED AT HIGHT T - RAPID COOLING (TIME DEPENDING ON COMPOSITION);
- **AFTER MACHINING** THE STEEL CAN BE HARDENED BY A **SINGLE "AGEING" HEAT TREATMENT** AT FAIRLY (ABBASTANZA) **LOW T**, WHICH CAUSES NO DISTORSION OF THE COMPONENT;
- RESISTANCE TO CORROSION;
- ULTRA HIGH STRENGTH (σ_Y = 1310 [MPa] ; σ_R = 1450 [MPa] FOR 17-7 PH SS);
- LOW DEFORMABILITY (1÷6% FOR 17-7 PH SS);

				Mechanical Properties			
AISI Number	UNS Number	Composition (wt%)[a]	Condition[b]	Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	Typical Applications
Precipitation Hardenable							
17-7PH	S17700	0.09 C, 17 Cr, 7 Ni, 1.0 Al, 1.0 Mn	Precipitation hardened	1450 (210)	1310 (190)	1–6	Springs, knives, pressure vessels

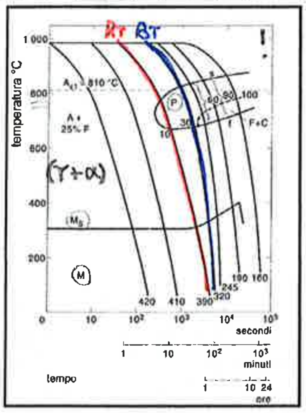
AISI: POSSIBLE APPLICATIONS:
- 17-7PH - SPRINGS;
- 17-7PH - KNIVES;
- 17-7PH - PRESSURE VESSELS;

3.5.3 CCT DIAGRAMS

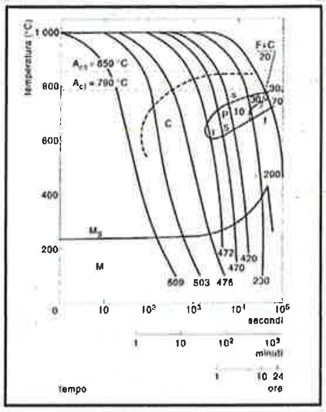
CCT = CONTINUOUS COOLING TRASFORMATION: WE USE THEM FOR VERY FAST TRANSFORMATIONS.

→ EVERY CURVE REPORTS THE FINAL VICKERS HARDNESS.

[REMEMBER: $\sigma_y \cong HV \cdot 3$]



Steel: AISI 410



Steel: AISI 420

EUTECTOID T = 800 [°C]: ABOVE THIS T TWO PHASES ARE STABLE: $\gamma+\alpha$

A_1 = EUTECTOID T = 723 [°C] (NO ALLOY)

A_2 = CURIE T: ABOVE THIS T → NO FERROM. BEHAVIOR

A_3 = T TO ENTER IN γ FIELD (AUSTENITIZING T).

BELOW A_1 → METASTABLE γ

BELOW M_S LINE: $\gamma \to M$

C: MEANS I HAVE CARBIDES FORMATION DURING C.

FOLLOWING THE BLUE TRANSFORMATION (B_T):

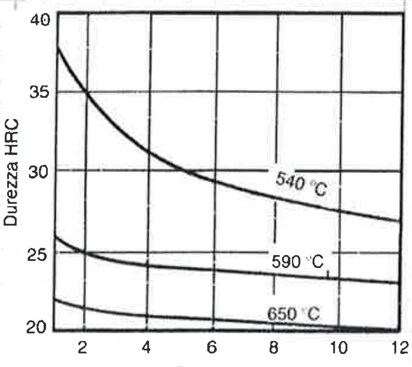
BELOW A_1 γ STARTS TO TRANSFORM IN P (PERLITE); AT THE END: 70% γ + 30% P

THEN 70% γ → 70% M; FINAL PRODUCT: 70% M + 30% P

FOLLOWING THE RED TRANSFORMATION (R_T):

FINAL PRODUCT: 90% M + 10% P

EFFECT OF TEMPERATURE AND TIME OF TEMPERING



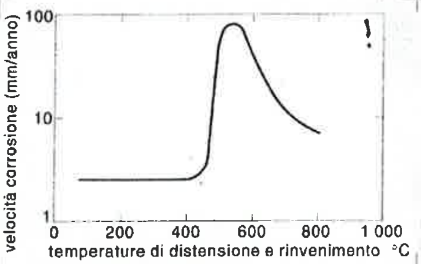
$\boxed{T\uparrow, t\uparrow \Rightarrow HRC \searrow}$

WITH MARTENSITIC SS WE HAVE TO BE CAREFUL WITH T OF TEMPERING NOT TO LOOSE THE CORROSION RESISTANCE.

*CARBIDES CATCH Cr FROM THE MATERIAL : LOW % CR ⇒ CORROSION !.

→ KRUPP PROBLEM.

KRUPP PROBLEM



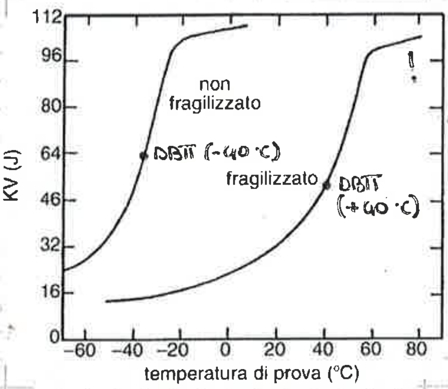
THERE IS A RANGE OF T OF TEMPERING WHERE CORROSION RATE REACH HIGH VALUES. AT LOW T THE VALUES REMAIN LOW.

⇒ SO WE HAVE TO AVOID THE CRITICAL RANGE OF TEMPERING.

THE DIAGRAM OF A AISI 410 STEEL EVIDENCES THAT THE CORROSION RATE VALUES [mm/YEAR] REACH HIGH VALUES IN THE CRITICAL RANGE (450-650 [°C]) OF TEMPERING, WHILE THEIR VALUES REMAIN LOWER AT LOW TEMPERING TEMPERATURE.

(THE TEST AT THE DIFFERENT TEMPERING TEMPERATURE WAS EFFECTED TO EVIDENCE THE CORROSIVE PHENOMENA, IN A 10% BOILING ACETIC SOLUTION FOR A TIME OF 50 HOURS).

TEMPERING BRITTLENESS (AFTER COOLING)



LEFT CURVE: RAPID COOLING AFTER TEMPERING

RIGHT CURVE: 1h TEMPERING + SLOW COOLING IN AIR.

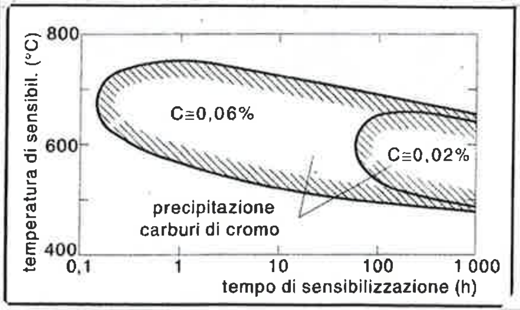
RESULT OF IMPACT TEST AFTER COOLING:

LEFT CURVE → NOT BRITTLENESS INDUCED

RIGHT CURVE → BRITTLENESS INDUCED

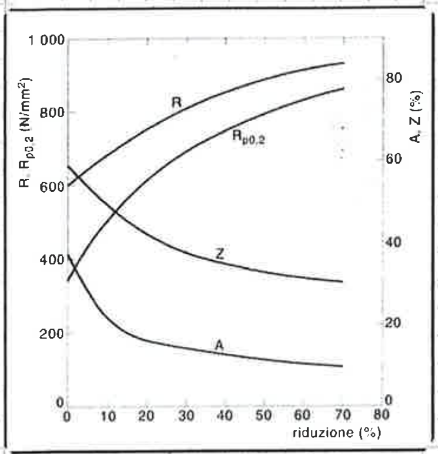
SLOW COOLING: CARBIDES PRECIPITATE AT GRAIN BOUNDARIES AND THAT GIVE BRITTLENESS: ⇒ SO, TO AVOID THIS, WE HAVE TO COOL RAPIDLY.

* CARBIDE PRECIPITATION



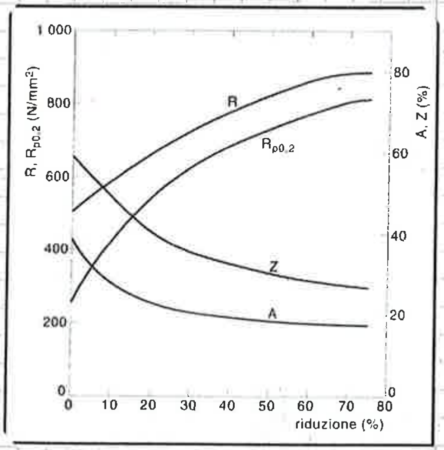
CHROMIUM CARBIDE PRECIPITATION CURVES OF AUSTENITIC SS 304/304L

- (HARDENING CURVES AT DIFFERENT PERCENTAGE OF STRAIN HARDENING) $R, R_{P02} \left[\frac{N}{mm^2}\right] = f(\text{REDUCTION \%})$



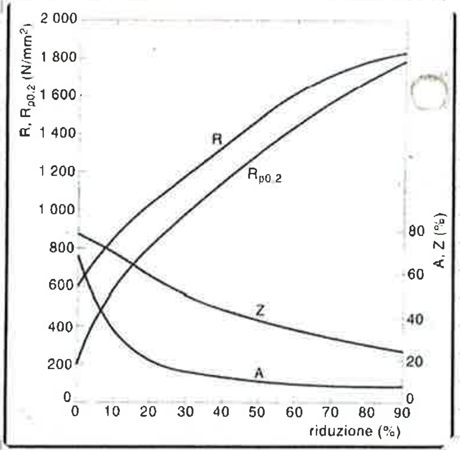
AISI 304 (X30 CR13)

(MARTENSITIC SS)



AISI 430 (X6CR17)

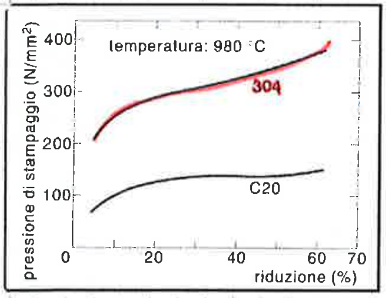
(FERRITIC SS)

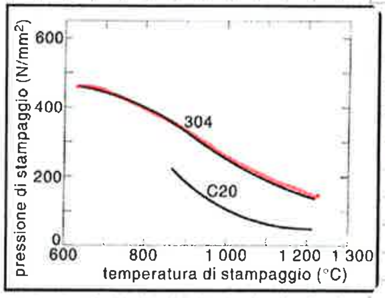


AISI 304 (X5 CRNi 18-10)

(AUSTENITIC SS)

- DEFORMABILITY : PRESSURE NEEDED TO DEFORM $\left[\frac{N}{mm^2}\right] = f(T)$





$C20 \Rightarrow \frac{20}{100} = 0.2\% C$ (ONLY CARBON STEEL)

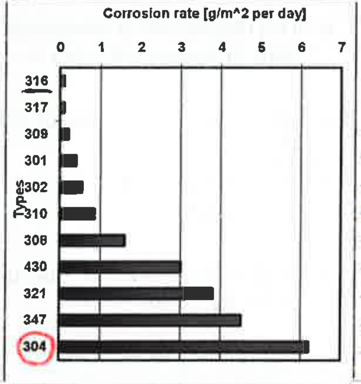
IF WE NEED A STEEL TO ABSORBE SHOKS

→ 304 IS BETTER BECAUSE IT REQUIRES

MORE LOAD TO BE DEFORMED. (IT CONTAINS Cr, Mn).

AUSTENITE = HIGH LOAD TO DEFORM.

- CORROSION RATE $\left[\frac{g}{m^2} \text{ PER DAY}\right]$



NW!:

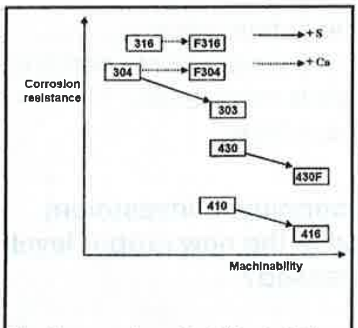
$\left(F = \frac{+S}{+Ca}\right)$

TO INCR. MACH.

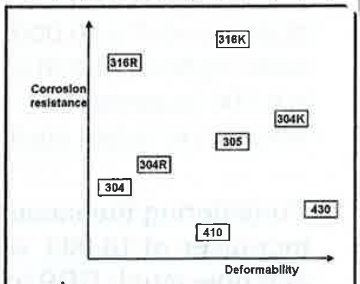
$\left(L = \frac{+Nb}{+Ti}\right)$

TO INCR. CR

- MACHINABILITY (OR WORKABILITY)

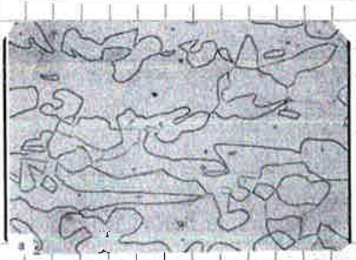


The increase of machinability of stainless steels is obtained with S addition or with Ca addition in melting. In the diagram is evidenced the influence of S and Ca addition.



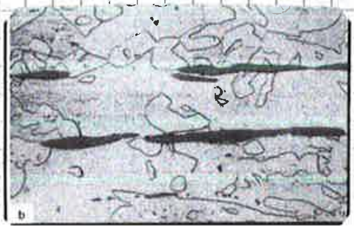
NW!:

The choice of a stainless steel for cold working is a compromise among cold deformability, plasticity and corrosion resistance. The complexity of final component often influence the material type choose.



← AISI 430 (FERRITIC SS)

→ (L) <=> TO AVOID SENSITATION PROBLEM

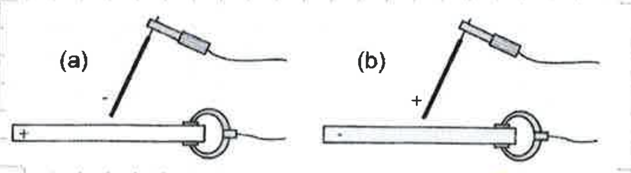


← AISI F430 => +S, +Ca

WELL DETECTABLE GRAINS OF Mn AND Ca SULPHITES WHICH INTERRUPT THE METALLIC MATERIAL AND THEREFORE IMPROVE THE WORKABILITY OF THE MATERIAL.

3.10 WELDING

- ARC WELDING

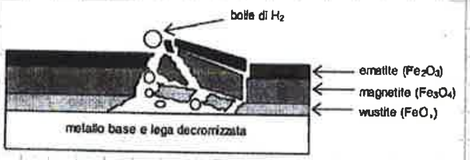


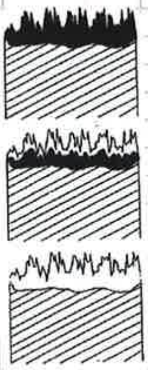
IN THE CONTINUOUS CURRENT ARC WELDING AND FILLER ROAD LINED (FODERATA) WITH PROTECTIVE MATERIAL CAN BE USED TWO ELECTRICAL CONFIGURATIONS:

(a) DIRECT POLARITY

(b) REVERSE POLARITY

CLEANING AFTER ARC WELDING →





(ANALYSIS WITH MICROSCOPE)

↓ STUDY:

- RELATIVE COMPOSIT.
- CRYSTALS OF DIFF. PHASES

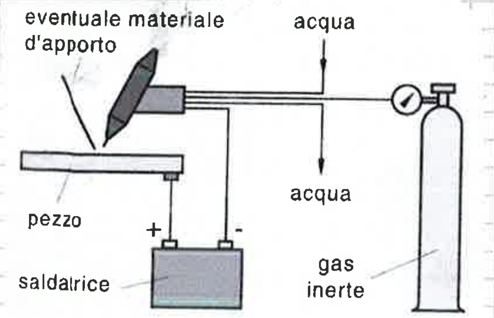
FILLING MATERIALS

CONSUMABLE ELECTRODES:

FOR FERRITIC SS: E 308
E 309
E 310
E 312
E 316
E 317
E 347

FOR MARTENSITIC SS: " " + E 420
E 430

- TIG WELDING



TIG = "TUNGSTEN INERT GAS" WELDING

CONSIDERATIONS:

- THE AREAS TO BE WELDED MUST NOT PRESENT POROSITY.
- (AUSTENITE IS ALWAYS HARDER THAN FERRITE).

VICKERS HARDNESS: WE MEASURE THE DIAGONAL OF THE LEFT FOOTPRINT; IF IT IS SMALLER THAN THE CHARACTERISTIC SIZE OF THE CRYSTAL ⇒ WE TALK ABOUT: MICROHARDNESS. (VERY SMALL LOAD APPLIED → LEAVES A SMALL TRACK). THIS TEST PUTS IN EVIDENCE THAT IN BASE MATERIAL AND ALSO IN HEATED OR WELDED ZONES THE AUSTENITE IS ALWAYS HARDER THAN FERRITE.

- WHEN WE HAVE A FRACTURE IN A DUPLEX:

IF IT CROSS γ → BRITTLE FRACTURE

IF IT CROSS α → DUCTILE FRACTURE

4.2 DESIGNATION OF WROUGHT Al - ALLOYS

SERIES	FAMILIES
1xxx	PURE Al
2xxx	Al - Cu
3xxx	Al - Mn
4xxx	Al - Si
5xxx	Al - Mg
6xxx	Al - Mg - Si
7xxx	Al - Zn
8xxx	OTHER (Al-Li) (Al-Fe)...

- THE FIRST NUMBER DEFINES THE PRESENCE OF THE PRINCIPLE ALLOY ELEMENTS. IF IT IS 1 THERE ARE NOT PARTICULAR ALLOY EL.
  ⇒ WE HAVE 99% Al + 1% OTHER ELEMENTS, OFTEN IMPURITIES (Fe, Cu, Mn, Mg)
- THE OTHER NUMBERS:

2x14 → Al - Cu 14th ALLOY OF THE 2000 SERIES

14 → NUMBER OF STANDARDIZATION

x → OTHER ALLOY ELEMENT (SPECIFICATION WITH RESPECT OF BASE ALLOY)

1x50 → 99.5 % Al

1x70 → 99.7 % Al

1050 → 99.5 % Al

1250 → 99.5 % Al + Fe MAX = 0.15%

1350 → 99.5 % Al + Mn = 0.3%

4.3 HEAT TREATMENTS

WHY TAKE A HEAT TREATMENT?

HEAT TREATMENTS CAN BE PERFORMED TO:

1. SOFTEN THE ALLOY TO IMPROVE WORKABILITY AND FORMABILITY;
2. INCREASE STRENGTH AND PRODUCE SPECIFIC MECHANICAL PROPERTIES;
3. STABILISE MECHANICAL OR PHYSICAL PROPERTIES;
4. INCREASE CORROSION RESISTANCE;
5. AVOID CHANGES THAT NORMALLY WOULD OCCUR WITH TIME OR AT HIGH TEMPERATURES;
6. ENSURE DIMENSIONAL STABILITY DURING SERVICE, ESPECIALLY FOR PARTS THAT OPERATE AT HIGH T
7. RELIVE RESIDUAL STRESSES INDUCED BY DIFFERENTIAL DEFORMATION OR NON-UNIFORM COOLING AFTER CASTING, QUENCHING, WELDING OR FORMING OPERATIONS.

DESIGNATION OF HEAT TREATMENTS

DESIGNATION	HEAT TREATMENT
F	AS FABRICATED
O	ANNEALED (RICOTTO) (ONLY FOR WROUGHT PRODUCTS)
W	SOLUTION HEAT TREATED (SOLUBILIZZATO)
T	HEAT TREATMENTS DIFFERENT FROM F OR O

T1	NATURALLY AGED TO A SUBSTANTIALLY STABLE CONDIT.	T6	SOLUTION HEAT TREATED AND T5
T2	ANNEALED (RICOTTO) (ONLY FOR CAST PRODUCTS)	T7	SOLUTION HEAT TREATED AND OVERAGED
T3	SOLUTION HEAT TREATED, COLD WORKED AND T1	T8	SOLUTION HEAT TREATED, COLD WORKED AND T5
T4	SOLUTION HEAT TREATED AND T1	T9	SOLUTION HEAT TREATED, T5 AND COLD WORKED
T5	ARTIFICIALLY AGED	T10	T5 AND COLD WORKED.

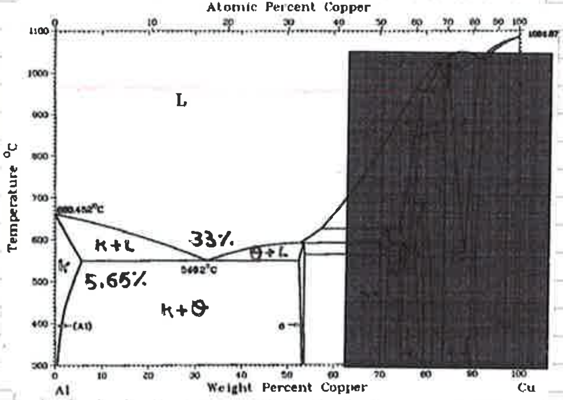
(ARTIFICIALLY) AGING = PRECIPITATION HEAT TREAT. → PRECIPITATION HARDENING

W - SOLUTION HEATING:

IT IS THE TREATMENT THAT ALLOWS TO INCREASE THE CONTENT OF ALLOYING ELEMENT IN THE SOLID SOLUTION.

TO BETTER UNDERSTAND THIS TYPE OF HEAT TREATMENT WE TAKE AS REFERENCE THE:

Aℓ - Cu PHASE DIAGRAM



$T_M(A\ell) = 660{,}45$ [°C]

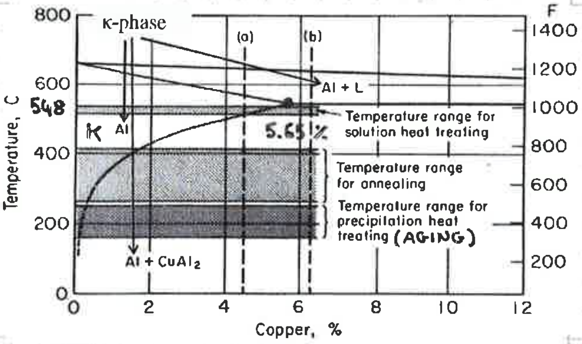
$T_M(Cu) = 1084{,}6$ [°C]

$T_E = 548$ [°C] (EUTECTIC T) EUTECTIC COMP: 33% Cu.

SOLID SOLUTION K: IT CAN MELT AT MOST: 5.65% Cu.

SOLID SOLUTION θ: $A\ell_2Cu$

(↕ ZOOM)



W - SOLUTION HEATING

1 WE PUT THE COMPONENT IN THE FURNACE AT THE SOLUBILIZATION TEMPERATURE (SLIGHTLY LOWER THAN EUTECTIC T)

2 WE WAIT FOR COMPLETE SOLUBILIZATION OF THE θ PHASE: θ PHASE DISAPPEARS AND K PHASE IS ENRICHED IN Cu. THIS STEP REQUIRES LONG SOLUBILIZATION TIME BECAUSE THE ATOM OF Cu IS LARGE AND THE T IS NOT SO HIGH (8÷10h).

QUENCHING

3 THEN WE OPEN THE FURNACE, WE TAKE THE COMPONENTS AND WE QUENCH THEM. THERE ARE NO PHASE TRANSFORMATIONS; WE BLOCK THE HIGH TEMPERATURE SITUATION.

NATURAL AGING

4 ROOM T: WE HAVE OBTAINED A METASTABLE SOLID SOLUTION THAT WILL TRY TO SEND OUT THE EXCESS OF Cu OVER THE TIME.

THE AGING PROCESS AT ROOM T IS VERY LONG. DURING THIS PROCESS INTERMEDIATE METASTABLE PRECIPITATES ARE FORMED. THESE PRECIPITATES LEAD TO AN IMPORTANT INCREASE IN THE MECHANICAL CHARACTERISTICS.

WHEN AGING IS COMPLETED WE GET A SOLID SOLUTION K+θ. NOW K HAS THE Cu CONTENT REQUIRED BY THE STATE DIAGRAM. THE Cu THROWN OUT WENT TO FORM THE θ PHASE ($CuA\ell_2$). THUS WE OBTAIN THE STABLE COMPOUND.

INFLUENCE OF PARAMETERS 5

MANY PARAMETERS CAN INFLUENCE THE OPTIMAL CHARACTERISTICS OBTAINABLE AFTER THE AGE HARDENING CYCLE.

- TEMPERATURE DURING SOLUTION HEAT TREATING;
- THE RATE OF COOLING DURING QUENCHING;
- THE CHEMICAL COMPOSITION;
- THE COMPONENT DIMENSION (THICKNESS = SPESSORE);
- TIME AND TEMPERATURE OF AGING;

CONSIDERATION ON WELDING

7000 SERIES ALLOY : HIGHER MECHANICAL CHARACTERISTICS.

THE ALLOYS OF THE 7000 SERIES, WHEN THEY ARE WELDED, LOSE THE MAXIMUM PERFORMANCE IN THE WELDING AREA. WE HEAT THEM SO WE OVERAGE THEM. THE COOLING SPEED IS NOT SUFFICIENT TO GARANTEE A QUENCHING AS FAST AS NECESSARY. THE MOST EFFICIENT ALUMINUM ALLOYS WITH WHICH WE BUILD THE WINGS OF THE AIRPLAINS DO NOT WELD THEM BUT WE RIVET THEM.

4.4 ALCLAD

ALCLAD => PURE ALUMINUM COATING (CLADDING).

WHEN WE BUY AN ALUMINUM ALLOY, IF THE TERM "ALCLAD" IS PRESENT IT MEANS THAT THE ALLOY IS COATED WITH A THIN FILM OF PURE ALUMINUM.

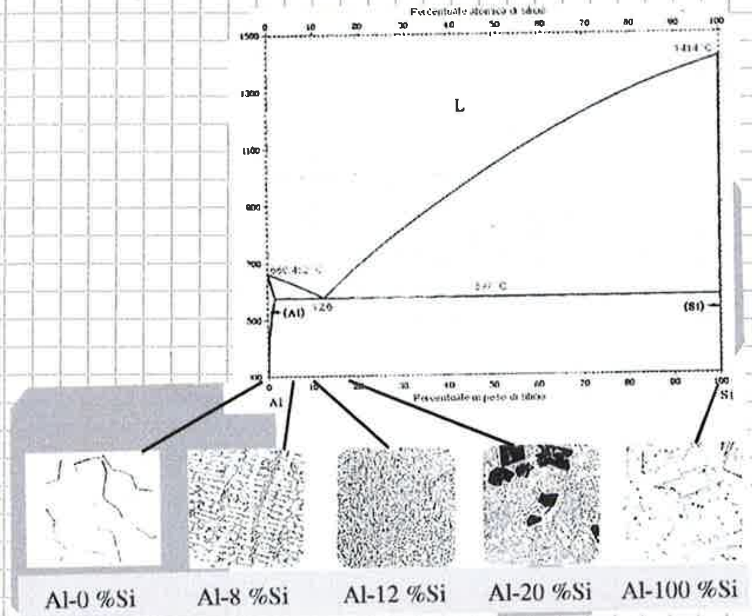
THE SINGLE-PHASE PURE ELEMENTS ARE MORE RESISTANT TO CORROSION.

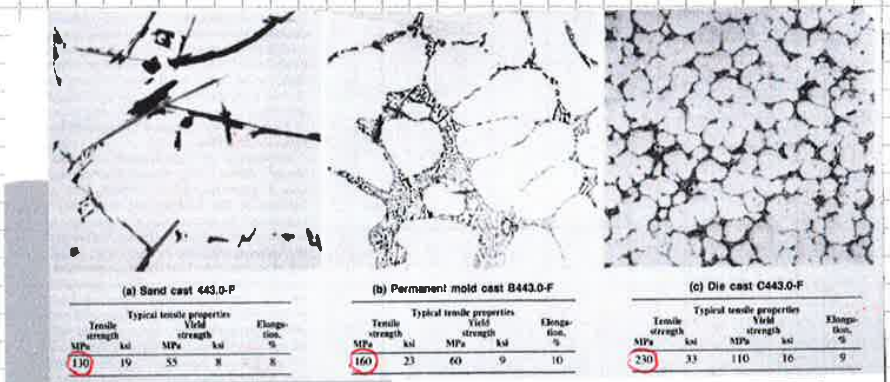
SO WE CAN HAVE AN ALLOY WITH A STRONGER CORE THAT GARANTEES STRENGTH AND A PURE ALUMINUM COATING/CLADDING.

NW: IN ANNEALING THIS COMPONENTS THE $T_{ANNEALING}$ MUST BE LIMITED TO AVOID EXCESSIVE DIFFUSION FROM CORE TO CLADDING.

TO THE PHASE SOLIDIFICATION WITH EUTECTIC MORPHOLOGICAL DISTRIBUTION, i.e. (CIOE') A MIXTURE OF α + 2nd PHASE.

-> IN SOLUBILIZATION PROCESSES IT IS NOT NECESSARY TO RISE ABOVE THE EUTECTIC TEMPERATURE (WE HEAT UP TO A CERTAIN T SO AS TO ACCELERATE THE SOLUTE DIFFUSION PHASE TO SPEED UP THE PRECIPITATION OF NEW METASTABLE PRECIPITATES).



 ← (ABOUT COOLING RATE)*

(a) Sand cast 443.0-F

Typical tensile properties				
Tensile strength MPa	Tensile strength ksi	Yield strength MPa	Yield strength ksi	Elongation, %
130	19	55	8	8

(b) Permanent mold cast B443.0-F

Typical tensile properties				
Tensile strength MPa	Tensile strength ksi	Yield strength MPa	Yield strength ksi	Elongation, %
160	23	60	9	10

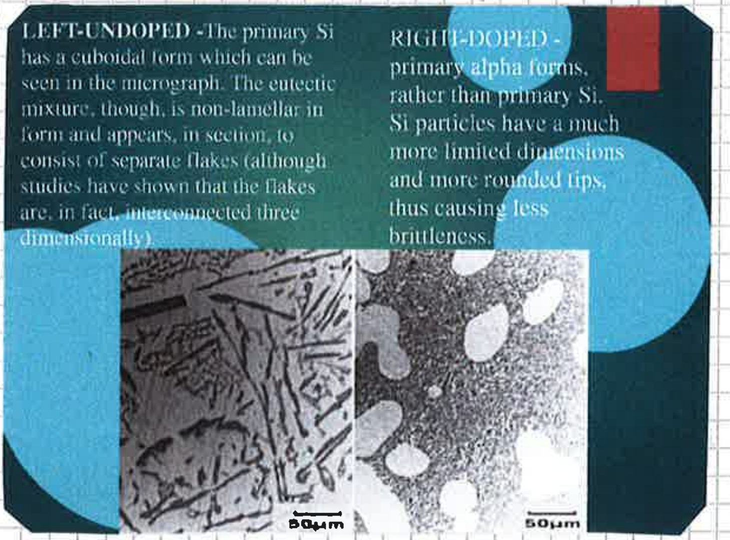
(c) Die cast C443.0-F

Typical tensile properties				
Tensile strength MPa	Tensile strength ksi	Yield strength MPa	Yield strength ksi	Elongation, %
230	33	110	16	9

The resultant microstructures are the consequence of different cooling rates during solidification, caused by different casting processes for the alloy Al-5% Si. The dimensions of the dendrites and those of the other particles decrease when increasing the cooling rate, from sand casting to die casting processes. Etching, 0.5% HF (500X).

IMPORTANT CONSIDERATIONS:

- IN CASTING ALLOYS THE COOLING RATE DURING THE SOLIDIFICATION IS VERY IMPORTANT; THE GREATER THE REMOVAL SPEED OF THE HEAT (SOLIDIFICATION SPEED), THE SMALLER THE CRYSTALS (CRYSTALLINE GRAINS) WILL BE.
- THE Al-Si CASTING ALLOYS CAN BE STRENGHTENED BY THE EUTECTIC MODIFICATION PHENOMENA.



LEFT-UNDOPED - The primary Si has a cuboidal form which can be seen in the micrograph. The eutectic mixture, though, is non-lamellar in form and appears, in section, to consist of separate flakes (although studies have shown that the flakes are, in fact, interconnected three dimensionally).

RIGHT-DOPED - primary alpha forms, rather than primary Si. Si particles have a much more limited dimensions and more rounded tips, thus causing less brittleness.

4.8 HYPOEUTECTIC Aℓ-Si ALLOYS

- Si PARTICLES WEAKEN (INDEBOLISCE) THE ALLOYS, SINCE THEY ARE BRITTLE AS GRAPHITE IN CAST IRONS.
- TO INCREASE UTS, ALLOYS WITH LESSER Si CONTENT THAN THE EUTECTIC ONES ARE USED FOR SPECIAL PARTS THAT REQUIRE A HIGHER STRENGTH.
- 7% Si ALUMINUM ALLOYS ARE MOSTLY USED, USUALLY WITH SOME Mg ADDITIONS TO EXPLOIT THE STRENGTHENING POSSIBILITIES GIVEN BY THE PRECIPITATION OF Mg_2Si PRECURSORS.
- SINCE THEY ARE LESS CASTABLE THAN EUTECTIC OR HYPEREUTECTIC ALLOYS, THEY ARE USUALLY PRESSURE DIE CASTED.
- THIN WALL Aℓ ALLOY CASTINGS ARE ALSO MADE BY SUCH A TECHNOLOGY.

STRENGTHENING PRECIPITATES IN VARIOUS SYSTEMS

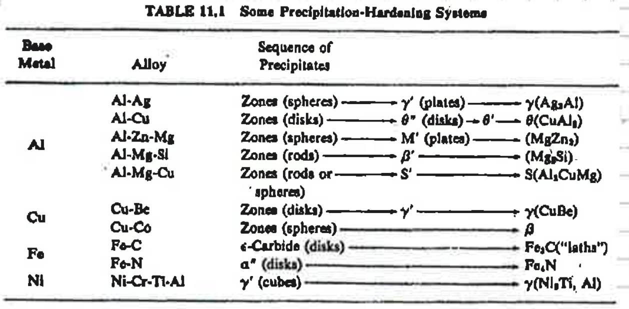


TABLE 11.1 Some Precipitation-Hardening Systems

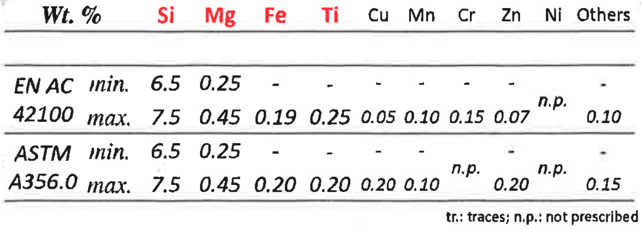
Base Metal	Alloy	Sequence of Precipitates
Al	Al-Ag	Zones (spheres) → γ′ (plates) → γ(Ag_2Al)
	Al-Cu	Zones (disks) → θ″ (disks) → θ′ → θ($CuAl_2$)
	Al-Zn-Mg	Zones (spheres) → M′ (plates) → ($MgZn_2$)
	Al-Mg-Si	Zones (rods) → β′ → (Mg_2Si)
	Al-Mg-Cu	Zones (rods or spheres) → S′ → S(Al_2CuMg)
Cu	Cu-Be	Zones (disks) → γ′ → γ(CuBe)
	Cu-Co	Zones (spheres) → β
Fe	Fe-C	ε-Carbide (disks) → Fe_3C("laths")
	Fe-N	α″ (disks) → Fe_4N
Ni	Ni-Cr-Ti-Al	γ′ (cubes) → γ(Ni_3Ti, Al)

Na ACICULAR EUT. Si → GLOB. EUT. Si

Mn β (Aℓ-Fe-Si) → α (Aℓ-Fe-Si-Mn)
(LAMELLAR MORPH.) → INFRAGILISE THE MAT.
(LESS HARD AND LESS DANG. ARRANGED)

Mg INCREASES THE STRENGTH OF THE ALLOY (PRECIPITATION OF Mg_2Si)

A356.0 ELEMENT COMPOSITION, HARDNESS



Wt. %		Si	Mg	Fe	Ti	Cu	Mn	Cr	Zn	Ni	Others
EN AC	min.	6.5	0.25	-	-	-	-	-	-	n.p.	-
42100	max.	7.5	0.45	0.19	0.25	0.05	0.10	0.15	0.07		0.10
ASTM	min.	6.5	0.25	-	-	-	-	n.p.	-	n.p.	-
A356.0	max.	7.5	0.45	0.20	0.20	0.20	0.10		0.20		0.15

tr.: traces; n.p.: not prescribed

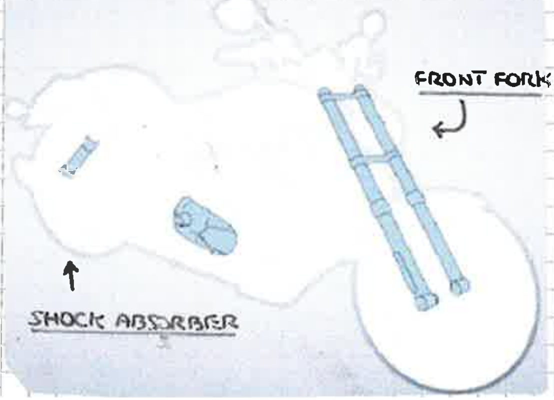
Standard minimum requirements for die cast EN AC 42100-T6:

UTS 290 MPa, YS 210 MPa, A 4 %, HB 90

Other expected properties (from the literature):

K_{Ic} 27 MPa√m, σ_D 95 MPa (at $5 \cdot 10^7$ cycles)

PIECES FABRICATED WITH A356.0 CAST Aℓ ALLOY



5.2 DESIGNATION OF Mg-ALLOYS

First part 1ST	Second part 2nd	Third part 3TH	Fourth part 4th
The two main alloying elements are indicated in capital letter, they are ordered considering the weight (or alphabetic if percentages are equal)	Indicates the quantity of these elements	It distinguish alloys with the same mains alloying elements percentage.	Heat treatment condition.
	Two integer numbers that indicate percentage of the two mains alloying elements ordered as in the first part.	Alphabet letters in progressive order assigned when a composition become standard.	Letters and numbers separated from the third part by a dash.
A-aluminium B-bismuth C-copper C = Cu D-cadmium D = Cd E-rare earths F-iron H-thorium K-zirconium K = Zr L-lithium M-manganese M = Mn N-nickel P-lead P = Pb Q-silver R-chromium S-silicon W-yttrium Y-antimony Z-zinc Z = Zn	Numbers	Alphabet letters except I and O.	F-as produced O-annealed H10 and H11- strain hardened H23, H24 e H26- strain hardened and partially annealed. H4-solubilized T5-artificially aged only T6-solubilized and artificially aged T8-solubilized, strain hardened and artificially aged.

AZ 91 D

1ST → MAIN ALLOWING ELEMENTS ↓ (ALFABETIC ORDER IN FUNCTION OF THE WEIGHT)

3TH → MODIFICATION OF THE ALLOY (ADDITION OF ELEMENTS) (D ~ ADDITION OF Mn)

2nd → %A = 9% Al ALLOWING ELEMENTS

→ %Z = 1% Zn (IN REALITY IT IS 0.7% BUT WE USE INTEGER NUMBER)

+ 4th HEAT TREATMENT

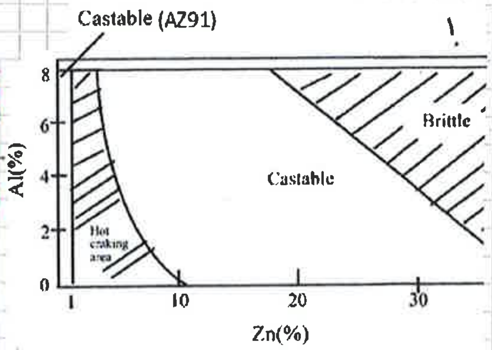
5.3 WROUGHT Mg-ALLOYS

Alloy	H.T.	Composition	Properties
AZ10A	F	Al 1.2%, Zn 0.4%, Mn 0.2%	σ_r = 240 MPa, σ_s = 145 MPa, A% = 10
AZ61A	F	Al 6%, Zn 1%	σ_r = 310 MPa, σ_s = 230 MPa, A% = 16
Az80a	T5	Al 8.5%, Zn 0.5%,	σ_r = 380 MPa, σ_s = 275 MPa, A% = 7
ZK60A	T5	Zn 5.5%, Zr 0.45%,	σ_r = 365 MPa, σ_s = 305 MPa, A% = 11

5.4 DIE CASTING Mg-ALLOYS

Alloy (*)	Chemical composition	General characteristics
AZ91D	Al 9%, Zn 0.7%, Mn 0.13%	Is the most used alloy. Good strength at room temperature, low viscosity good stability at atmospheric conditions, excellent sea water corrosion resistance
AM60B	Al 6%, Mn 0.13%	Good strain rupture and toughness, excellent corrosion resistance in sea water, good tensile properties and yielding properties.
AS21X1	Al 1.7%, Si 1.1%, Mn 0.4%	The best, creep resistant, die casting alloy, good room temperature properties, it can be used at high temperatures
AS41XB	Al 4.3%, Si 1%, Mn 0.35%	Good creep resistance up to 175 °C, good room temperature properties, excellent corrosion resistance in sea water, it can be used at high temperatures.

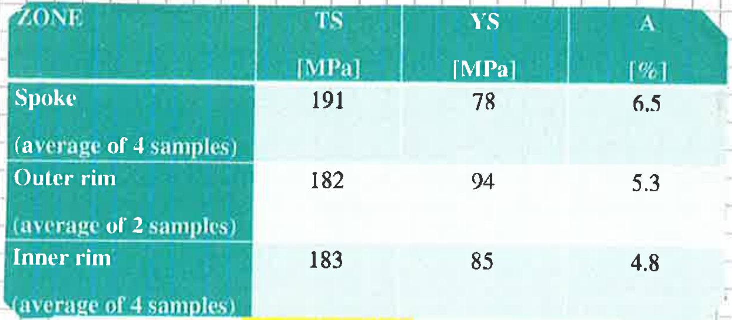
(*) All characteristics in the as cast condition.



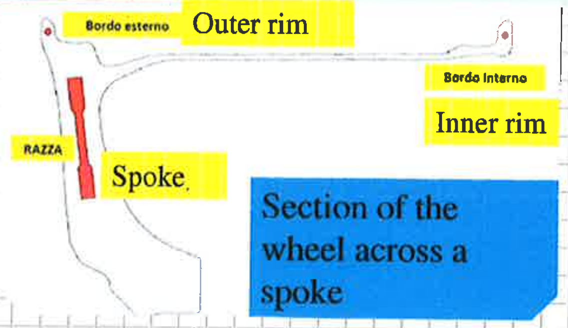
AZ91D ALLOY WHEEL: FABRICATION CYCLE (5)

- MATERIAL: AZ91D Mg ALLOY INGOTS.
- MELTING AND LOW PRESSURE CASTING IN STEEL PERMANENT MOULDS.
- MECHANICAL TURNING AND DRILLING.
- T4 HEAT TREATMENT IN A FURNACE WITH THREE INCREASING TEMPERATURES LEVELS UP TO A MAXIMUM OF 410 [C] FOR A TOTAL DURATION OF 23.5 h, FOLLOWED BY RAPID COOLING BY FORCED AIR FLOW.
- HIGH TEMPERATURE PAINTING WITH TWO 20 min TRAVELS IN A CONTINUOUS BAKING FURNACE AT 180 [C] AND 160 [C], RESPECTIVELY.

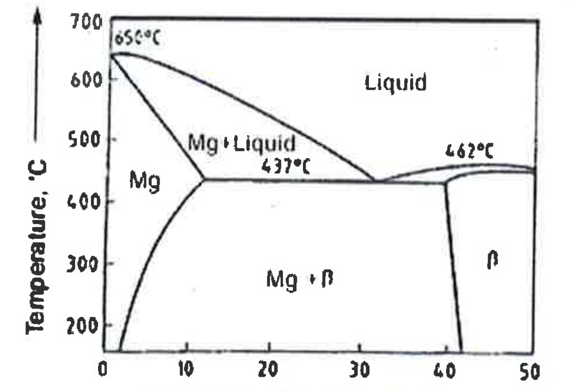
AZ91D ALLOY WHEEL: MECHANICAL CHARACTERISTICS



ZONE	TS [MPa]	YS [MPa]	A [%]
Spoke (average of 4 samples)	191	78	6.5
Outer rim (average of 2 samples)	182	94	5.3
Inner rim (average of 4 samples)	183	85	4.8

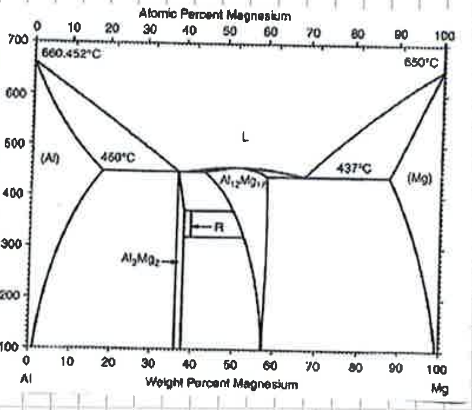


5.7 PHASE DIAGRAM FOR THE BINARY SYSTEM Mg-Al



Phase diagram for the binary system Mg-Al

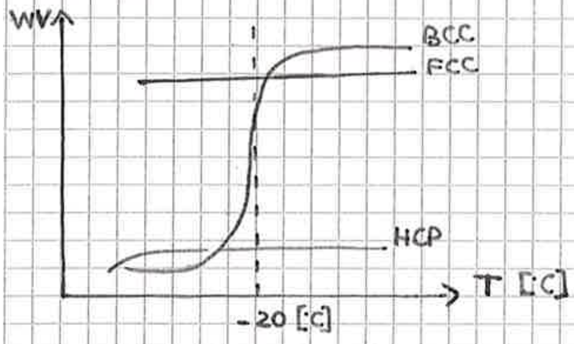
(a)



5.9 MECHANICAL CHARACTERISTICS

Alloy	UTS [MPa]	σ_y [MPa]	Elongation %	Notch toughness [J] at 24 °C
AM100A - T61	275	150	1	-
AZ91C - T6	290	132	6.3	7.96
AZ92A - T6	290	160	4	7.62
EQ21A - T6	235	195	2	-
EZ33A - T5	190	115	7.6	7.46
HZ32A - T5	185	90	4	-
QE22A - T6	280	213	4.4	23.5
ZE41A - T5	205	140	3.5	-
ZH62A - T5	275	192	5.7	15.02
ZK61A - T5	310	185	-	-
AZ10A - F	240	145	10	-
AZ61A - F	310	230	16	-
Az80A - T5	380	275	7	-
ZK60A - T5	365	305	11	-

ABOUT IMPACT TEST



- VERY LOW LOAD REQUIRED TO CRACK Mg ALLOYS WITH AN IMPACT TEST (HCP).

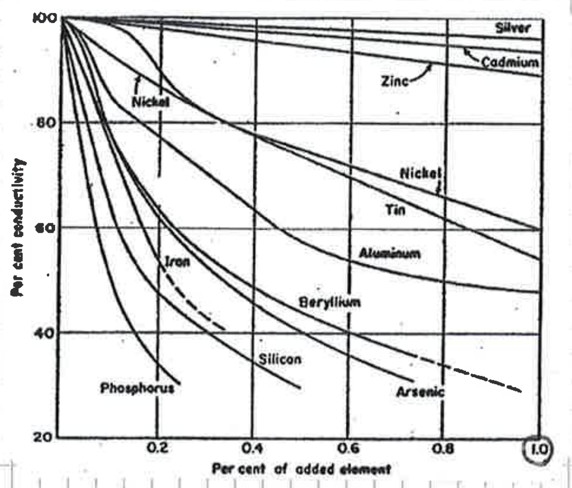
6.2 COPPER IN PENNIES (USA)

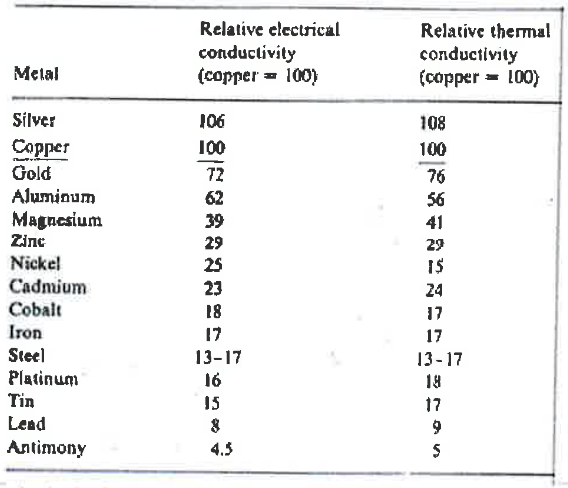
- 1793-1837 US PENNY WAS MADE FROM PURE Cu.
- 1837-1857 US PENNY WAS MADE OF BRONZE (Cu-Sn).
- 1857 US PENNY WAS MADE OF 88% Cu + 12% Ni (WHITISH APPARENCE).
- 1864-1962 US PENNY WAS MADE OF BRONZE (95% Cu + 5% Zn AND Sn).
- 1962, THE COIN'S COMPOSITION WAS CHANGED TO ZINC COATED STEEL DUE TO THE CRITICAL USE OF COPPER FOR THE WAR EFFORT (SFORZO).
- 1962-1982 US PENNY WAS MADE OF 95% Cu + 5% Zn (BRASS)
- 1982 US PENNY STARTED TO BE MADE OF Cu-PLATED Zn: 97.5% Zn + 2.5% Cu.

6.3 TYPICAL APPLICATIONS OF Cu-ALLOYS

- ELECTRICITY CONDUCTION (POWER / DATA TRASMISSION);
- HEAT CONDUCTION (RADIATORS).
- MARINE CONDENSER OR EXPOSED MARINE FIXTURE (HEAT/SALT WATER EXPOSURE);
- INITIALLY USED IN COINS FOR CORROSION RESISTANCE (COPPER ACETATE OF THE ROOFS → GREEN);

6.4 EFFECT OF ADDITIONS ON CONDUCTIVITY





Metal	Relative electrical conductivity (copper = 100)	Relative thermal conductivity (copper = 100)
Silver	106	108
Copper	100	100
Gold	72	76
Aluminum	62	56
Magnesium	39	41
Zinc	29	29
Nickel	25	15
Cadmium	23	24
Cobalt	18	17
Iron	17	17
Steel	13-17	13-17
Platinum	16	18
Tin	15	17
Lead	8	9
Antimony	4.5	5

ALL THESE DECREASE CONDUCTIVITY;

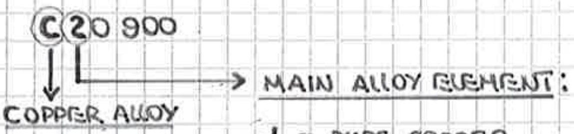
ESPECIALLY P, Si, Fe, AR, Be (Al, Ni, Zn, Ca, Ag)

JUST SILVER (Ag) IS A BETTER CONDUCTOR, BUT IT IS EXPENSIVE.

GOLD (Au) IS A GOOD CONDUCTOR BUT IT HAS THE PROBLEM THAT IT OXIDATES EASILY LOSING HIS PROPERTIES.

6.8 DESIGNATION OF Cu-ALLOYS

Name	UNS Number	Composition
Wrougth Alloys		
Copper	C10100-C15760	> 99% Cu
Copper	C16200-C19600	> 96% Cu
Brass	C20500-C28580	Cu-Zn
Lead Brass	C31200-C38590	Cu-Zn-Pb
Lead Brass	C40400-C49080	Cu-Zn-Sn-Pb
Phosphorus Bronze	C50100-C52400	Cu-Sn-P
P-Pb Bronze	C53200-C54800	Cu-Sn-Pb-P
Cu-P and Cu-Ag-P Alloys	C55180-C55284	Cu-P-Ag
Aluminium Bronze	C60600-C64400	Cu-Al-Ni-Fe-Si-Sn
Silicon Bronze	C64700-C66100	Cu-Si-Sn
Other Cu-Zn alloys	C66400-C69900	. . . .
Copper –Nickel	C70000-C79900	Cu-Ni-Fe
Copper –Nickel - Silver	C73200-C79900	Cu-Ni-Zn
Cast Alloys		
Copper	C80100-C81100	> 99% Cu
Copper	C81300-C82800	> 94% Cu
Red and Pb Brass	C83300-C85800	Cu-Zn-Sn-Pb (75-89% Cu)
Yellow and Pb Brass	C85200-C85800	Cu-Zn-Sn-Pb (57-74% Cu)
Mn and Mn-Si Brass	C86100-C86800	Cu-Zn-Mn-Fe-Pb
Silicon Bronze and Brass	C87300-C87900	Cu-Zn-Si
Sn and Sn-Pb Bronze	C90200-C94500	Cu-Sn-Zn-Pb
Ni-Sn Bronze	C94700-C94900	Cu-Ni-Sn-Zn-Pb
Aluminium Bronze	C95200-C95810	Cu-Al-Fe-Ni
Copper –Nickel	C96200-C96800	Cu-Ni-Fe
Nickel-Silver	C97300-C97800	Cu-Ni-Zn-Pb-Sn
Copper-Leas	C98200-C98800	Cu-Pb
Different alloys	C99300-C99750	. . . .



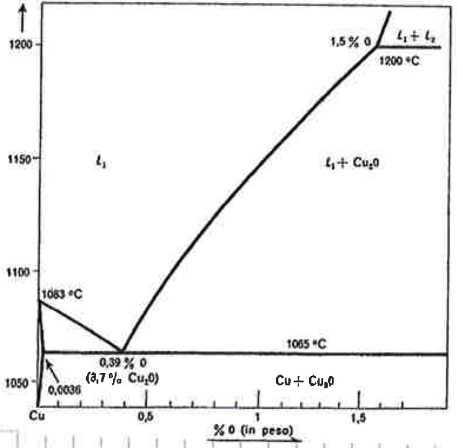
1 = PURE COPPER

2 = Zn

3 = Cu-Zn-Pb

6.9 FORMATION OF Cu_2O

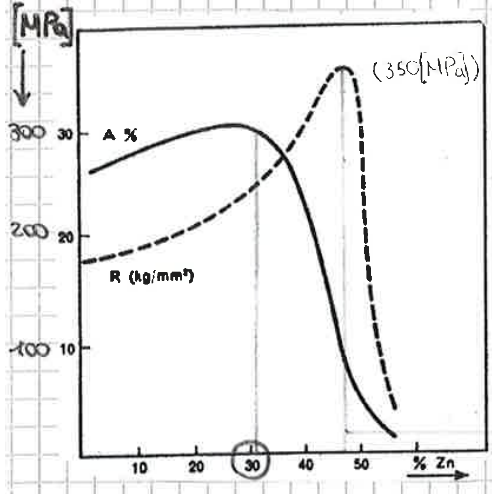
$Cu-Cu_2O$ PHASE DIAGRAM



- THE OXYGEN (O) HAS A VERY LOW SOLUBILITY IN Cu SOLIDS.
- THEREFORE EVEN A VERY LOW PERCENTAGE OF OXYGEN INDUCES THE PRECIPITATION OF OXIDE Cu_2O.
- Cu_2O DECREASES THE COPPER ELECTRIC CONDUCTIVITY.
- A VERY THIN LAYER OF Cu_2O LAYS ON GRAIN OF Cu.
- THE MATERIAL NEEDS A DEOXIDIZER.
- ADDING P IN LIQUID PHASE, IT CATCHES THE O; THE RESIDUAL P CAN SOLVE.

⇒ 0.0036% MAX SOLUBILITY OF O IN Cu TO AVOID THE FORMATION OF Cu_2O.

6.10.6 Cu-Zn MECHANICAL PROPERTIES



---- STRENGTH (R)

—— ELONGATION (A%)

REMEMBER: $[MPa] = 10^6 \left[\frac{N}{m^2}\right] = 1 \left[\frac{N}{mm^2}\right] = 0.1 \left[\frac{Kgf}{mm^2}\right] = 10 [bar]$

$1 [Pa] = \left[\frac{N}{m^2}\right]$

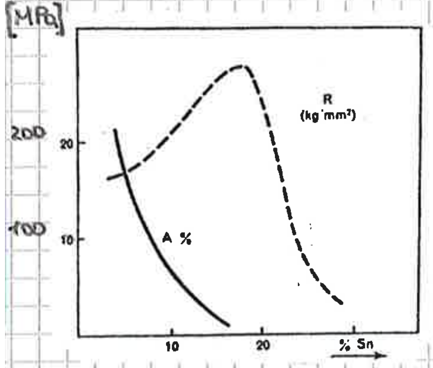
$1 [N] = \left[\frac{Kg \cdot m}{s^2}\right]$

- → β' : HIGH RESISTANCE BUT LOW DEFORMABILITY

- THE POINT WITH THE BEST COMBINATION

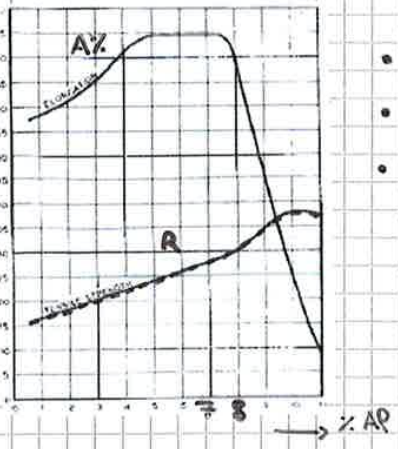
6.11 BRONZES (Cu-Sn OR Cu-Al OR Cu-Si)

6.11.1 Cu-Sn MECHANICAL PROPERTIES



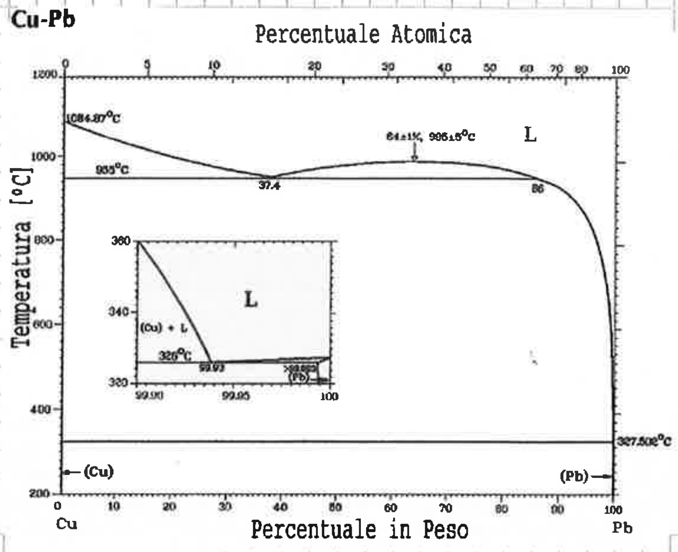
- 15% Sn MAX SOLUBILITY OF Sn IN Cu.
- ABOVE 10% Sn → BRITTLENESS
- 9% Sn (TIN = STAGNO) → PHOSPHOR BRONZE.

6.11.2 Cu-Al MECHANICAL PROPERTIES



- Al% ↑ ⇒ INCREASE OF STRENGTH
- < 8% Al ⇒ GOOD DUCTILITY
- 8% Al : GOOD AVERAGE VALUE FOR STRENGTH AND DEFORMABILITY.

6.13 Cu-Pb PHASE DIAGRAM

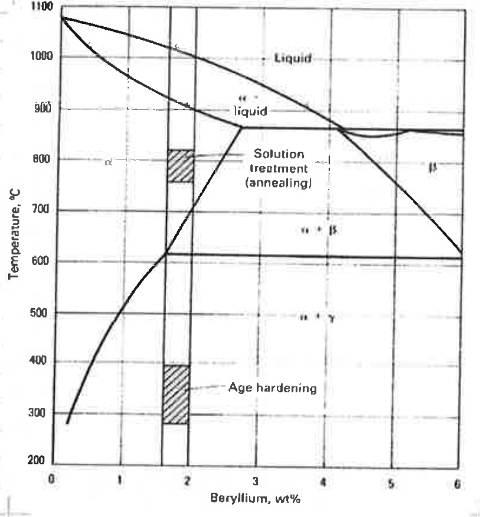


- TM OF Cu =
- TM OF Pb =

(VEDI APP EDO)

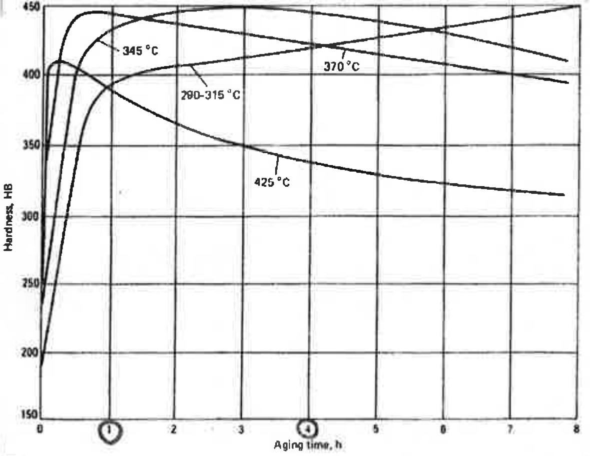
6.14 Cu-Be

6.14.1 Cu-Be PHASE DIAGRAM

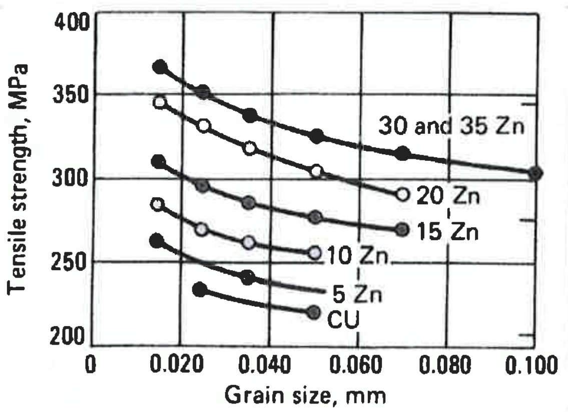


- TM OF Cu =
- TM OF Be =
- WIDE α PHASE FIELD;
- SOLUTION HEAT TREATMENT (ANNEALING) AT 800 [°C] FOR SOME HOURS;
- QUENCHED => OVERSATURED Cu ALLOY;
- AGED AT 350 [°C] FOR 4 [h] => STRENGTH X10 WITH RESPECT TO PURE Cu.

6.14.2 Cu-Be AGEING



6.15.4 INFLUENCE OF GRAIN SIZE ON TENSILE STRENGTH



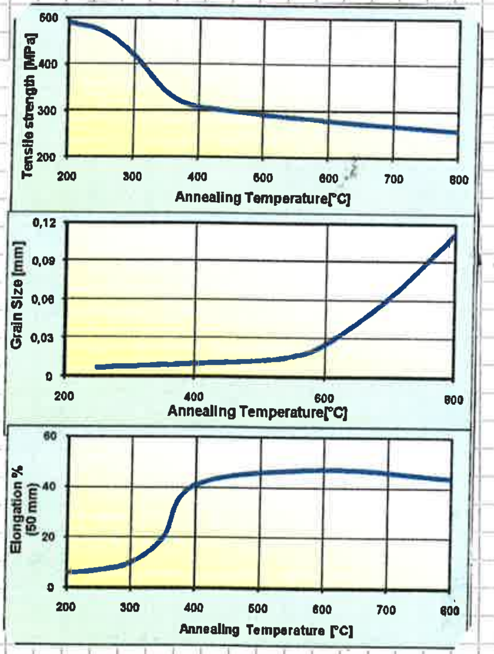
Brass ribbon (1 mm depth)

(RIBBON = NASTRO)

6.15.5 ANNEALING

ALLOY C22600 RIBBON (1 [mm]) FOR JEWELLERY → ANNEALED FOR 1 [h]

INITIAL GRAIN SIZE OF 0.035 [mm], COLD ROLLED - 50% OF REDUCTION.



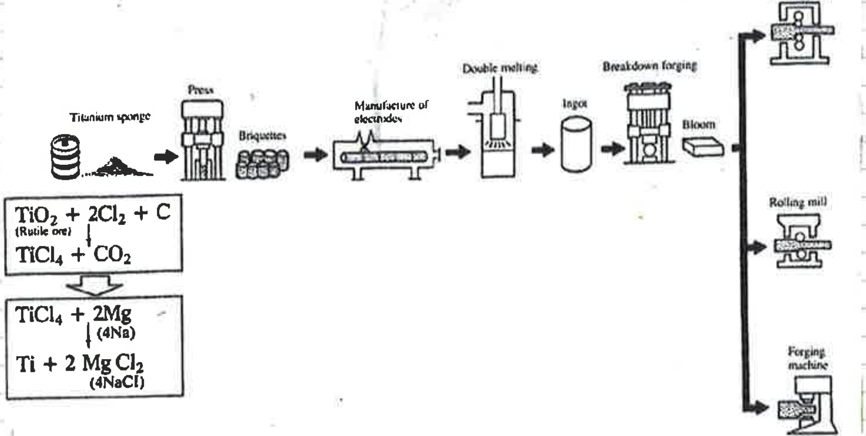
7.2 PRODUCTION OF Ti

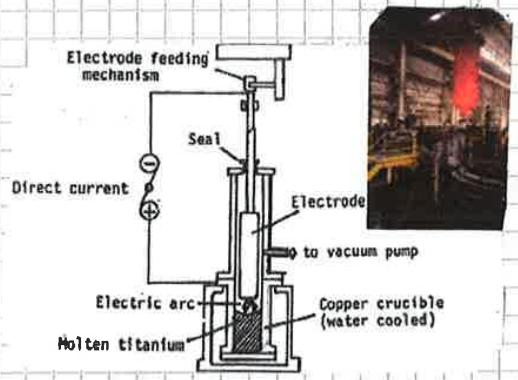
7.2.1 PRIMARY PRODUCTION OF Ti – KROLL PROCESS

- Ti COMMON IN EARTH'S CRUST;
- ENERGY TO SEPARATE: ~125 [MWhR/tomme] (7 [€/Kg] JUST IN POWER);
- OBTAINED FROM MINERALS: RUTILE (TiO_2); ILMENITE (FeO-TiO_2) APPROX 97÷98% TiO_2;
- BATCH PROCESS OVER 5 DAYS:
  - PRODUCE $TiCl_4$ FROM TiO_2 AND Cl_2;
  - KROLL PROCESS: $TiCl_4$ REACTS WITH LIQUID Mg AT ~773÷873 [C] IN A CLOSED STAINLESS-STEEL VESSEL (RETORT): $TiCl_4$ (GAS) + 2Mg (LIQUID) → Ti (SOLID) + $2MgCl_2$ (LIQUID) OBTAINED Ti (SOLID) = Ti SPONGE.
  - CHIP OUT Ti SPONGE (5-8[t]) FROM REACTOR;
  - COST 8 [€/kg];
  - CHLORIDES CORROSIVE, NASTY;
- WORLD ANNUAL CAPACITY: ~100 000 [t]; DEMAND: ~ 60 000 [t];
- NEED A CHEAPER PROCESS THAT IS DIRECT;

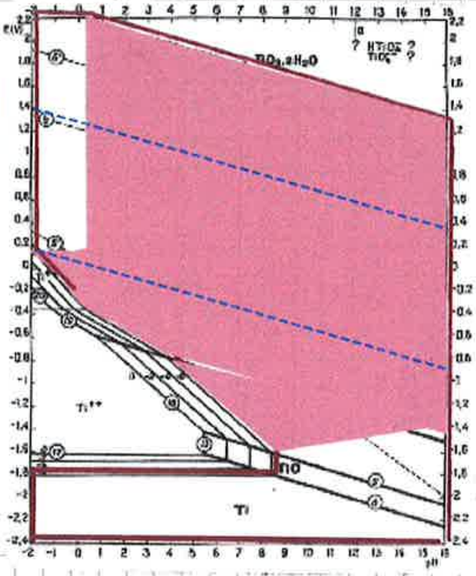
7.2.2 PREPARATION OF Ti INGOTS

- MOLTEN Ti REACTS WITH OXYGEN & NITROGEN;
- Ti SPONGE CRUSHED & COMPACTED INTO ELECTRODE COMPACTS;
  - THESE WELDED TOGETHER;
  - FORM CONSUMABLE ELECTRODE;
  - FOR VACCUM ARC MELTING;
- FOR ALLOY INGOTS THE ALLOYING MATERIALS ARE MIXED WITH THE CRUSHED Ti SPONGE BEFORE COMPACTING.

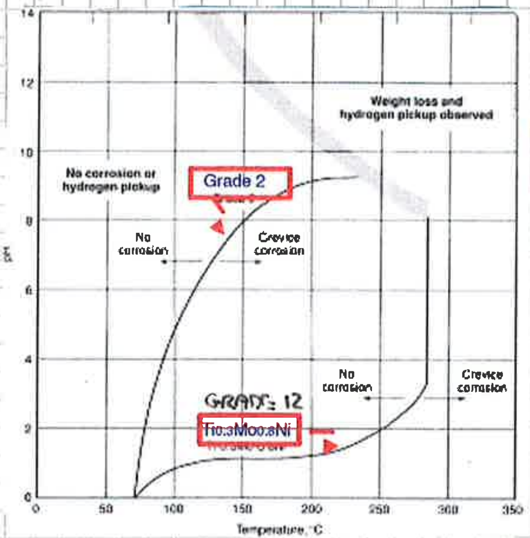




7.6 Ti: POURBAIX DIAGRAM : GOOD CORROSION RESISTANCE



7.5 SUSCEPTIBILITY TO CREVICE CORROSION



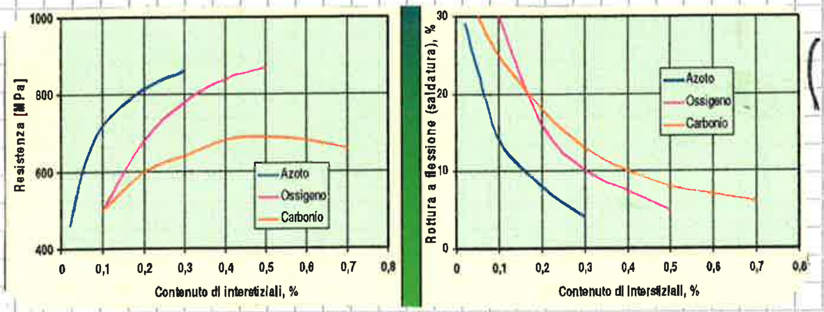
CREVICE CORROSION OF Ti0.3Mo0.8Ni AND GRADE 2 UNALLOYED Ti IN SATURATED NaCl SOLUTION.

SHADED BAND REPRESENTS TRANSITION ZONE BETWEEN ACTIVE AND PASSIVE BEHAVIOUR.

7.8 ALLOYS DESIGNATION

CATEGORY		CATEGORY	
Grade 1	Pure Titanium, low oxygen	Grade 16	Pure Titanium + 0,04÷0,08% Pd, standard oxygen
Grade 2	Pure Titanium, standard oxygen	Grade17	Pure Titanium + 0,04÷0,08% Pd, low oxygen
Grade 3	Pure Titanium, high oxygen	Grade 18	Alloy (Al 3%, V 2,5%) + 0,04÷0,08% Pd
Grade 4	Pure Titanium, very high oxygen	Grade 19	Alloy (Al 3%, V 8%, Cr 6%, Zr 4%, Mo 4%)
Grade 5	Alloy (Al 6%, V 4%) α+β	Grade 20	Alloy (Al 3%, V 8%, Cr 6%, Zr 4%, Mo 4%) + 0,04÷0,08% Pd
Grade 6	Alloy (Al 5%, Sn 2,5%) α	Grade 21	Alloy (Mo 15%, Al 3%, Nb 2,7%, Si 0,25%)
Grade 7	Pure Titanium + 0,12÷0,25% Pd, standard oxygen	Grade 22	-------
Grade 8	-------	Grade 23	Alloy (Al 6%, V 4%) ELI
Grade 9	Alloy (Al 3%, V 2,5%)	Grade 24	Alloy (Al 6%, V 4%) + 0,04÷0,08% Pd
Grade 10	------ -	Grade 25	Alloy (Al 6%, V 4%) + Ni 0,3÷0,8%, 0,04÷0,08% Pd
Grade 11	Pure Titanium + 0,12÷0,25% Pd, low oxygen	Grade 26	Pure Titanium + 0,08÷0,14% Ru
Grade 12	Alloy (Mo 0,3%, Ni 0,8%)	Grade 27	Pure Titanium + 0,08÷0,14% Ru
Grade 13	Alloy (Ni 0,5%, Ru 0,05%), very low oxygen	Grade 28	Alloy (Al 3%, V 2,5%) + 0,08÷0,14% Ru
Grade 14	Alloy (Ni 0,5%, Ru 0,05%) low oxygen	Grade 29	Alloy (Al 6%, V 4%) ELI + 0,08÷0,14% Ru
Grade 15	Alloy (Ni 0,5%, Ru 0,05%) standard oxygen	Grade 30	Pure Titanium + Co 0,20÷0,80%, 0,04÷0,08% Pd

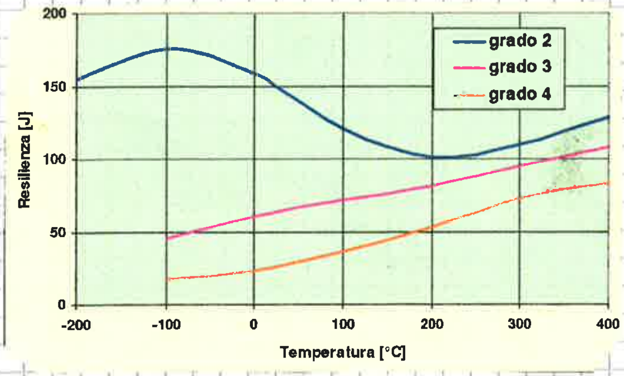
7.9 INFLUENCE OF INTERSTITIAL ELEMENTS



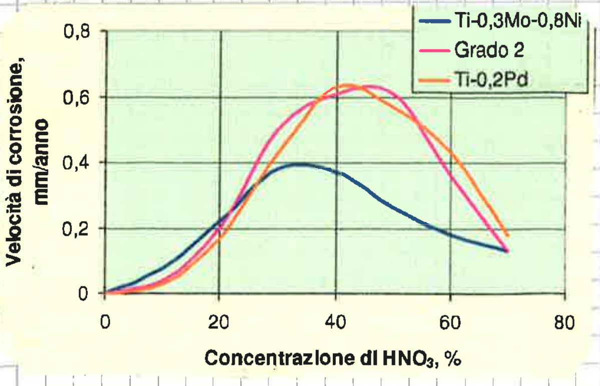
(N O C)

THE GRAPHS EVIDENCE THE STRENGTH AND ELONGATION AS A FUNCTION OF INTERSTITIAL ELEMENTS Qty.

7.10 IMPACT PROPERTIES



7.11 CORROSION RESISTANCE



CORROSION RESISTANCE AS A FUNCTION OF NITRIC ACID CONCENTRATION OF THREE TITANIUM ALLOYS.

7.15 INFLUENCE OF ALLOYING ELEMENTS

Alloying Element	Range weight %	Effect on structure
Aluminium	2 ÷ 7	α stabilizing
Tin	2 ÷ 6	α stabilizing
Vanadium	2 ÷ 20	β stabilizing
Molibdenum	2 ÷ 20	β stabilizing
Chromium	2 ÷ 12	β stabilizing
Copper	2 ÷ 6	β stabilizing - α e β hardening
Zirconium	2 ÷ 8	-
Silicon	0,05 ÷ 1	Increase creep resistance

- A VERY IMPORTANT PROPERTY OF THE ALLOYING ELEMENTS IS THEIR INFLUENCE ON THE STABILIZATION OF THE α PHASE (LOW TEMPERATURE) OR THE β PHASE (HIGH TEMPERATURE).
- CARBON (C), OXYGEN (O) AND NITROGEN (N) ARE α STABILIZING.

7.16 4 ALLOYS TO BE CONSIDERED

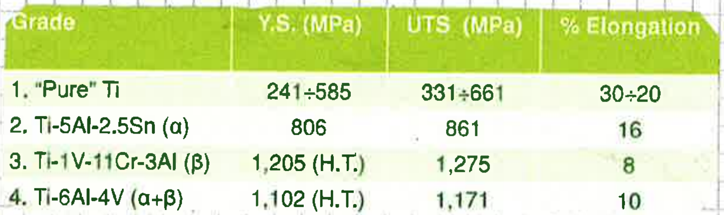
GRADES 1÷4 INCREASE IN O-C-N ;	USAGE:
A. "PURE" Ti (99.0 + %Ti) HCP	35%
B. α ALLOY (Ti - 5Al - 2.5Sn) GRADE 6	10%
C. β ALLOY (Ti - 13V - 11Cr - 3Al) BCC	~1%
D. α + β ALLOY (Ti - 6Al - 4V) GRADE 5	55%

NOTE:

Al, Sn : α-PHASE STABILIZER

V, Cr : β-PHASE STABILISER

MECHANICAL PROPERTIES:



	Grade	Y.S. (MPa)	UTS (MPa)	% Elongation
A	1. "Pure" Ti	241÷585	331÷661	30÷20
B	2. Ti-5Al-2.5Sn (α)	806	861	16
C	3. Ti-1V-11Cr-3Al (β)	1,205 (H.T.)	1,275	8
D	4. Ti-6Al-4V (α+β)	1,102 (H.T.)	1,171	10

NOTE:

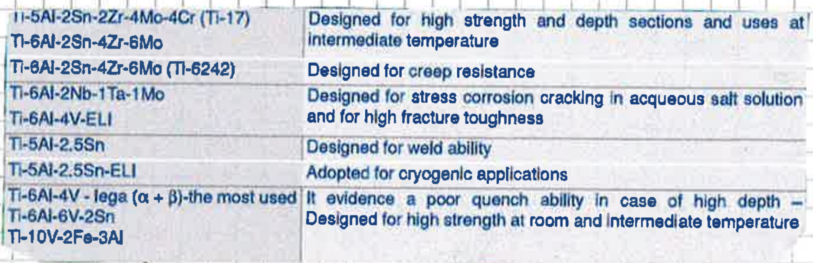
900°C 625°C

(H.T.) = SOLUTION ANNEAL - QUENCH AND AGED.

↓

- TO FORM α
- SPHEROIDISE β
- STRESS RELIEF

7.17 ALLOY : α

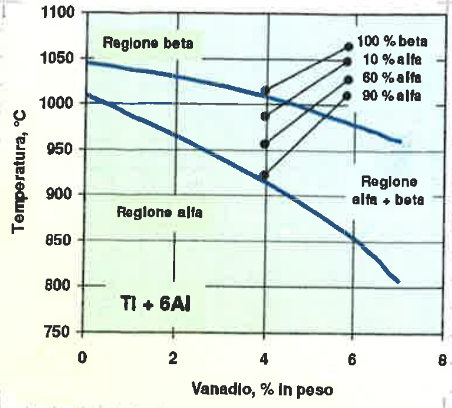


Ti-5Al-2Sn-2Zr-4Mo-4Cr (Ti-17) Ti-6Al-2Sn-4Zr-6Mo	Designed for high strength and depth sections and uses at intermediate temperature
Ti-6Al-2Sn-4Zr-6Mo (Ti-6242)	Designed for creep resistance
Ti-6Al-2Nb-1Ta-1Mo Ti-6Al-4V-ELI	Designed for stress corrosion cracking in acqueous salt solution and for high fracture toughness
Ti-5Al-2.5Sn	Designed for weld ability
Ti-5Al-2.5Sn-ELI	Adopted for cryogenic applications
Ti-6Al-4V - lega (α + β)-the most used Ti-6Al-6V-2Sn Ti-10V-2Fe-3Al	It evidence a poor quench ability in case of high depth – Designed for high strength at room and intermediate temperature

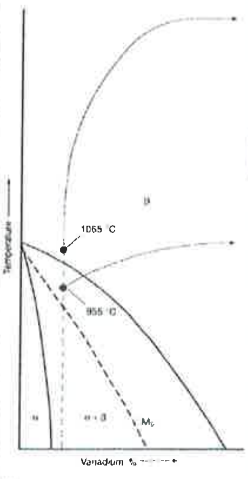
THE MOST IMPORTANT ALLOYING ELEMENT IS Al.

- ALLOY α, SUCH AS Ti - 5Al - 2.5Sn, ARE SLIGHTLY LESS CORROSION RESISTANT BUT HAVE A HIGHER STRENGTH THAN PURE Ti.
- ALLOY α ARE GENERALLY DUCTILE ; THE ELI GRADE MAINTAINS THIS PROPERTY AT CRYOGENIC TEMPERATURE.
- ALLOY α ARE NOT HARDENABLE BY HEAT TREATMENT BECAUSE THIS ALLOYS ARE STABLE. THESE ALLOYS CAN BE HARDENED BY GRAIN SIZE REDUCTION.

7.21 HEATING TEMPERATURE



- THE HEATING TEMPERATURE IS FUNDAMENTAL IN THE WORKABILITY AND IN THE FINAL OBTANAIBLE PROPERTIES.
- DIFFERENT FORGING AND/OR HEAT TREATMENT TEMPERATURE ARE ADOPTED FOR THE Ti-6Al-4V ALLOY ($\alpha+\beta$).
- THE HIGHER THE TEMPERATURE OF TREATMENT, THE GREATER IS THE AMOUNT OF β PHASE THAT CAN BE TRASFORMED IN QUENCHING AND TEMPERING.



(a)

Air cooled

(b) Acicular alpha (transformed beta) with prior beta grain boundaries

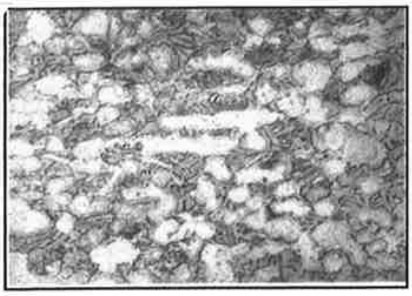
Water quenched

(c) Alpha prime (martensite) matrix with beta (dark) and prior beta grain boundaries

(d) Grains of primary alpha (light) in a matrix of transformed beta containing acicular alpha

(e) Equiaxed primary alpha in a matrix of alpha prime (martensite)

7.25 MICROSTRUCTURE: Ti6Al4V ($\alpha+\beta$)



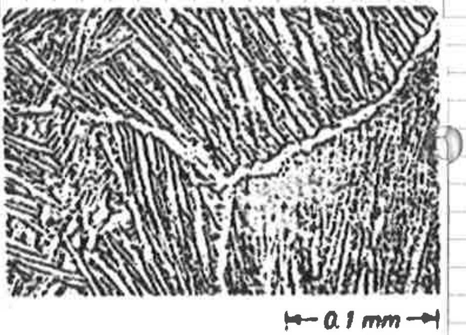
Rolled alloy, annealed from α + β range temperature.

The microstructure is polygonal α and β - 500x

Alloy as produced, quenched from α + β range temperature.

The microstructure is acicular α' and α inside primary grains of β - 500x

7.26 $\alpha+\beta$ ALLOYS : MICROSTRUCTURES



(1) Blocky and plate-like acicular α (transformed β); α at prior β grain boundaries.

- CONTAIN SIGNIFICANT β STABILISERS TO ENABLE β TO BE RETAINED TO RT.
- CLASSIC Ti ALLOY: Ti6Al4V (50% OF ALL Ti USED)
- CLASSICALLY:
  - 1065 [°C] ALL β.
  - FORGE AT 955 [°C] - ACICULAR α ON GRAIN BOUNDARIES TO INHIBIT β COARSENING.
  - AIR COOL - PRODUCE α LAMELLAE COLONIES FORMED IN PRIOR β GRAINS (MINIMISE STRAIN), W/β IN BETWEEN (THINK AT THE PEARLITE).

7.27 Ti-6-4 (Ti6Al4V): MECHANICAL PROPERTIES

Heat Treatment	0.2% Proof Stress, MPa	Tensile Strength, MPa	Ductility, %
β treat 0.5hr / 1000C + AC	910	1060	10
α + β: 2hr / 700C	990	1000	14.5
α + β 0.5hr / 900C WQ, Age 8hrs / 500C	1100	1300	13

PREC. HARDENING + GRAIN SIZE

NB: MUST AVOID Ti_3Al FORMATION:

$$Al\ EQUIV. = Al + 0.33Sn + 0.16Zr + 10(O+C+2N)$$

$$Al\ EQUIV. < 9\ wt\%$$

Heat Treatment (a)	Strength [MPa]	Yield Strength [MPa]	Elongation %	Reduction %
1065 °C - WQ	1108	954	7,7	19,2
After aging	1170	1057	8.5	19,2
955 °C - WQ	1120	954	17	60,2
After aging	1183	1069	16,5	56,4
900 °C - WQ	1117	924	16,2	53.9
After aging	1117	1014	15,3	47,5
845 °C - WQ	1009	772	20	54,7
After aging	1178	977	16,5	48,8
1065 °C - AC	1060	944	7	10,3
After aging	1060	940	9,8	16
955 °C - AC	955	846	17,8	54,1
After aging	1020	898	16,1	45,7
900 °C - AC	1002	869	17,5	54,7
After aging	1029	936	17,3	60,2
845 °C - AC	1020	878	17,8	47,7
After aging	1036	931	16,8	46,9
1065 °C - FC	1041	938	10,5	15,6
After aging	1011	938	9,5	15,4
955 °C - FC	940	836	18,8	46
After aging	967	883	18,2	49,1
900 °C - FC	963	855	16,5	43,3
After aging	963	876	16,8	48,3
845 °C - FC	997	924	17.3	48.9
After aging	1060	954	17	49,6

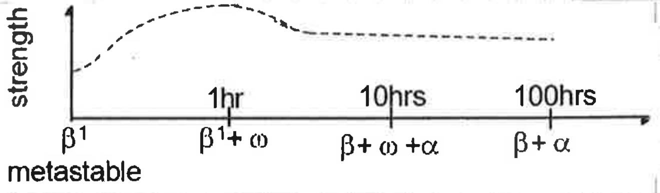
(a) Aging: 540 °C for 4 hours. WQ – water quench, AC – air cooling, FC – furnace cooling. β transus 1000 °C ± 14. Sample: rods 16 mm of diameter.

7.28 β ALLOYS : CHARACTERISTICS

- HIGHEST STRENGTH Ti ALLOYS → USED IN SPECIALIZED APPLICATIONS ;

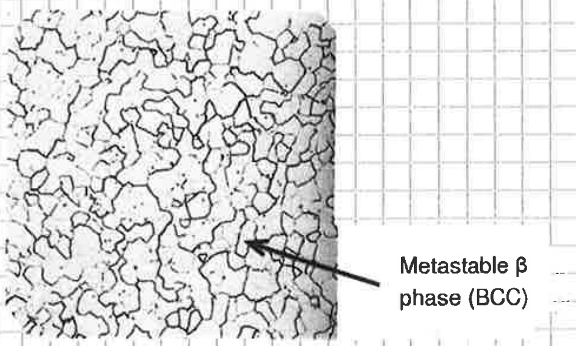
(STRENGTHEN NEAR-β ALLOYS BY : SOLID SOLUTION , HALL-PETCH (Fe , Nb , V) , COLD WORK).

- THEY ARE HIGHLY FORMABLE → LANDING GEAR , AUTO BODIES ...
- HIGHER DENSITY BECAUSE OF Mo, V, Fe ADDITIONS ;
- ADD Al TO LOWER DENSITY AND GIVE SOLID SOLUTION STRENGTH AND HIGH TEMPERATURE OXIDATION RESISTANCE ;
- EASY TO COLD WORK (BCC) IN SOLUTION TREATED AND QUENCHED CONDITION ;
- CAN BE SUBSEQUENTLY AGED TO VERY HIGH STRENGHTS ;



- ω : TRANSITION PHASE IS BRITTLE ;
- Ti -13%V-11%Cr-3%Al - ONLY β-ALLOY PRODUCED IN LARGE QUANTITIES ;
- LIMITED USE BECAUSE OF :
  - RELATIVELY HIGH DENSITY BECAUSE OF V, Mo .
  - LOW DUCTILITY IN HIGH STRENGTH CONDITION ;
  - IN THICK SECTIONS - CHEMICAL SEGREGATION ; LARGE GRAIN SIZE , THEREFORE LOW TENSILE DUCTILITY AND POOR FATIGUE PERFORMANCE .

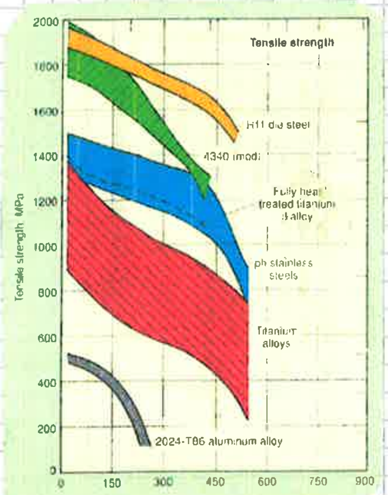
7.29 Ti -13%V-11%Cr-3% Al : MICROSTRUCTURE

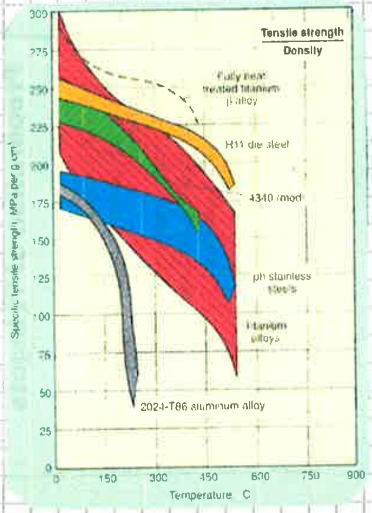


7.30 STRENGTH AND SELECTION OF β ALLOYS

	σ_y	E	σ_y/ρ	
Ti – 10 V – 2Fe – 3Al	**970-1170**	**105**	**210-250**	**Landing Gear**
Ti – 3Al – 8V – 6Cr – 4Mo – 4Zr	**825**	**88**	**171**	**Springs (Beta C)**
Ti – 15V – 3Cr – 3Al – 3Sn	**780-1050**	**70-103**	**163-219**	**Springs**
Ti – 4.5Fe – 6.8Mo – 1.5Al	**950-1400**	**110**	**250-290**	**Low Cost Beta (LCB) Development of Beta C**

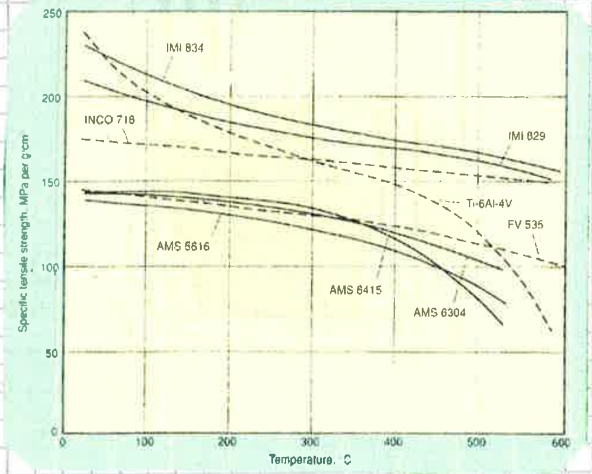
7.32 HIGH TEMPERATURE PROPERTIES AS COMPARED TO STEELS





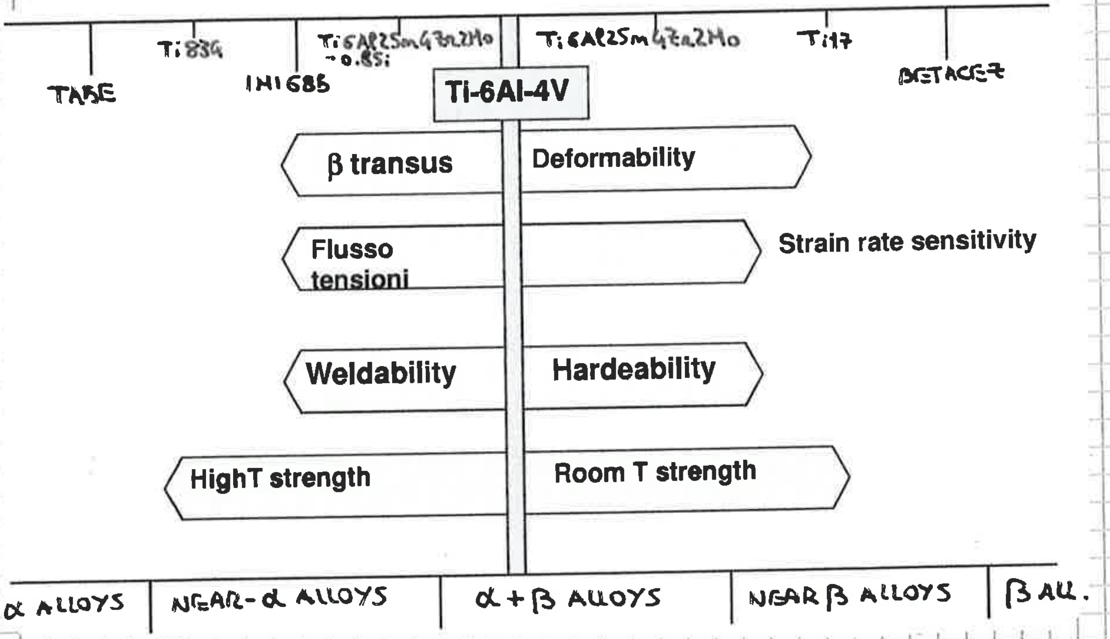
OTHER COMPARISON:

THE MECHANICAL PROPERTIES AT HIGH T OF Ti ALLOYS ARE MAINLY THAT OF α OR NEAR α ALLOYS. WHENEVER THE CREEP PHENOMENON IS NOT SO IMPORTANT AT HIGH T, THE TENSILE STRENGTH OF β ALLOYS, AT HIGH T FOR SHORT TIME, IS HIGHER. IN FACT THESE ALLOYS, UNTIL ABOUT 425 [°C], HAVE HIGHER SPECIFIC TENSILE STRENGHT THAN H-11 TOOL STEELS, WHILE α AND NEAR α ALLOYS ARE NOT IN ADVANTAGE. FOR LONG TIME APPLICATIONS, THE α AND NEAR α ALLOYS HAVE SUBSTITUTED THE STEELS IN AERONAUTICAL TURBINES.



IN FIGURE ARE PLOTTED THE CURVES OF SPECIFIC TENSILE STRENGH OF TWO Ti ALLOYS AND THREE STEELS ADOPTED FOR AERONAUTICAL TURBINES, IN THE AVERAGE LOW TEMPERATURE RANGE. IN COMPARISON WITH STEELS, THE Ti ALLOYS HAVE HIGHER PROPERTIES UNTIL 640 [°C].

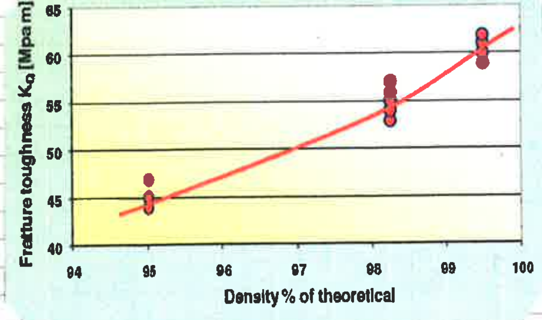
7.36 SCHEME OF PROPERTIES



P/M Ti ALLOYS?

- HAVE BEEN PRODUCED: WOULD BE USEFUL IN e.g. CONTROLLING GRAIN SIZE IN PURE β FORGING.
- BUT: PROBLEM OF AVOIDING OXIDE LAYER ON POWDER PARTICLES AND CONSEQUENT TiO_2 AND α INCLUSIONS.

7.37 SINTERED COMPONENTS TOUGHNESS



EFFECT OF DENSITY ON FRACTURE TOUGHNESS OF SINTERED Ti6Al4V PARTS.

8.1 DEFINITION OF FAILURE ANALYSIS

- THE FAILURE ANALYSIS IS THE CRITICAL METHOD ADOPTED TO IDENTIFY THE PHYSICAL REASONS THAT ORIGINATE THE FRACTURE OR THE FUNCTIONAL ANOMALY.
- THE WORD "FAILURE" DOES NOT REFER EXCLUSIVELY TO "BREACKAGE" BUT TO ANY PHENOMENON THAT INDUCES A PERCEPTION OF A NOT REGULAR OPERATION OF A MECHANICAL PART.
- IT IS A TECHNICAL INSTRUMENT TO IMPROVE THE QUALITY AND THE RELIABILITY OF PRODUCT.
- IT EVIDENCES THE CRITICAL SITUATIONS OF A COMPONENT (PART OR COMPLEX PRODUCT) THAT LEAD TO ECONOMIC DECLINE, OBJECT OR PEOPLE DAMAGES OR ACCIDENTS.
- IT IS AN INSTRUMENT OF CONTINUOUS IMPROVEMENT OF THE PRODUCT.

FAILURE CAUSES:	%
DESIGN	10 %
MATERIAL/PROCESS	60 %
USE	30%

8.2 FAILURE ANALYSIS AND PREVENTION

8.2.1 QUALITY AND EXPECTED USE OF A PRODUCT

IN THE EARLY 80S, BY OPENING OF MARKETS, EMERGED THE NEED TO IMPROVE THE PRODUCT QUALITY AND TO ORIENT BUSINESS STRATEGY TO CUSTOMER SATISFACTION. GREATER ATTENTION TO PRODUCT, RESULTED IN DEVELOPMENT OF ACTIVITIES DESIGNED TO: MANUFACTURE PRODUCTS IMMEDIATELY COMPLY (DO THE RIGHT THING, RIGHT THE 1ST TIME). THIS CHOICE HAS GENERATED QUALITY PRODUCTS, ABLE TO SATISFY GREATER EXPECTATIONS OF CONSUMERS AND USERS.

CUSTOMER SATISFACTION:

- MAJOR SAFETY
- MAJOR RELIABILITY
- MORE PERFORMANCE
- HIGHER EFFICIENCY
- EASY MAINTENANCE
- LOW OPERATING COSTS
- LOW ENVIRONMENTAL IMPACT

8.3 AIM OF FAILURE ANALYSIS

FAILURE ANALYSIS:

- IT IS CARRIED OUT TO IDENTIFY THE CAUSES OF FAILURE AND PREVENT THE PHENOMENON HAPPEN AGAIN.
- IT CAN, BUT DOES NOT NECESSARILY, LEAD TO THE IDENTIFICATION OF THE CAUSES OF FRACTURE.
- IT IS USED TO ACTIVATE CORRECTIVE ACTIONS FOR RECOVERY OR IMPROVEMENT.

LEVELS OF INVESTIGATION:

THERE ARE THREE LEVELS TO IDENTIFY:

1. PHYSICAL CAUSES: EMERGING FROM THE LABORATORY ANALYZES, CALCULATIONS, SIMULATIONS AND RELATED MATERIALS.
   (EX: RUPTURE OF A PRESSURE VESSEL → CORROSION WITH THICKNESS REDUCTION)
2. HUMAN CAUSES: HUMAN FACTORS, OPERATING ERRORS, IMPROPER USE, ETC...
   (EX: → INADEQUATE INSPECTION CONTROLS)
3. UNDERLAYING CAUSES: PROCEDURAL ERRORS, ENVIRONMENT PROBLEMS, OR IMPONDERABLE CAUSES.
   (EX: → INSUFFICIENT TRAINING OF INSPECTION STAFF)

REQUIREMENTS:

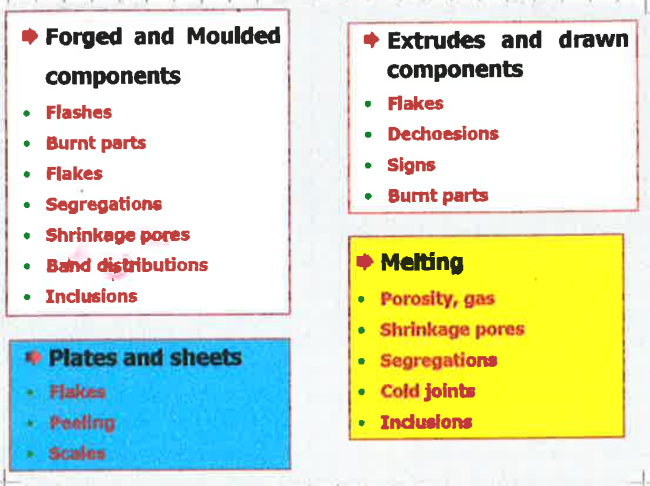
FAILURE ANALYSIS REQUIRES AN INTERDISCIPLINARY APPROACH FOR AN APPROPRIATE CHOICE OF CORRECTIVE ACTIONS.

MANY BREAKING INVOLVE FACTORS CROSSING SEVERAL DISCIPLINES, SUCH AS: METALLURGY, MECHANICAL ENGINEERING, QUALITY CONTROL, MAINTENANCE, HUMAN FACTORS, ETC... ⇒ (TEAMWORK)

8.4 CAUSES OF RUPTURE

PRIMARY CAUSES:

- DESIGN DEFICIENCY (8.4.1)
- MATERIAL DEFECTS (8.4.2)
- MANUFACTURING DEFECTS (8.4.3)
- INSTALLATION DEFECTS (8.4.4)
- UNSUITABLE CONDITIONS OF USE (8.4.5)
- ENVIRONMENT (8.4.6)



Forged and Moulded components
- Flashes
- Burnt parts
- Flakes
- Segregations
- Shrinkage pores
- Band distributions
- Inclusions

Plates and sheets
- Flakes
- Peeling
- Scales

Extrudes and drawn components
- Flakes
- Dechoesions
- Signs
- Burnt parts

Melting
- Porosity, gas
- Shrinkage pores
- Segregations
- Cold joints
- Inclusions

8.6.3 MANUFACTURING DEFECTS

MANUFACTURING: IS THE TECHNOLOGICAL PROCESS AIMED TO THE REALIZATION OF A PRODUCT AS DESCRIBED BY TECHNICAL DOCUMENTATION, USING RAW MATERIALS.

MACHINING

- CRACKS
- VIBRATIONS
- MICROSTRUCTURAL DAMAGES DUE TO WORN TOOLS.
- RE-MELTING DUE TO ELECTROSTATIC DISCHARGES.
- INTERGRANULAR -ECTROCHEMICAL ATTACK
- RESIDUAL STRESS
- GRINDING DEFECTS

PLASTIC DEFORMATION (MOLDING)

- CRACKS, RIPS, FAILED FILLING
- THREAD FOLDING (ROLLING)
- DIE TRACKS
- SURFACE RIPPS
- RESIDUAL STRESS
- STRESS CORROSION CRACKING (LUBRICANTS)

HEAT TREATMENT

- GRAIN COARSENING
- INCOMPLETE PHASE
- TRASFORMATIONS
- QUENCHING CRACKS
- DECARBURIZING

WELDING

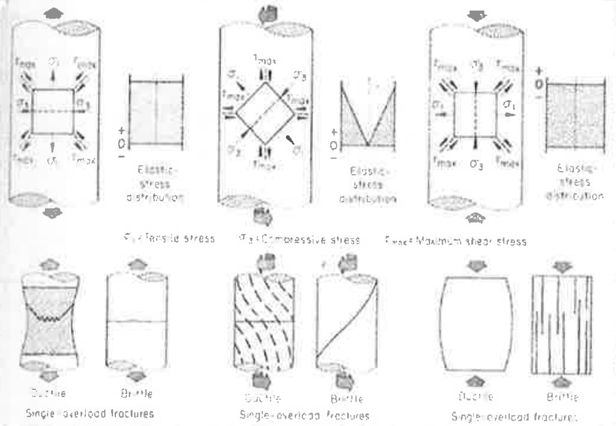
- LACK OF MELTING
- CRACKS AND BRITTLENES IN HAZ
- RESIDUAL STRESSES
- POROSITIES
- SLAG INCLUSIONS
- CRATERS
- HYDROGEN EMBRITTLEMENT

MECHANICAL PROCESSING

8.4.6 ENVIRONMENT

- NOT ALWAYS EVALUABLE IN ADVANCE (HUMIDITY, TEMPERATURE, CONTAMINATION, ETC...)
- DIFFICULT TO ASSESS IN RETROSPECT, DOWNSTREAM OF THE FAILURE.
- OFTEN IT'S SYNERGISTIC WITH OTHER CRITICAL FACTORS (i.e. PRESSURE VARIABILITY, INTERNAL STRESS, ETC...)
- TRIGGERS FAILURE MODES PECULIAR, OFTEN UNEXPECTED.

8.5 TYPES OF STRESSES AND CRACKING MODE: OVERLOADED



Single-overload fractures
(a) Tension

Single-overload fractures
(b) Torsion

Single-overload fractures
(c) Compression

8.6 METHOD OF RESEARCH

THERE IS AN OLD SAYING OF AMERICAN CARPENTERS THAT ANALYSTS HAVE ADOPTED FOR FAILURE ANALYSIS:

"MEASURE TWICE BEFORE CUT"

- THE FAILURE ANALYSIS CAN BE CONSIDERED AS A SURVEY INVESTIGATION OF AN INANIMATE BODY.
- BEFORE START, WELL IT'S NECESSARY ORGANIZE MENTALLY ABOUT THE PROCEDURE THAT HAVE BEEN ADOPTED.
- IT'S THEREFORE ESSENTIAL WORKING WITH: METHOD.

ORGANIZATION FOR FAILURE ANALYSIS

- DATA COLLECTION (8.6.1)
- VISUAL ANALYSIS (8.6.2)
- NON-DESTRUCTIVE TESTING (8.6.3)
- RESIDUAL STRESS RELIEF
- DESTRUCTIVE TESTING
- ANALYSIS OF RESULTS
- GUESSES AND REPORT OF ANALYSIS

SAMPLES TAKING

-> IDENTIFY THE SITES OF TAKING AND PHOTOGRAPH IT BEFORE CUTTING.

-> TAKE AS MUCH AS POSSIBLE IN THE AREA OF RUPTURE.

-> AVOID DAMAGE OF THE ZONES OF RUPTURE.

-> CLEAN SAMPLE BEFORE EXAMINE IT.

-> DO NOT USE ABRASIVES OR ACIDS FOR CLEANING.

8.6.3 NON-DESTRUCTIVE TESTING

- RADIOGRAPHY
- CT (COMPUTERIZED TOMOGRAPHY)
- MAGNETOSCOPY
- PENETRATING LIQUIDS
- ULTRASOUNDS
- INDUCED CURRENTS

8.7 MODES OF FRACTURE

- FRACTURE : IS TYPICALLY DEFINED AS SEPARATION OF MATERIAL
- IT IS ANY MECHANISM OF STRUCTURAL SEPARATION, WHICH PROGRESSIVELY LEADS TO RUPTURE.
- IT CAN BE : INSTANTANEOUS:
  - INSTANTANEOUS DUCTILE FRACTURE BY OVERCHARGING (8.7.1)
  - INSTANTANEOUS BRITTLE FRACTURE BY OVERCHARGING (8.7.2)

  PROGRESSIVE:
  - CORROSION (8.7.3)
  - WEAR (ABRASIVE, ADHESIVE, EROSIVE) (8.7.4)
  - FATIGUE (8.7.5)
  - CREEP

PLASTIC STRAIN

IT OCCURS WHEN A GEOMETRIC MODIFICATION PREVENTS THE COMPONENT TO PERFORM ITS FUNCTION.

CHANGES IN THE GEOMETRY RESULT IN CHANGES IN VOLUME (BULGE, SHRINKAGE) OR SHAPE (TWISTING, BENDING OR CRUSHING).

8.7.3 CORROSION

IT IS THE DECAYING OF THE MATERIAL FOR ENVIRONMENTAL CAUSES.

THE MOST COMMON TYPE OF CORROSION METALS IS THE ELECTROCHEMICAL CORROSION.

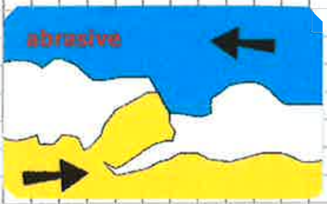
OTHER FORMS COMPRISE BRITTLENESS BY IMMERSION IN LIQUID, MOLTEN SALTS, HEAT OXIDATION, ETC...

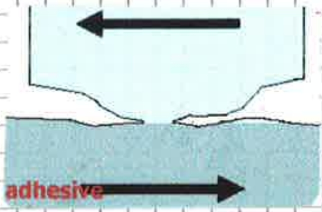
- GALVANIC CORROSION
- WET CORROSION
- PITTING CORROSION
- CREVICE CORROSION (INTERSTITIAL C.)
- INTERGRANULAR CORROSION
- (FATIGUE CORROSION : THE CORROSION CAN NUCLEATE FATIGUE FRACTURE)

8.7.4 WEAR (LOGORAMENTO)

IT IS REMOVAL OR DISTRIBUTION OF SURFACE BY CONTACT AND RELATIVE MOTION WITH SOLID, LIQUID OR GAS.

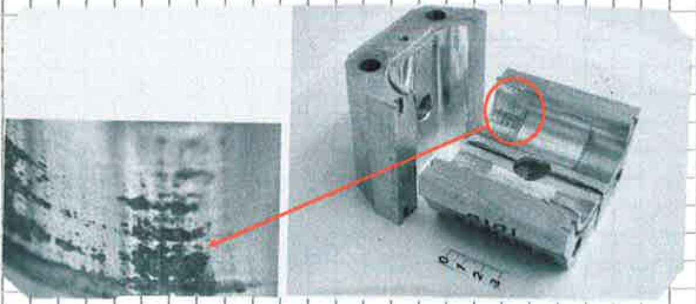
CONSEQUENCES: LOSS OF MATERIAL AND LOAD-BEARING CAPACITY, PHENOMENA OF ADHESION, INCREASED FRICTION AND FORMATION OF METAL CHIPS.





- ABRASIVE
- ADHESIVE
- EROSIVE

EXAMPLE OF ABRASIVE WEAR:



← ABRASION OF INNER WALL: INSUFFICIENT HYDROSTATIC CAPACITY OF OIL AT LOW [Rpm].

0. GENERALITIES

G

0.1 LATTICE STRUCTURES

BCC : BODY CUBIC CENTERED

- (IRON < 907 °C ; IRON > 1400 °C ; W, V, Mo, Cr, ALCALINE METALS (Na, K))
- IT IS A UNITARY CUBIC CELL IN WHICH THERE IS A CENTRAL ATOM AND AN ATOM AT EACH VERTEX OF THE CUBE.
- n. OF ATOMS PER CELL = $(8 \cdot \frac{1}{8} + 1) = 2$
- COORDINATION NUMBER = 8 (N. OF ATOMS NEAR WHICH AN ATOM IS BOUND)
- ATOMIC PACKING FACTOR (APF) = $\frac{\text{n. OF ATOMS PER CELL} \cdot \text{SINGLE ATOM'S VOLUME}}{\text{CELL VOLUME}}$

  $APF = \frac{2 \cdot \frac{3}{4}\pi R^3}{a^3} = (4R = \sqrt{3}a \Rightarrow R = \frac{\sqrt{3}}{4}a) = \frac{2 \cdot \frac{3}{4}\pi (\frac{\sqrt{3}}{4}a)^3}{a^3} = 0{,}68$
- THE DIRECTION WITH THE HIGHEST PACKING : ⟨111⟩ (LINEAR DENSITY 100%)

  [ ] -> ⟨ ⟩

  ( ) -> { }
- THE PLAN WITH THE HIGHEST PACKING : {110} (PLANAR DENSITY : 88 %)

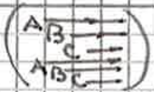
(T ↑ => V ↑)

NON COMPACTED STRUCTURES ↓

LENDS ITSELF MORE FOR P.DF

THINK ON Y (FCC) ↓

FCC : FACE CUBIC CENTERED



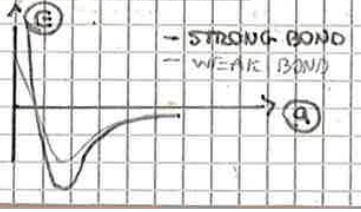
- (907 °C < IRON < 1400 °C, Cu, Ag, Au, Ni, Al, LEAD (Pb), Pt)
- IT IS A UNITARY CUBIC CELL IN WHICH THERE ARE AN ATOM ON EACH FACE AND AN ATOM AT EACH VERTEX OF THE CUBE.
- n. OF ATOMS PER CELL = $\left(8 \cdot \frac{1}{8} + 6 \cdot \frac{1}{2}\right) = 4$
- COORDINATION NUMBER = 12
- $APF = \frac{4 \cdot \frac{4}{3}\pi R^3}{a^3} = \left(a = 4R\cos 45 = 4R\frac{\sqrt{2}}{2} \Rightarrow R = \frac{a}{2\sqrt{2}}\right) = \frac{4 \cdot \frac{4}{3}\pi \left(\frac{a}{2\sqrt{2}}\right)^3}{a^3} = 0.74$
- THE DIRECTION WITH THE HIGHEST PACKING IS : ⟨110⟩ (LINEAR DENSITY 100%)
- THE PLAN WITH THE HIGHEST PACKING IS : {111} (PLANAR DENSITY : 90,7 %)

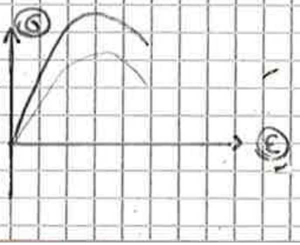
HCP : COMPACT HEXAGONAL

- (Be, Ca, Co, Zn, Zr, Mg, Ti)
- UPPER AND LOWER FACES: SIX ATOMS FORM A REGULAR HEXAGON CONTAINING AN ATOM IN THE CENTRE PLUS AN INTERMEDIATE PLAN CONSISTING OF 3 ATOMS.
- n. ATOMS PER CELL = 6
- COORDINATION NUMBER = 12
- APF = 0.74

CONSIDERATION : FCC AND HCP CAN BE DESCRIBED AS TWO VARIANTS OF THE SAME LATTICE STRUCTURE : THEY ARE VERY DENSE STRUCTURES

BOND ENERGY :





THE GREATER THE ENERGY BOND, THE HIGHER THE E AND T_M

1. POWDER METALLURGY

PM

ELEMENTS:

W, Ta, Mo;

Zr AND SUPERHARD TOOL MATERIALS;

Cu + $C_{GRAPHITE}$

PM WORKING MATERIALS:

ALLOYS OF Fe, STEELS AND Al;

Cu, Ni AND REFRACTARY METALS SUCH AS W, Mo;

METALLIC CARBIDES SUCH AS W;

EXPLOSIVITY:

MOSTLY FOR POWDERS OF Zr, Mg, Al, Li, Na

HIGH: Zr, Mg, Al, Li, Na (20-50 [g/m³] REQUIRED TO EXPLOSION);

MEDIUM: Zm, Fe (100-500 [g/m³] REQUIRED TO EXPLOSION);

LOW: Mo, Co POWDERS WITH BURNING T ≈ 700 [°C];

AlN = ALUMINUM NITRIDE -> YTTRIUM ALLUMINATE (LIQUID PHASE SINTERING OF)

Pd, Ni (EFFECTS)
K (POTASSIUM)

MECHANICAL PROPERTIES

$\lambda = \lambda_0 (1-2\varepsilon)$ THERMAL CONDUCTIVITY ($\varepsilon < 20\%$)

$B_{MAX} = a - b\varepsilon$ SATURATION INDUCTION

$\sigma_m = \sigma_{m0} \, EXP(-4{,}3\varepsilon)$ TENSILE STRENGTH

$\sigma_y = \sigma_{y0} \, EXP(-4{,}3\varepsilon)$ YIELD STRENGTH

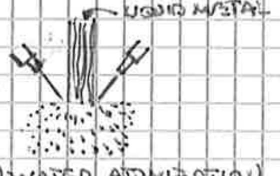
$\sigma_y = \sigma_{y0} + b\varepsilon + c(1-\varepsilon)$ YIELD STRENGTH

$E = E_0 (1-\varepsilon)^{3{,}4}$ YOUNG MODULUS ($\varepsilon < 50\%$)

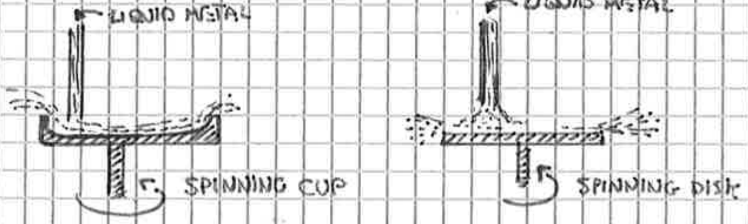
$\nu = \nu_0 \, EXP[1.372(1-\varepsilon)]$ POISSON RATIO ($5\% < \varepsilon < 35\%$)

$\lambda_0 = \frac{(1-\varepsilon)}{C_0}$ QUENCHABILITY, C_0 = THERMAL PROPERTIES OF THE MATERIAL

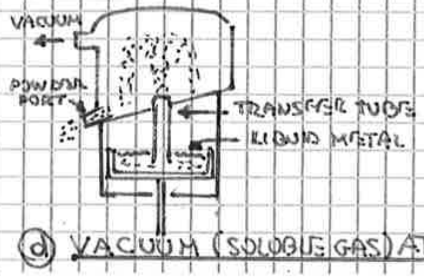
ATOMIZATION:



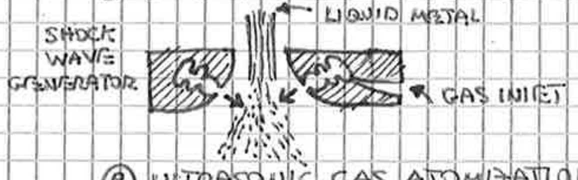
ⓐ WATER ATOMIZATION
ⓑ GAS ATOMIZATION



ⓒ CENTRIFUGAL ATOMIZATION



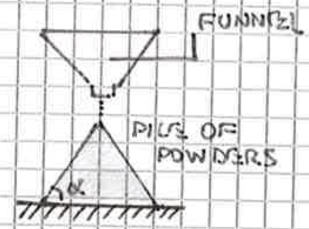
ⓓ VACUUM (SOLUBLE GAS) ATOMIZATION



ⓔ ULTRASONIC GAS ATOMIZATION

INTERPARTICLE FRICTION AND FLOW CHARACTERISTIC (1ST ANALYSIS)

- THE FRICTION BETWEEN PARTICLES AFFECTS ABILITY OF A POWDER TO FLOW READILY AND PACK TIGHTLY.
- A COMMON TEST OF INTERP. FRICTION IS THE ANGLE OF REPOSE (α) WHICH IS THE ANGLE FORMED BY A PILE OF POWDERS AS THEY ARE POURED FROM A NARROW FUNNEL.



1. SMALLER PARTICLE SIZE GENERALLY SHOW GREATER FRICTION, THEREFORE A STEEPER α
2. SPHERICAL SHAPES HAVE THE LOWER INTERP. FRICTION

2 ⇒ AS SHAPE DEVIATES FROM SPHERICAL, FRICTION BETWEEN PARTICLES TENDS TO INCREASE ⇒ SO α RESULTS STEEPER. ⚠ (SEE PARTICLE SHAPES)

OTHER ANALYSIS (6)

1. MASSIVE AND SURFACE CHEMICAL ANALYSIS
2. SURFACE AREA, DENSITY, POROSITY
3. APPARENT DENSITY
4. OUTFLOW SPEED
5. COMPRESSIBILITY
6. GREEN TENSILE STRENGTH = STRENGH OF UNSINTERED MATERIAL (7 MPa min)

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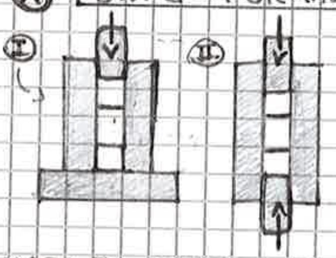
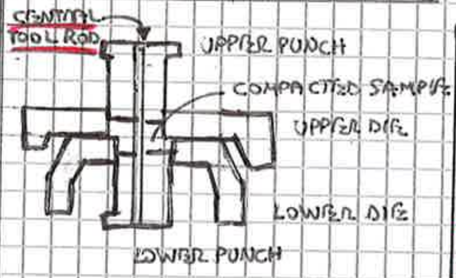
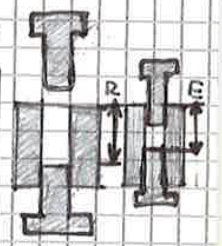
3) FORMING (LOWER DENSITY → POROSITY DECREASE ⇒ HIGHER M.P.)

Ⓐ POWDER FORMING IN RIGID DIES



SCHEME OF A RIGID DIE:





R = FULFIL DISTANCE
E = EXPULSION DIST.

CLASS I: COMPONENTS WITH A SINGLE THICKNESS AND ONLY ONE SIDE PRESSED;
(A GRADIENT IN DENSITY IS EVIDENT: CHANGE OF δ IN THE PRESSING DIRECTION)

CLASS II: COMPONENTS WITH A SINGLE THICKNESS AND PRESSED FROM TWO SIDES (OPPOSITE)

CLASS III: COMPONENTS WITH TWO THICKNESS AND PRESSED FROM TWO SIDES.

CLASS IV: COMPONENTS WITH MORE THAN TWO THICKNESS AND PRESSED FROM TWO SIDE

TYPES OF DIE
- SINGLE EFFECT DIE
- DOUBLE EFFECT DIE
- FLOATING DIE

(D) POWDER INJECTION MOULDING

- THE TECHNOLOGY FOR PLASTIC MATERIALS MOULDING IS ADOPTED.
- IT CAN BE USED FOR COMPACTING METALLIC, CERAMIC AND METAL-C. POWDER
- FINER AND MORE ROUNDED POWDERS MUST BE ADOPTED.
- A HIGH PERCENTAGE OF THERMOPLASTIC FILLER IS USED.
- THE DIE IS FILLED AT LOW PRESSURE AND VERY SLOWLY.
- A HIGH SHRINKAGE IS DETECTED DURING SINTERING PROCESS (24-48 h INTO FURNACE)

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(4) SINTERING (DECREASE OF POROSITY ⇒ INCREASE IN DENSITY ⇒ INCREASE IN M.P.)

1 - THE COMPONENTS ARE ...

2 - THE T IS ALWAYS LOWER THAN $\boxed{T_M}$ OF THE MAIN ELEMENT OF THE ALLOY

3 - FORMATION OF METALLIC BONDS ...

4 - DECREASE OF POROSITY AND VOLUME (SHRINKAGE) ⇒ INCREASE IN DENSITY ⇒ INCREASE OF MP

5 - * MAIN PARAMETERS (FOR DENSITY) { TIME (t) PRESSURE (P)
TEMP. (T) IF t ↗ T ↗ ⇒ POROSITY ↘, SHRINKAGE ↗

6 - THE MOST IMPORTANT SHRINKAGE IS EVIDENCED DURING THE FIRST 8 HOURS INTO THE FURNACE;

7 - AVERAGE t OF SINTERING ~ 1h ⇒ 5 ÷ 7% SHRINKAGE;

8 - IT IS NOT REQUIRED TO ELIMINATE ALL THE POROSITY;

9 - IF THE SHRINKAGE IS HIGHER THAN 12% THE SHAPE IS NOT THE ONE WANTED (DISTORSION)

10 - DURING SINTERING PROCESS: THERE IS RECRYSTALLIZATION $\frac{T_M}{3} < T_{RECR.} < \frac{T_M}{2}$ (DURING RECR. THE NUMBER OF DISLOCATIONS DECREASES)

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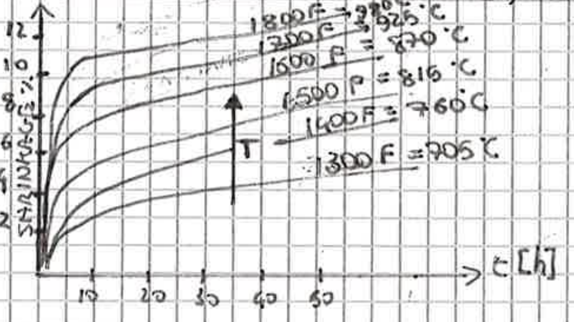
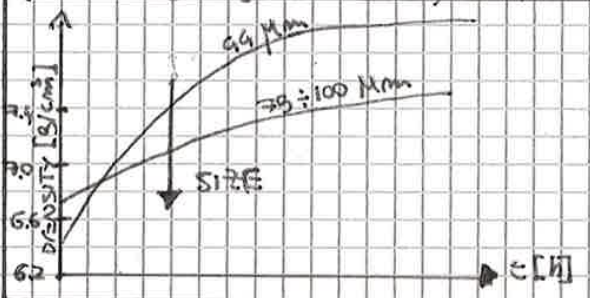
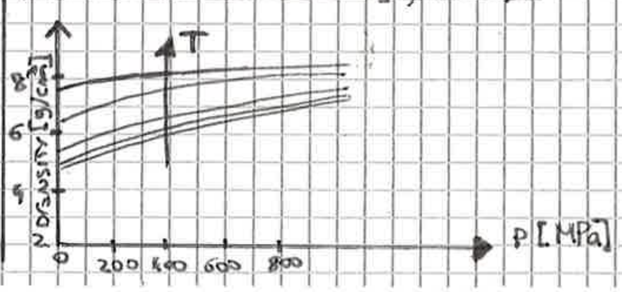
* SHRINKAGE % - TIME [h]; f(t, T)



DENSITY [g/cm³] - TIME [h]; f(t, SIZE)



DENSITY [g/cm³] - P [MPa]; f(P, T)



5) SECUNDARY OPERATIONS (AFTER SINTERING)

- THEY ARE PERFORMED TO INCREASE DENSITY, IMPROVE ACCURANCY, OR REALISE ADDITIONAL SHAPING ON THE SINTERED PART.

REPRESSING: PRESSING THE SINTERED PART IN A CLOSED DIE TO INCREASE DENSITY AND SO TO IMPROVE PROPERTIES.

SIZING: PRESSING THE SINTERED PART TO IMPROVE ACCURANCY.

COINING: PRESS WORK OPERATION TO PRESS ON THE SINTERED PART DETAILS INTO ITS SURFACE.

MACHINING: CREATING GEOMETRICAL FEATURES THAT CANNOT BE ACHIEVED BY PRESSING, SUCH AS SCREW THREADS, SIDE HOLES AND UNDERCUTS ...

6) JOINING AND WELDING

7) HEAT AND/OR THERMOCHEMICAL TREATMENTS

8) FINAL PRODUCT

IMPREGNATION AND INFILTRATION

- POROSITY IS A UNIQUE AND INHERENT CHARACTERISTIC OF PM TECHNOLOGY.
- IT CAN BE EXPLOITED TO CREATE **SPECIAL PRODUCTS** BY FILLING THE AVAILABLE PORE SPACE WITH:

- OILS
- POLYMERS → IMPREGNATION
- METALS → INFILTRATION

IMPREGNATION: TERM USED WHEN **OIL OR OTHER FLUID** IS PERMEATED INTO THE PORES OF THE **SINTERED PART**.

- COMMON PRODUCTS ARE **OIL-IMPREGNATED BEARINGS**, **GEARS** AND SIMILAR COMP.
- AN OTHER APPLICATION IS WHEN PARTS ARE IMPREGNATED WITH **POLYMER RESINS** THAT ENTER INTO THE PORE SPACES IN LIQUID FORM AND THEN SOLIDIFY TO CREATE A **PRESSURE TIGHT PART**.

INFILTRATION: THE PORES ARE FILLED WITH A **MOLTEN METAL**.

- THE T_M OF THE FILLER MUST BE LOWER.
- **CAPILLARY ACTIONS** LEAD THE FILLER INTO THE PORES.

→ THE RESULTING STRUCTURE IS **RELATIVELY NON POROUS**

→ THE INFILTRATED PART HAS A **MORE UNIFORM DENSITY**, AS WELL AS **TOUGHNESS AND STRENGTH**.

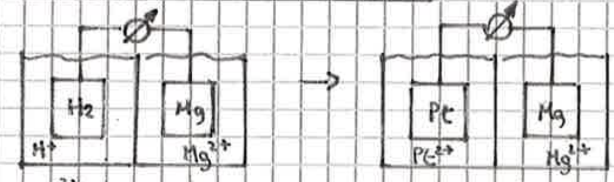
METAL FOAMS: { METAL POWDER, BINDING, FOAM AGENT } → Ⓜ MIXING → Ⓜ MOULDING → HT

(VERY POROUS STRUCT.)

2. CORROSION

C

ELECTROCHEMICAL SERIES



$Mg/Mg^{2+} = -2.37\ V$ $Pt/Pt^{2+} = +1.2\ V$
$Fe/Fe^{2+} = -0.44\ V$

$Pt^{2+} + \cancel{2e^-} \rightarrow Pt\ (+1.2V)$ | $Pt^{2+} \rightarrow Pt + 1.2V$
$Mg\ (-2.37V) \rightarrow Mg^{2+} + \cancel{2e^-}$ | $Mg \rightarrow Mg^{2+} + 2.37V$
$\Rightarrow Mg + Pt^{2+} \rightarrow Pt + Mg^{2+} + 1.2V + 2.37V$
$\Rightarrow Mg + Pt^{2+} \rightarrow Pt + Mg^{2+} + 3.57V$

GALVANIC SERIES : SEAWATER

ANODIC SIDE. [B] OR [M]

MAGNESIUM (Mg)
ZINC (Zm)
ALUMINIUM (Al)
CARBON STEELS
ALLOYED STEELS
CAST IRON
MARTENSITIC SS (ACTIVE)
FERRITIC SS (ACTIVE)
AUSTENITIC SS (ACTIVE)
BRASS (Cu-Zm) } NW
BRONZE (Cu-Sm) } NW
COPPER (Cu)
CUPRONICKEL
NICKEL (Ni) Ni MORE NOBLE THAN Cu
INCONEL
MARTENSITIC SS (PASSIVE)
FERRITIC SS (PASSIVE)
AUSTENITIC SS (PASSIVE)
TITANIUM (Ti)
SILVER (Ag)
GOLD (Au)
PLATINUM (Pt) Pt TOP!

CATODIC SIDE

NERNST EQUATION [M]

$$E = E_0 - \frac{RT}{zF} \ln \frac{a_{red}}{a_{ox}}$$

E = HALF-CELL REDUCTION POTENTIAL (AT A CERTAIN T)
E_0 = STANDARD HALF-CELL REDUCTION POTENTIAL
R = UNIVERSAL GAS CONST. = 8.314 [J/Kmol]
T = ABSOLUTE TEMP.

a = CHEMICAL ACTIVITY

→ a_{RED} = REDUCTANT ; a_{ox} = OXIDANT

F = FARADAY CONSTANT (THE NUMBER OF COULOMB PER MOLE)

z = IS THE NUMBER OF MOLES OF ELECTRONS TRANSFERRED IN THE CELL REACTION OF HALF REACTION.

ENVIRONMENT EFFECTS :

→ DISSOLUTION IS ALWAYS PRESENT. IT IS INFLUENCED BY

- (S) CONCENTRATION OF THE SOLUTION.
- (S) FLUID VELOCITY ↗ CORROSION RATE ↗
- (S) TEMPERATURE : T ↗ CHEMIC. REACTIONS RATE ↗ CORR. RATE ↗
- (S) COMPOSITION : CONC. OF CORROSIVE SPECIES ↗ CORR. RATE ↗
- MICROSTR. OF METAL : COLD-W.....
- ALLOYING : ALLOYS TEND TO HAVE...

FORMS AND MECHANISM OF CORROSION :

.... → A UNIFORM OVERALL CORROSION.

- RUSTING OF STEEL !
- TARNISHING OF SILVER (Ag)

PITTING CORROSION

1 LOCALIZED ATTACK WHICH FORMS SMALL HOLES OR PITS

2 THEY CAN BE VERY DEEP AND PENETRATE THROUGH MAT. WITHOUT MUCH WARNING / INDIC.

3 SIMILAR TO CREVICE CORROSION

4 IT STARTS AT SURFACE SCRATCHES, DEFECTS.

5 DUE TO GRAVITY, THE SOLUTION ENTERS INTO A PIT MAKING IT GROW.

6
- PENETRATING TYPE
- BIG HOLE TYPE

7 THE e^- MOVE AROUND THE PITTING ZONE THROUGH THE CATHODIC AREA

8 NW: THE SOLUTION, INITIALLY NEUTRAL, DUE TO THE INCREASING PRESENCE OF IONS$^+$; REACHES ph ACID VALUES (ph<<7); THEREFORE IT WILL INCREASE THE DISSOLUTION IN A LOCALIZED WAY.

TO REDUCE THE PROBLEM: (2)

→ POLISHING

→ SS ARE AFFECTED ⇒ + ②% Mo

CREVICE CORROSION

1 CC IS AN INTERSTITIAL CORROSION INDUCED BY MOUNTS OR JUNCTIONS ... OR PRESENC OF.

2 IT CONSISTS IN A L. EC A IN CR WHERE: A STAGNANT SOLUTION EXISTS (CRACKS, CREVICES, UNDER PAINT, UNDER GASKET, RIVETS, BOLTS, POROUS DEP.)

3 **CONCENTRATION CELLS FORM** DUE TO IONS CONC. IN THE **ELETTROLYTE** BETWEEN

4 **METAL IN CONTACT** WITH MORE CONCENTRATE ELECTROLYTE BECOMES "CATHODE"!

5 ELECTRONS e^- FLOW FROM LOW-OXYGEN AREAS OF Me WHICH ACTS AS ANODE.

6 IT OCCURS IN MANY ALLOYS: **SS, Al-ALLOY, Cu-ALLOYS, Ti-ALLOYS**

TO REDUCE CREVICE CORROSION: (5)

→ MOUNTING AND JUNCTIONS WELL DONE!

→ DESIGN (VESSELS) WITHOUT **STAGNANT AREAS**.

→ USE WELDING RATHER THAN BOLTED OR RIVETED **JOINTS**.

→ USE **NON-ABSORBING GASKET**.

→ REMOVE ACCUMULATE DEPOSITS!

STRESS CORROSION CRACKING

1 IT IS A CONNECTED EFFECT OF **TENSILE STRESS** ON METAL AND A PARTICOULAR CORROSIVE ENVIRONMENT. (ONLY WHEN BOTH TOGETHER AND ONLY ON CERTAIN METALS: EX: **SS** AND **CHLORIDE IONS** **BRASS** AND **AMMONIA**)

2 SMALL CRACKS FORM AND PROPAGATE PERPENDICULAR TO TENSIL STRESS. WITH BRITTLE FRACTURE (NO OR LITTLE PLASTIC DEF).

3 STRESS MAY BE EXTERNAL OR INTERNAL RESIDUAL STRESS.

TO AVOID SCC: (3)

→ CHECK COMBINATIONS OF Me AND ENVIRONMENT;

→ KEEP STRESSES LOW;

→ IF NECESSARY → STRESS RELIEVE;

EROSION - CORROSION

- IT IS A COMBINED EFFECT OF **CHEMICAL ATTACK** AND **MECHANICAL ABRASION**
- ALL METALS ARE AFFECTED: THE SOFT METALS ARE MORE SUSCEPTIBLE: **Cu, Al** AND VERY BAD FOR METALS THAT ARE NORMALLY PROTECTED BY **PASSIVE LAYER** SUCH AS **SS** AND **Al**. → THE EROSION REMOVES PROT. FILM EXPOSING...
- MORE PREVALENT IN PIPING, ELBOWS, BENDS; WHERE FLOW CHANGES DIRECTION OR BECOME TURBOLENT (CAVITATION AND BUBBLES CAN CAUSE PROB)

TO AVOID THIS PHENOMENON:

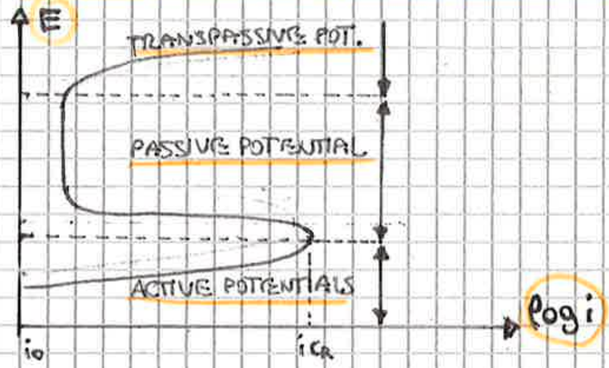
→ REDUCE TURBOLENCE;

SELECTIVE LEACHING

- IT IS **FOUND IN SOLID SOLUTION**;
- WHEN ONE ELEMENT IS PREFERENTIALLY REMOVED BY CORROSION
- EXAMPLE: **DEZINCIFICATION OF BRASS** (Cu-Zn): Zn IS REMOVED LEAVING WEAK, POROUS COPPER (Cu) MASS. (OFTEN WITH COLOUR CHANGE FROM YELLOW TO ORANGE/RED).

POLARIZATION CURVE

- WE TAKE A COMPONENT;
- WE PUT IT IN AN **ELECTROCHEMICAL CELL**;
- A CERTAIN POTENTIAL IS INDUCED ON THE COMP. (**POTENTIAL RAMP**);
- THEN WE MEASURE THE CURRENT THAT PRODUCE (FUNCTION OF THE e^- PRESENT ON THE MATERIAL, FUNCTION OF HOW MANY Me ATOMS BECOMES Me^+);
- FOR A CERTAIN VALUE OF POTENTIAL WE WILL HAVE A CERTAIN VALUE OF CURRENT AND THEREFORE A CERTAIN DISSOLUTION.
- **A PASSIVATE LAYER OF OXIDES** START TO BE CREATED.
- **WHEN THIS PHASE ENDS, EVEN** INCREASING THE POTENTIAL **THE DISSOLUTION DOES NOT CONTINUE**; => THE MEASURATED CURRENTS FALL.
- FURTHER INCREASING THE POTENTIAL, THE CURRENTS REMAIN LOW (NEVER NU
- FOR VERY HIGH (TRANSPASSIVE) POTENTIAL VALUES WE DETECT **MANY** e^- INSIDE THE MATERIAL;
- THESE e^- WILL GO AWAY REACTING WITH HYDROGEN.



STAINLESS STEELS (PREVIEW)

CORROSION RESISTANCE OF STEEL DEPENDS ON:

- TEMPERATURE
- ENVIRONMENT
- MOSTLY BY ITS CHEMICAL COMPOSITION

3.2 FERRITIC SS

- CR PERCENTAGE CONTENT, ON AVERAGE : 10÷18 % Cr (BUT ALSO TO 27 % Cr);
- MODERATE CR;
- GOOD STRENGTH;
- MODERATE DUCTILITY;
- BECAUSE OF PRODUCTION PROCESS : PHOSPHOROS (P) AND SULFUR (S) CAN BE PRESENT IN ALLOY.
  P,S ARE IMPURITIES → THEY INCREASE BRITTENESS.
- BCC LATTICE (α-PHASE);
- MAGNETIC;
- RELATIVELY INEXPENSIVE;
- EX : 409 [(0.08 % C), 11,5 % Cr], 446 [(0,2 % C), 23÷27 % Cr], ANNEALED
- APPLICATIONS:
  - 409 : AUTOMOTIVE EXHAUST COMPONENTS;
  - 409 : TANKS FOR AGRICOLTURAL SPRY;
  - 446 : HT APPL : VALVES;
  - 446 : GLASS MOLDS;
  - 446 : COMBUSTION CHAMBERS;
- EVENTUALLY + LOW % Mo, % Ni, % Mn; + GOOD RESISTANCE TO SCC (SEE DUPLEX)

3.3 MARTENSITIC SS

- AVERAGE CR CONTENT : 16 % Cr (LESS THAN 18 %)
- 0.1 ÷ 1 % C CONTENT;
- EVENTUALLY + Ni : EX : 431 : 16 % Cr - 2 % Ni;
- HIGH HARDNESS AND STRENGTH;
- MAGNETIC;
- MARTENSITE MICROSTRUCTURE; BCT LATTICE;
- EX : 410 [(0.15 % C), 12.5 % Cr], 440A [(0.7 % C), 17 % Cr];
- ANNEALED, QUENCHED AND TEMPERED;
- APPLICATIONS:
  - 410 : RIFLE BARRELS;
  - 410 : CUTLERY;
  - 410 : JET ENGINE PARTS;
  - 440A : CUTLERY;
  - 440A : BEARINGS;
  - 440A : SURGICAL TOOLS;
- EVENTUALLY + LOW % Mo, % Ni, % Mn;

HEAT TREATMENTS (SS)

THE USUAL HTs FOR STEELS ARE:

ANNEALING + NORMALIZING

- AUSTENITIC SS → SOLUTION HEAT TREATING
- FERRITIC SS → RECRYSTALIZATION
- MARTENSITIC SS → ANNEALING, QUENCHING AND TEMPERING
- DUPLEX SS → DEPENDING ON THE DESIRED CHARACT.
- PH SS → SOLUTION HEAT TREATING;

SCHAFFLER'S DIAGRAM (SS)

2 - AFTER WELDING WE DON'T WANT γ SO WE HAVE TO CHOOSE ADDITIONAL ELEMENTS TO AVOID THE "CORNERS" IN SHAEFFLER'S DIAGRAM

1 - (IT IS **USED TO UNDERSTAND WHAT HAPPENS WHEN WE WELD**);

3 - VERTICAL AXIS: $Ni_{EQ} = \%Ni + 30\%C + 0.5\%Mn$

ORIZONTAL AXIS: $Cr_{EQ} = \%Cr + \%Mo + 1.5\%Si + 0.5\%Nb$

4 - MOST OF THE SS SHOWS A CERTAIN % OF FERRITE (α) IN WELDED ZONES (DUPLEX: HIGH AMOUNT OF FERRITE IN W. ZONES): α NEGATIVE FOR CR BUT IT AVOIDS CRACKS IN WELDED ZONES.

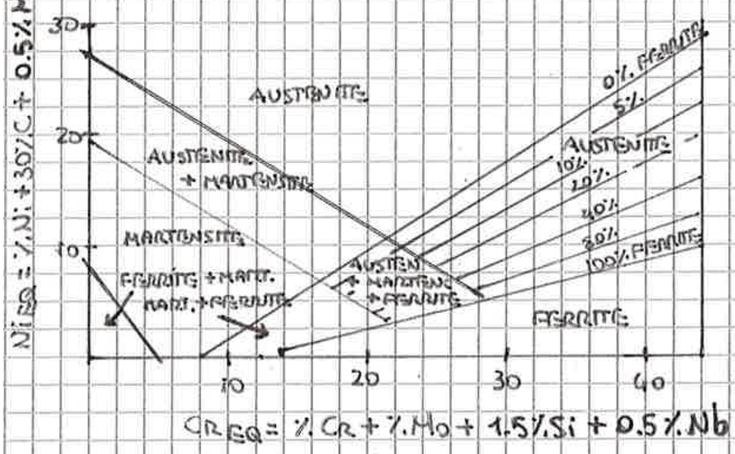
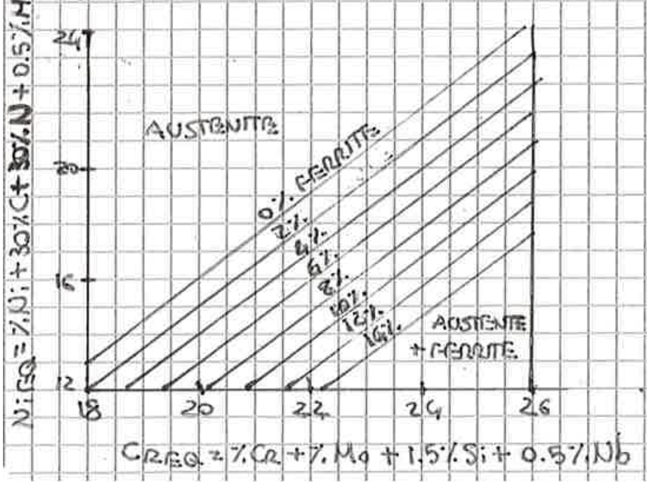


DIAGRAM OF DE LONG

- NITROGEN INFLUENCE ON SCHAEFFLER'S DIAGRAM.



MARTENSITE MICROSTRUCTURE (SS)

- THE QUENCHING TEMPERATURE DETERMINES THE AMOUNT OF CARBIDES DISSOLVED IN γ AND THE PRESENCE OF CARBIDES AFTER QUENCHING AFFECTS THE FINAL HARDNESS.
- HIGHER THE AUSTENITIZATION T (A3) --> HIGHER AMOUNT OF DISSOLVED CARBIDES IN AUSTENITE (γ) -> HIGHER HARDNESS AFTER QUENCH.
- BUT HIGH A3 MEANS TO HAVE A LOT OF RECRYSTALLIZATION AND SO BIG GRAINS => BRITTLENESS AFTER QUENCH.

a) ANNEALED T < A1 (EUTECTOID T)

b) HEATING AT 980 °C -> COMPLETE AUSTENITIZATION -> COMPLETE DISSOLUTION OF CARB. IN γ; BY COOLING: $\gamma \rightarrow M$ WITH FEW CARBIDES.

TEMPERING (SS)

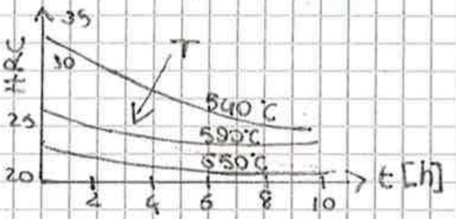
- IT IS A HEAT TREATMENT IN FURNACE TO TRANSFORM MARTENSITE.
- TO CHANGE SOME PROPERTIES;

DURING TEMPERING (HEATING AFTER QUENCHING) (SS)

- LOSS IN HARDNESS;
- LOSS IN STRENGTH;
- INCREASE IN RESILIENCE (KCU) (IMPACT TEST).

EFFECT OF TEMPERATURE AND TIME OF TEMPERING (SS)

T ↗ t ↗ => HRC ↘

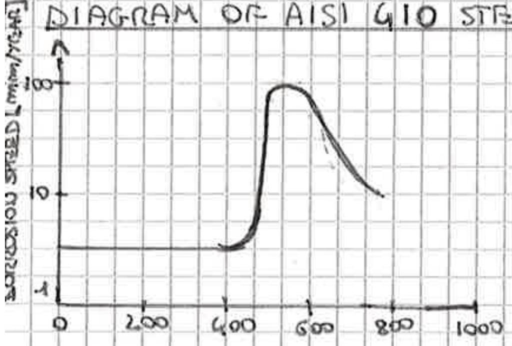


KRUPP PROBLEM (SS)

IF T ↗ t ↗ DURING TEMPERING: CARBIDES CATCH CR : CR ↘

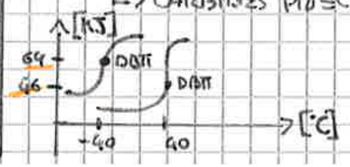
THERE IS A RANGE OF T OF TEMPERING WHERE CORROSION RATE REACHES HIGH VALUES => SO WE HAVE TO AVOID THE CRITICAL RANGE OF TEMPERING.

DIAGRAM OF AISI 410 STEEL (CRITICAL RANGE: 450 - 600 °C)



COOLING RATE AFTER TEMPERING (SS)

- RAPID COOLING -> NO BRITTLENESS INDUCED
- SLOW COOLING -> BRITTLENESS INDUCED
  - -> CARBIDES PRECIPITATE AT GB GIVING BRITTLENESS



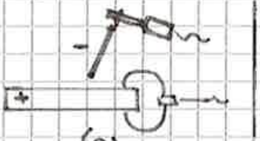
WELDING (SS)

⊙ ARC WELDING

TWO ELECTRICAL CONFIGURATIONS:

(a) DIRECT POLARITY

(b) REVERSE POLARITY



(a)

AFTER ARC WELDING → CLEANING!

FILLING MATERIAL: CONSUMABLE ELECTRODES

FOR FERRITIC SS: E 308
E 309
E 310
E 312
E 316
E 317
E 347

FOR MARTENSITIC: " " + E 420
E 430

⊙ TIG WELDING

TIG = "TUNGSTEN INERT GAS" WELDING

CONSIDERATIONS:

- THE AREAS TO BE WELDED MUST NOT PRESENT POROSITY.
- (AUSTENITE IS ALWAYS HARDER THAN FERRITE)

T1	NATURALLY AGED TO STABLE COND.
T2	ANNEALED (CAST ALLOYS)
T3	SOLUTION HEAT TREATED + COLD WORKED + T1
T4	SOLUTION HEAT TREATED + T1
T5	ARTIFICIALLY AGED
T6	SOLUTION HEAT TREATED + T5
T7	SOLUTION HEAT TREATED + OVERAGE
T8	SOLUTION HEAT TREATED + COLD WORKED + T5
T9	SOLUTION HEAT TREATED + T5 + COLD WORKED
T10	T5 + COLD WORKED

NW: ARTIFICIALLY AGING = PRECIPITATION HEAT TREAT → PRECIPITATION HARDENING

Q - ANNEALING ($280°C \le T_{ANN} \le 400°C \iff \frac{T_M}{3} < T_{ANN} < \frac{T_M}{2}$)

- IT CAN BE REQUIRED BEFORE FORMING OR COLD WORKING;

→ TO HOMOGENIZE THE PROPERTIES OF DEFORMABILITY;

- THE MAX T AND COOLING RATE MUST BE CONTROLLED CAREFULLY TO AVOID PRECIPITATION HARDENING.

W - SOLUTION HEAT TREATMENT

- IT IS THE HT THAT ALLOWS TO INCREAS THE CONTENT OF ALLOYING ELEMENT IN THE SOLID SOLUTION.
- TO BETTER UNDERSTAND, LET'S CONSIDER:

AL - Cu DIAGRAM (VEDI "DIAGRAMS")

1. WE PUT THE COMPONENT IN THE FURNACE AT THE **SOLUBILIZATION T** (SLIGHTLY LOWER THAN EUTECTIC T)
2. WE WAIT FOR COMPLETE SOLUBILIZATION OF THE θ PHASE;
3. θ DISAPPEAR AND K PHASE IS ENRICHED IN Cu;

IT IS REQUIRED A LONG SOLUBILIZATION TIME BECAUSE THE **ATOM OF Cu** IS LARGE AND THE T IS NO SO HIGH ($\Rightarrow$ **8÷10 h**)

QUENCHING

4. THEN WE QUENCH THE COMP. THERE ARE NO PHASE TRANSF; WE BLOCK THE HT SITUA.

NATURAL AGING

ROOM T: WE HAVE OBTAINED A **METASTABLE SOLID SOLUTION** THAT WILL TRY TO **SEND OUT THE EXCESS OF Cu OVER THE TIME**.

THE AGING PROCESS AT ROOM T IS VERY LONG; DURING THIS PROCESS **INTERMEDIATE METASTABLE PRECIPITATES** ARE FORMED; THESE LEAD TO A IMPORTANT INCR. IN M.P.

- WHEN AGING IS COMPLETED WE GET A SOLID SOLUTION $K+\theta$ **WITH CONTENTS** REQUIRED BY DIAGR.

CONSIDERATION ON WELDING

7000 SERIES ALLOY : HIGHER M.P.

THE 7000 SERIES ALLOYS WHEN ARE WELDED LOSE PERFORMANCE IN THE WELDED AREA. WE HEAT SO WE OVERAGE.

THE FACT IS: THE COOLING SPEED IS NOT SUFFICIENT TO GARANTEE A QUENCHING AS FAST AS NECESSARY.

→ THEREFORE THE MOST EFFICIENT Al-ALLOYS WITH WHICH WE BUILD THE WINGS OF THE AIRPLANES DO NOT WELD THEM BUT WE RIVET THEM.

ALCLAD

ALCLAD ⇒ PURE ALLUMINIUM COATING/CLADDING.

THE ALLOY IS COATED WITH THIN FILM OF PURE Al.

BECAUSE : THE SINGLE-PHASE PURE ELEMENTS ARE MORE RESISTANT TO CORROSION

⇒ **SO**, WE CAN HAVE AN ALLOY WITH A STRONGER CORE THAT GARANTEES STRE AND A PURE Al COATING TO ENSURE CR.

NW: IN ANNEALING THIS COMP. THE T_{ann} MUST BE LIMITED TO AVOID EXCESSIVE DIFFUSION FROM CORE TO CLADDING.

CAST ALLOYS : Al-Si PHASE DIAGRAM [← SEE "DIAGRAMS"]

IN THE Al(α)+L FIELD: THE CRYSTALS OF Al(α) ARE BORN AND GROW IN A BRANCHED WAY (→ DENDRITES). BY COOLING WE OBTAIN PREFORMED Al(α) DENDRITIC STRUCTURES PLUS EUTECTIC COMPOSITION (Al-Si).

HEAT TREATMENT OF THE INGOTS:

- AT POINT P THE FIRST SOLID CRYSTAL OF COMP. C_p IS FORMED.
- DECREASING T, THE SOLID CONTENT INCREASES AND, DURING NEW SOLID CRYSTALS FORMATION, THESE WILL PRESENT AN ALWAYS HIGHER CONCENTRATION OF Si.
- THE THICKNESS OF THE INGOT IS BEGINNING IMPORTANT
- WE DON'T HAVE A HOMOGENEUS COMPOSITION OF THE SOLID BUT SHELLS OF DIFFERENT COMPOSITION MORE AND MORE RICHED OF SOLUTE.
- ALL THE SOLID MUST BE ENRICHED OF Si, NOT JUST THE LAST SHELLS THAT HAS BEEN FORMED → DIFFUSION PHENOMENA ; BUT THE DISTANCES TO BE TRAVELED BY THE SOLUTE ARE ALWAYS MORE IMPORTANT.
- REACHED THE T_E THE REMAINING COOLANT LIQUID GIVES RISE TO PHASE SOLIDIFICATION WITH EUTECTIC MORPHOLOGICAL DISTRIBUTION, i.e. A MIXTURE OF α AND 2nd PHASE.

→ IN SOLUBILIZATION (SOLID HEAT T.) IT IS NOT NECESSARY TO RISE ABOVE THE T_E

WE HEAT UP TO A CERTAIN T TO ACCELERATE THE SOLUTE (Si) DIFFUSION TO SPEED UP THE PRECIPITATION OF NEW METASTABLE PRECIPITATES.

5. Mg - ALLOYS

Mg

Mg	VS. Al
LATTICE STRUCTURE : HCP	FCC
$T_M = 650\,°C$	$T_M = 660{,}45\,°C$
$E = 42$ GPa	$E = 70$ GPa
$\delta = \mathbf{1{,}738}$ $[Kg/dm^3]$	$\delta = 2.7$ $[Kg/dm^3]$

- CORR. RES. LOWER THAN Al.
- Mg IS FLAMMABLE AND EXPLOSIVE.
- SOME Mg-ALLOYS CAN BE STRENGHTENED BY SOLUTION H.T. + AGING

DESIGNATION OF Mg-ALLOYS

*$\underbrace{AZ}\underbrace{91}\underbrace{D}$: 9% Al - 0.7% Zm D -> + 0.13% Mm

(REALLY: Al : 8.3 ÷ 9.7% ; Zm : 0.3 ÷ 1% ; Mm : 0.13 ÷ 0.5%)

+ 4TH : HT : E, O, $\underbrace{H10, H11}_{\text{STRAIN HARDENED}}$, $\underbrace{H23, H24, H26}_{\text{STRAIN HARDENED + PARTIAL ANNEALED}}$, $\underbrace{H4, T4}$, T6, ... -> SOLUBILIZED

WROUGHT Mg-ALLOYS :

A|Z 10|A (HT = F) : ~ 1% Al, 0.4% Zm (+ 0.2% Mm) ; σ_R = 220 MPa, σ_Y = 145 MPa, A% = 1

A|Z 61|A (HT = F) : ~ 6% Al, 1% Zm ; σ_R = 310 MPa, σ_Y = 230 MPa, A% = 16

A|Z 80|a (HT = **T5**) : ~ 8.5% Al, 0.5% Zm $\sigma_R = \underset{-15}{380}$ MPa, $\sigma_Y = \underset{+30}{275}$ MPa, A% = 7

ZK 60 A (HT = **T5**) : ~ 5.5% Zm, 0.5% Zr σ_R = 365 MPa, σ_Y = 305 MPa, A% = 11

DIE CASTING Mg-ALLOYS:

A|Z 91 D	MOST USED ALLOY. GOOD STRENGTH AT T_{ROOM} ; LOW VISCOSITY, EXCELLENT SEAW. CR
A|M 50 A	(M = Mm) MORE DUCTILE!
A|M 60 B	GOOD STRAIN RUPTURE AND TOUGHNESS, EXCELLENT SEAW. CR
A|S 21|X1	(S = Si) (THE BEST) { CREE RESISTANT, IT CAN BE USED AT HIGH T.
A|S 41|X B	} { GOOD PROP. AT ROOM T / AS41XB EXC. SW. CR.

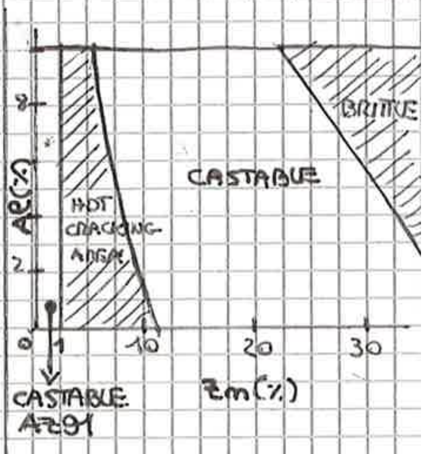
---

*ALFABETIC ORDER IN FUNCTION OF THE WEIGHT :

A = Al
B = BISMUTH
C = Cu
D = Ca
E = RARE EARTHS
F = Fe
H = THORIUM

K = Zr (Z = Zm)
L = Li
M = Mm
N = Ni
P = Pb
Q = Ag
R = Cr

S = Si
W = YTTRIUM
Y = ANTIMONY
Z = Zm



Mg-ALLOYS IN AUTOMOTIVE (6)

1 IN EUROPE THE INCREASE IN USING Mg - ALLOYS AS STRUCTURAL LIGHT WEIGHT MATERIAL IS BEING LED BY VOLKSWAGEN GROUP. OTHER UTILIZERS ARE: BMW, JAGUAR AND FORD (...);

2 ABOUT 14 Kg OF Mg-ALLOYS ARE USED IN VW PASSAT AND GOLF PLATFORMS

3 AZ91D OFFERS A 20÷25% WEIGHT SAVING OVER Al.

4 OTHER APPLICATIONS INCLUDE:

4.1 INSTRUMENT PANELS

4.2 CYLINDER HEAD COVERS

4.3 STEERING COMPONENT

4.4 SEAT STRUCTURE WITH SAFETY BELT ROLLING UP.

5 SOME OF THEES APPLICATIONS UTILIZE THE NONE DUCTILE Mg-ALLOYS: AM50A OR AM60B

6 IN NORTH AMERICA, THE USE OF Mg-ALLOYS FOR AUTO. APPL. IS ADVANCED. THE **GM** FULL SIZED **SAVANA** AND THE **EXPRESS VANS** USE UP TO **26 Kg** OF Mg-

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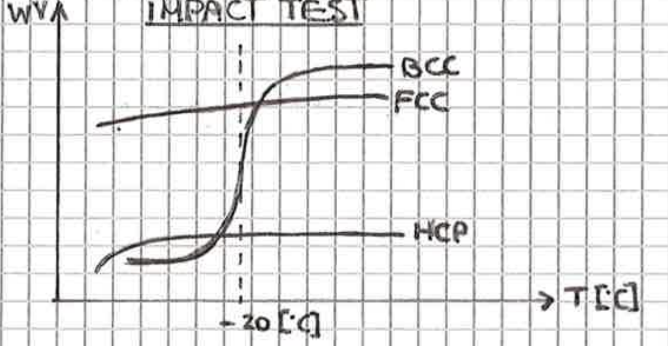
IMPACT TEST



NW: VERY LOW LOAD REQUIRED TO CRACK Mg-ALLOYS WITH AN IMPACT TEST BECAUSE OF THE HCP LATTICE.

REMEMBER:

BCC: IRON < 907; IRON > 1400°C; W, ~~Ta~~ V, Mo, CR, ALCALINE METALS (Na, K) [2, 8, 0.68]

FCC: 907°C < IRON < 1400°C; Cu, Ag, Au, Ni, Al, LEAD (Pb), Pt [4, 12, 0.74]

HCP: Be, Ca, Co, ZR, Zn, Mg, Ti [6, 12, 0.74]

DEOXIDERS

(LUCIA NASCE BENE, MANGIA BENE, ANCHE CON SUO PAPA') (9)

- Li, Na, Be, Mg, B, Al, ~~Ca~~, Si, P CAN BE USED; (EASY TO REMOVE) + Li => LiO (LOW S_{Li}) -> TOP
- Ca, Mg, Zn SOMETIMES (NORMALLY OTHER ROLES: EX Zn: SOLID SOLUT. STRENGTHENER)
- REQUIREMENTS OF A DEOXIDER:
  - -> AFFINITY FOR OXYGEN IN MOLTEN Cu;
  - -> RELATIVELY INEXPENSIVE COMPARED TO Cu;
- NOTES:
  - -> IN TIN BRONZE (Cu-Sn): OXYDER = P
  - -> CR-Cu: OXYDER = Si

- INSOLUBLE ELEMENTS: Pb*, Te, Se
- AGE HARDENABLE ALLOY: Be, Zr, CR ↑ (DEOX = Si)

ADVANTAGES OF Cu-ALLOYS (4)

1. GOOD CORROSION RESISTANCE;
2. EXCELLENT ELECTRICAL AND THERMAL CONDUCTION;
3. VARIANCE IN COLOUR WITH ALLOY ADDITION (AESTHETIC VALUE);
4. EASY FABRICATION DUE TO THE EXCELLENT DUCTILITY;

DISADVANTAGES OF Cu-ALLOYS (3)

1. SUSCEPTIBLE TO HYDROGEN EMBRITTLEMENT, SCC AND EROSION-CORROSION;
2. RELATIVE LOW STRENGTH (WITH RESPECT TO Al AND STEEL);
3. DRAMATIC CHANGES IN PROPERTY WITH VARYING ALLOY CONTENTS; (ESPECIALLY IN CONDUCTIVITY WITH INCREASING IMPURITY CONTENT)

Cu-ALLOY FAMILIES

ALLOYING ELEMENT | FAMILY

Zn (SOLUBILITY = 37%) -> BRASSES (Cu-Zn)
Sn (SOLUBILITY = 9%) -> PHOSPHORUS BRONZE (Cu-Sn)
Al (SOLUBILITY = 19%) -> Al BRONZE (Cu-Al)
Si (SOLUBILITY = 8%) -> Si BRONZE (Cu-Si)
Ni (SOLUBILITY = 100%) -> Cu-NICKEL (Cu-Ni)

-> SOLID SOLUTION ALLOYS

DESIGNATION OF Cu-ALLOYS

C 20 900

C ↓ COPPER ALLOY

2 -> MAIN ALLOYING ELEMENT:

1 = PURE Cu
2 = Zn -> Cu-Zn = BRASS
3 = Zn, Pb* -> Cu-Zn-Pb

BRASSES: Cu-Zn

BRONZES: Cu-Sn, Cu-Al, Cu-Si, Cu-Ni

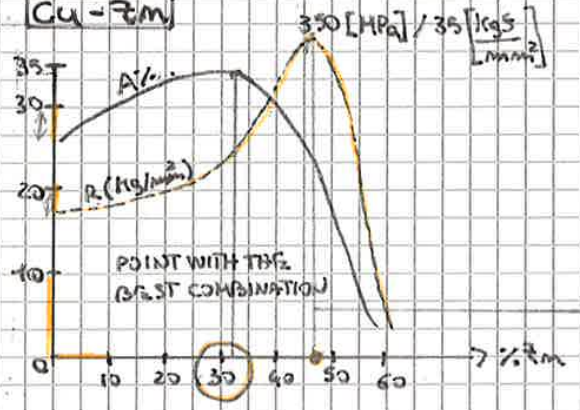
PHOSPHOR BRONZE → Cu-Sn ← BRITTLE!

MAX SOLUBILITY OF Sn = 9% MAX SOLUBILITY OF Sn = 15%

→ (ABOVE ↑ 10% Cu-Sn = BRITTLE ALLOY) ←

MECHANICAL PROPERTIES: STRENGTH (R) - ELONGATION (A%)

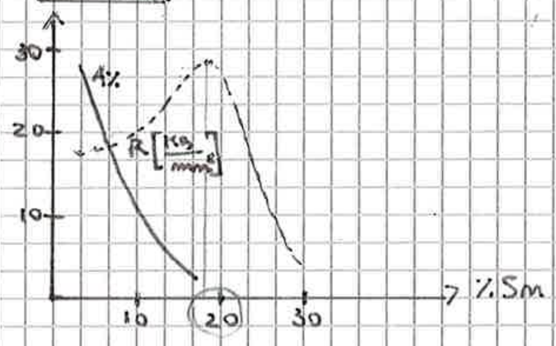
Cu-Zn



SOLUBILITY OF Zn ≈ 37%

β': HIGH STRENGTH, LOW DUCTILITY ⇒ BRITTLE

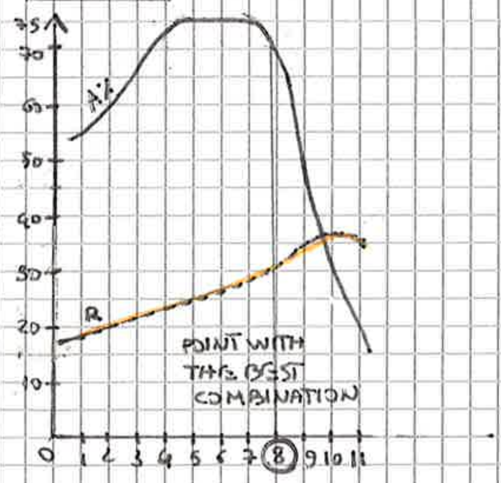
Cu-Sn



SOLUBILITY OF Sn = 15% → Cu-Sn BRONZE

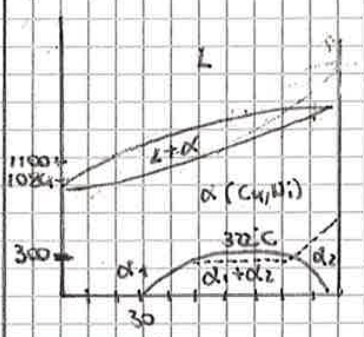
SOLUBILITY OF Sn = 9% → PHOSPHOR BRONZE

Cu-Al



ONLY Zn AND Al ADDED TO Cu INCREASE DUCTILITY INITIALLY (→ 33÷35% Zn; → 8% Al, THEN ↘)

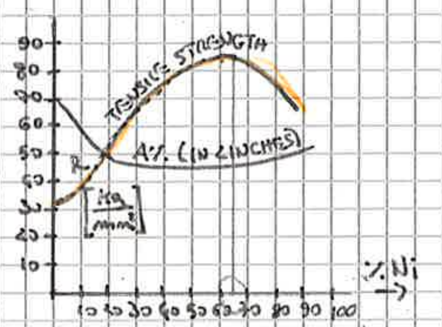
Cu-Ni PHASE DIAGRAM



- T_M OF Cu = 1084,6 °C
- T_M OF Ni = 1455 °C
- BOTH FCC

SOLUBILITY OF Ni = 100%

Cu-Ni



Cu + 40% Ni = INVAR ALLOY

⇒ NO CHANGING SHAPE WITH T↗

7. Ti-ALLOYS

Ti

GENERALITIES:

- LATTICE STRUCTURE $\begin{cases} T < 882{,}5\,°C \rightarrow HCP & \delta = 4{,}507\,[Kg/dm^3] \\ 882{,}5 < T < 1668 \rightarrow BCC & \delta = 4{,}11\,[Kg/dm^3] \end{cases}$
- $T_M = 1668\,[C]$
- $E = 113\,[GPa]$
- $\delta = 4{,}507\,[Kg/dm^3]$
- HIGH CR (PASSIVATION)
- THERMAL CONDUCTIVITY COEFF: $6 \div 16\,[W/mK]$
- THERMAL DILATATION COEFF: $9 \div 11\,[\mu m/m°C]$

PRIMARY PRODUCTION OF Ti - KROLL PROCESS (4+5)

1 - Ti COMMON IN EARTH'S CRUST;

2 - ENERGY TO SEPARATE = 125 [MWhr/TONNE] (7[€/Kg] JUST IN POWER);

3 - OBTAINABLE FROM RUTILE (TiO_2) AND ILMENITE ($FeO-TiO_2$); 97÷98% FROM TiO_2;

4 - BATCH PROCESS OVER 5 DAYS:

- WE OBTAIN $TiCl_4$ FROM TiO_2 AND Cl_2;
- KROLL PROCESS: $TiCl_4$ REACTS WITH 2Mg AT 773÷873[C] IN A CLOSED SS VESSEL

$TiCl_4(GAS) + 2Mg(L) \rightarrow Ti(S) + 2MgCl_2(L)$

- Ti(SOLID) = Ti SPONGE;

5 - CHIP OUT Ti SPONGE (5÷8[t]) FROM REACTOR;

6 - 8[€/Kg];

7 - CHLORIDE CORROSIVE AND NASTY;

8 - WORLD ANNUAL CAPACITY: 100 000 [t]; DEMAND: 60 000 [t]

9 - NEED A CHEAPER PROCESS THAT IS DIRECT;

PREPARATION OF Ti INGOTS (3)

1 - MOLTEN Ti REACTS WITH OXYGEN AND NITROGEN;

2 - Ti SPONGE CRUSHED AND COMPACTED INTO ELECTRODE COMPACTS:

- THESE WELDED TOGETHER;
- FORM CONSUMABLE ELECTRODE;
- FOR VACUUM ARC MELTING;

3 - TO PRODUCE Ti ALLOYS THE ALLOYING ELEMENTS ARE MIXED WITH CRUSHED Ti BEFORE COMPACTING.

SCHEME ← [B]

CONSIDERING "PURE" Ti

- PURE Ti RANGE : 99.5 ÷ 99.0% Ti;
- MAIN ALLOYING ELEMENTS : Fe, C, O, N (INTERSTITIALS);
- CONSIDERING α-PHASE: CONTENT OF O% DETERMINES THE GRADE AND STRENGTH:

$\%O_{EQ} = \%O + 2\%N + 0.67\%C$: $\%O_{EQ} \uparrow \Rightarrow$ STRENGTH ↑ BUT TOWGHNESS ↘

- IF HIGH TOUGHNESS IS DESIRED, A SPECIAL ALLOY WILL BE PRODUTED: EXTRA LOW INTERSTITIAL (ELI) ALLOY.

DEFORMABILITY PROPERTY OF "PURE" Ti

- PURE Ti CAN BE COLD ROLLED AT ROOM T TO > 90% WITHOUT CRACKING;
- THE RELATIVELY HIGH DUCTILITY OF HCP Ti CAN BE ATTRIBUITE TO THE MANY OPERATIVE SLIP SYSTEMS AND TWINNING PLANES IN THE CRYSTAL LATTICE; i.e. SLIP OCCURS ON {1010} PRISM PLANES AND {1011} PYRAMIDAL PLANES AS WELL AS ON BASAL PLANES.
- TWINNING IN PLASTIC DEFORMATION IS MORE IMPORTANT IN Ti THAN Mg, Zn AND Ca.
- LOW c/a (UNUSUAL IN HCP METALS);

ALLOY DESIGNATION

GRADE 1	PURE Ti, LOW O
GRADE 2	PURE Ti, STANDARD O
GRADE 3	PURE Ti, HIGH O
GRADE 4	PURE Ti, VERY HIGH O
GRADE 5	Ti - 6Al - 4V α + β ALLOY
GRADE 6	Ti - 5Al - 2.5Sn α ALLOY
GRADE 12	Ti - 0.3Mo - 0.8Ni

CONSIDERATION ON α-ALLOYS

- α ALLOYS HAVE LOWER CR THAN PURE Ti BUT HIGHER STRENGTH
- α ALLOYS ARE GENERALLY DUCTILE. (THE GRADE ELI MANTAIN THIS PROP. AT CRYOGENIC T)
- α ALLOYS NOT HARDENABLE BY HT BUT BY GRAIN SIZE REDUCTION

INFLUENCE OF ALLOYING ELEMENTS

- A VERY IMPORTANT PROPERTY OF ALLOYING ELEMENTS IS THEIR INFLUENCE ON THE STABILIZATION OF α PHASE (LOW T) AND β PHASE (HIGH T):

α - STABILIZERS: C, O, N ; Al, Sn

β - STABILIZERS: V, Mo, Cu, Cr, Zr

NOTE: Si INCREASES CREEP RESISTANCE

4 ALLOYS TO BE CONSIDERED:	USAGE:	σ_y [MPa]:	σ_R [MPa]:	ELONGATION %.
PURE Ti (99.0 + % Ti)	35%	$\sigma_y = 241 \div 585$	$\sigma_R = 331 \div 661$	30 ÷ 20
α ALLOY (Ti - 5Al - 2.5Sn) GRADE 6	10%	$\sigma_y = 806$	$\sigma_R = 861$	16 %
β ALLOY (Ti - 13V - 11Cr - 3Al)	~1%	$\sigma_y = 1205$	$\sigma_R = 1275$	8 %
α+β ALLOY (Ti - 6Al - 4V) GRADE 5	55%	$\sigma_y = 1102$	$\sigma_R = 1171$	10 %

(HT)* = ANNEALED, QUENCHED AND AGED

$\alpha+\beta$ ALLOY (EX Ti - 6Aℓ - 4V)

- % β RANGE: 10 - 50% β
- HT: SOLUTION HEAT TREATING, QUENCHING AND TEMPERING: T_{RANGE}: 480-650 °C
- MICROSTRUCTURE: FINE MIXTURE OF $\alpha+\beta$ IN A METALLIC MATRIX OF RESIDUAL OR TRANSFORMED β.

PROPERTY:	β PROCESSED	α/β PROCESSED
- STRENGTH:	MODERATE	GOOD
- CREEP RESISTANCE:	GOOD	LOW
- FATIGUE RESISTANCE:	MODERATE	GOOD
- FRACTURE TOUGHNESS:	GOOD	LOW
- RATE OF CRACK PROPAG:	GOOD	MODERATE
- GRAINS SIZE:	COARSE	FINE

MICROSTRUCTURE:

THE PROPERTIES DEPEND ON MICROSTRUCTURE;

- MICROSTRUCTUR DEPENDS ON CHEMICAL COMP. AND HT;
- IT CAN BE:

EQUIAXED: OBTAINED HEATING IN $\alpha-\beta$ RANGE AND ANNEALD AT LOW T;

ACICULAR: OBTAINED BY MECH. WORKING OR HT OVER β TRANSUS T WITH A FOLLOWING RAPID COOLING.

PROPERTY	EQUIAXED	ACICULAR
- STRENGTH :	HIGHER	LOWER
- CREEP RESISTANCE :	LOWER	HIGHER
- FATIGUE RESISTANCE :	HIGHER	LOWER
- FRACTURE TOUGHNESS :	LOWER	HIGHER
- RATE OF CRACK PROPAG:	HIGHER	LOWER
- SCC RESISTANCE :	LOWER	HIGHER
- DUCTILITY :	HIGHER	LOWER
- HT DEFORMABILITY :	HIGHER	LOWER

Ti_3Al FORMATION

- WE HAVE TO AVOID Ti_3Al FORMATION;
- $\%Al_{EQ} = \%Al + 0.33\%\,Sm + 0.16\%\,Zr + 10\%\,(O+C+2N)$
- $\%A_{EQ} < 9\,wt\%$

7.26 $\alpha+\beta$ ALLOYS: MICROSTRUCTURE

(Ti - 6Aℓ - 4V): MECHANICAL PROPERTIES ← [B] | HEAT TREATMENT ← [B]

APPLICATIONS

IN MEDICAL FIELD:

- HIP PROSTHESIS
- AORTIC VALVES
- PEACEMAKER
- DENTAL PROSTESIS
- DENTAL PLANTS

IN AUTOMOTIVE FIELD:

- VALVES;
- CONNECTING ROD;
- EXHAUST GAS SYSTEM;
- SPRINGS

SEA APPLICATIONS

- ROTARY DRILLING SYSTEMS
- SUBMARINE COATING

IN AEROSPACE SECTOR:

- FIGHTER AIRPLAINS;
- GAS COMPRESSOR DEVICES;
- FAN BLADE TECNOLOGY;
- TANK OF SHUTTLE;
- RETRACTABLE UNDERCARRIAGE OF BOEING 747;

OTHER APPLICATIONS:

- HEAT EXCHANGERS, RADIATORS;
- FAN VAPOR TURBINES;
- TANKS;
- JEWELLERY AND FASHION;
- SAFETY;
- NANOTECHNOLOGIES;

IN SPORT FIELD:

- GOLF
- CYCLING;
- DIVING;
- TREKKING;
- WINTER SPORTS;

BUILDING APPLICATIONS

- VERY LOW THERMAL DILATATION COEFF ⇒ LESS INFLUENCED BY SEASON AND T CHANGES ⇒ HIGHER DIMENSIONAL AND GEOMETRICAL STABILITY;
- Ti DOESN'T CHANGE COLOUR
- Ti DOESN'T EVIDENCE PITTING CORROSION INDUCED FROM SEAWAT. OR ACID RAINS
- HIGH CORROSION RESISTANCE IN GENERAL (NOT INFLUENCED BY CHANGES OF T OR BY POLLUTION)

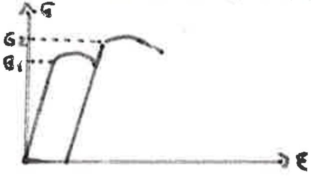
- GUGGENHEIM MUSEUM IN BILBAO;
- VAN GOGH MUSEUM;
- NATIONAL CENTER OF SCIENCE IN SCOTLAND;

2) SOLID SOLUTION:

- INCREASING THE RESISTANCE OF THE METAL BY INSERTING IN ALLOY ELEMENTS WITH DIFFERENT ATOMIC RADIUS (BIGGER OR SMALLER) FROM THE BASE METAL (SUBSTITUTIVE ATOMS) OR BY PLACING INTERSTITIAL ATOMS.
- THE LATTICE IS DISTORTED; IT PRESENTS TENSION FIELDS THAT OPPOSE TO THE PLASTIC DEFORMATION → INCREASE OF THE YIELD STRENGTH.
- SMALL ATOM → TENSILE STRAIN ON THE SURROUNDING LATTICE; LARGE ATOME → COMPRESSIVE STRAIN.

3) STRAIN HARDENING:

- PLASTIC DEFORMATION → INCREASE OF DISLOCATIONS DENSITY → BLOCK OF MOVEMENT OF DISLOCATIONS
- THEREFORE A METAL ALREADY DEFORMED IS LESS EASY TO DEFORM AGAIN.



- AT σ₁: SUFFICIENT STRENGTH TO START THE FIRST DISLOCATIONS TO MOVE;
- THE DISLOCATIONS MOVE AND MULTIPLY.
- REMOVED THE LOAD; AN ELASTIC RECOVERY FOLLOWS;
- WE CAN DO THIS MANY TIMES;
- AT EACH CYCLE THE LOAD NECESSARY TO TRIGGER THE PLASTIC DEFORM. INCREASES.

4) PRECIPITATION OF A SECOND PHASE

- ALLOYING ELEMENT ARE (INSERTED) BEYOND THE SOLUBILITY LIMIT → PRECIPITATION OF A SECOND PHASE.
- THE DISLOCATIONS MOVE HARDLY IN THE SECOND PHASE;

PRECIPITATION HARDENING (OR AGE HARDENING) MECHANISM:

IT IS A HEAT TREATMENT CONSISTING OF 3 STEPS: SOLUTION HEAT TREATING, QUENCHING AND AGING.
SOLUTION TREATMENT: THE ALLOY IS HEATED AT A T (SOLUBILIZATION T), SLIGHTLY LOWER THAT T_E; TO BETTER UNDERSTAND (EXPLAIN), LET'S CONSIDER FOR EX. THE Al-Cu DIAGRAM.
WE ARE ENTERED IN κ FIELD; WE WAIT FOR COMPLETE SOLUBILIZATION OF THE θ PHASE (Al_2Cu);

- θ DISAPPEARS AND κ PHASE IS ENRICHED OF Cu. THIS STEP REQUIRES LONG SOLUBILIZATION TIME BECAUSE THE ATOM OF Cu IS LARGE AND THE T IS NOT SO HIGH (≈ 8÷10h).
- THEN WE QUENCH: THERE ARE NO TRASFORMATION OF PHASE; WE BLOCKED THE HIGH T SITUATION.
- ROOM T: WE HAVE OBTAINED A METASTABLE SOLID SOLUTION THAT WILL TRY TO SEND OUT THE EXCESS OF Cu OVER THE TIME.
- NATURAL AGING TIME (AT ROOM T) IS VERY LONG; DURING THIS PROCESS INTERMEDIATE METASTABLE PRECIPITATES ARE FORMED; THESE PRECIPITATES LEAD TO AN IMPORTANT INCREASE IN MP.
- WHEN THE AGING IS COMPLETED WE GET A SOLID SOLUTION κ+θ WITH CONTENTS REQUIRED BY THE STATE DIAGRAM.
- WE CAN ACCELERATE THIS PHASE (AGING) BY INCREMENTING THE T ⇒ ARTIFICIAL AGING.

RECRYSTALLIZATION

- COLD/HOT WORKING + RECOVERY ( HOT ROLLING)

- AFTER HAVING PLASTICALLY DEFORMED THE MATERIAL WE HAVE OBTAINED AN INCREASE IN DISLOCATIONS DENSITY; SO AN INCREASE IN RESISTANCE (STRAIN HARDENING).

RECOVERY

1) THE COMPONENT (STRAIN HARDENED) IS PLACED INTO THE FURNACE AT HIGH T FOR SOME TIME.
2) AFTER A CERTAIN TIME THE MATERIAL TENDS TO REACH A SITUATION OF LOWER ENERGY. SOME DISLOCATIONS START TO MOVE, SOME TO OVERLAP AND CANCEL. RESULT: THERE WILL BE AREAS WHERE THE NUMBER OF DISLOCATIONS DECREASES AND AREAS IN WHICH THEY WILL CONCENTRATE.
→ CELL FORMATION (NW: THEY ARE NOT CRYSTALLINE GRAINS).
3) THE DISLOCATIONS IN THE CELLS DISAPPEAR (THE OTHER DISL. ARE NOT YET ORIENTATED).
4) START OF FORMATION OF SUBGRAINS. IN THE "WHITE" AREAS WE HAVE REACHED THE MINIMUM OF DISLOCATIONS FOR THE MINIMUM ENERGY OF THE MATERIAL. IN THE AREAS WITH THE HIGHEST CONCENTRATION THE DISLOCATIONS DECREASE IN NUMBER AND START TO ORIENT THEMSELVES DEFINING THE EDGES OF THE SUBGRAINS.
5) HIGH EDGES MEANS HAVING HIGH SURFACE ENERGY. TO DECREASE THE ENERGY WE HAVE TO GROW THE SUBGRAINS BY DECREASING THE NUMBER OF EDGES.

→ THIS IS THE STARTING POINT FOR THE NUCLEATION OF NEW CRYSTALLINE GRAINS WITH A LOW CONTENT OF DISLOCATIONS INSIDE THEM.

RECRYSTALLIZATION TIME DEPEND ON TEMPERATURE, T MUST BE: $\frac{T_M}{3} < T < \frac{T_M}{2}$ (IF $T > \frac{T_M}{2}$ THE MATERIAL RECRY. EVEN IF IT HAS NOT BEEN DEFORMED)

RECRYSTALLIZATION ENERGY = WORK HARDENING ENERGY + HEATING ENERGY

1. POWDER METALLURGY

- WHICH IS THE INFLUENCE OF GRAIN SIZE OF THE POWDERS IN THE COMPONENTS OBTAINED AFTER COMPACTING IN PM TECHNOLOGY?

(→ INFLUENCE ON PARTICLE DIMENSION → GREEN DENSITY, APPARENT DENSITY AND GREEN STRE)

FINER GRAINS → HIGHER σ_y AND LOWER ε ⇒ POWDER HARDER TO DEFORM (HIGH σ_{max}) AND TO COMPACT (LOW ε). ⇒ THE COMPRESSIBILITY DECREASES.

IT IS HARDER TO OBTAIN FINE PARTICLES WITH AN OMOGENEUS COMPOSITION.

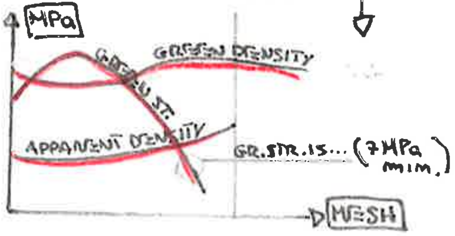
- WHICH IS THE INFLUENCE OF THE PARTICLE SIZE?

- THE PARTICLE SIZE AFFECTS THE FRICTION BETWEEN PARTICLES
- THE FRICTION AFFECTS THE ABILITY OF A POWDER TO FLOW READILY AND PACK TIGHTLY.
- SMALLER PARTICLE SIZES GENERALLY SHOW GREATER FRICTION (STEEPER ANGLE IN THE TEST OF "THE ANGLE OF REPOSE (α)").

→ IT AFFECTS THE COMPRESSIBILITY, THE POROSITY, SO THE SHRINKAGE THEREFORE, THE FINAL OBTAINABLE MP.

→ SMALLER PARTICLES → LESS POROSITY → HIGHER STRENGTH.

$$\text{PARTICLE SIZE} = \frac{1}{\text{GREEN STRENGTH}}$$



- COMPACTING: PRESSING IN RIGID DIES, ISOSTATIC PRESSING IN FLEXIBLE DIES, ROLLING COMPACTING FOR RIBBONS AND SHEETS AND INJECTION MOULDING. ADV. AND DISADV.?

- PRESSING IN RIGID DIES: GRADIENT OF DENSITY IS DETECTED IN THE DIRECTION OF PRESSING.
- ISOSTATIC PRESSING IN FLEXIBLE DIES: OMOGENEOUS DENSITY BUT LOW PRODUCTIVITY → HIGH COST
- ROLLING COMPACTING: EASY TECHN. USED TO PRODUCE LARGE AMOUNT OF STRIP; LOW PRICE
- INJECTION MOULDING: FINER AND MORE ROUNDED PARTICLES ARE REQUIRED AND ALSO HIGH PERCENTAGE OF THERMOPLASTIC FILLER IS REQUIRED; HIGH COST OF THE MACHINE BUT HIGH PRODUCT. A HIGH SHRINKAGE IS DETECTED DURING SINTERING PROCESS (24–48 h INTO FURNACE).

RIGID DIE: THE PART GEOMETRY MUST PERMIT EJECTION;

- WHAT IS THE INFLUENCE OF COMPACTION PRESSURE?

COMPACTION PRESSURE ↗ ⇒ COMPACTIBILITY OF THE POWDERS ↗ ⇒ DENSITY ↗ POROSITY ↘ ⇒ MP ↗

- DESCRIBE THE MAIN FEATURES OF PM IN COMPARISON TO WROUGHT TECH.

BASIC PRINCIPLE OF PM: METAL PROCESSING TECH. IN WHICH PARTS ARE PRODUCED FROM METALLIC POWDERS. ENTIRE CYCLE OF PM: PREPARATION OF POWDER, MIXING, FORMING, SINTERING, SECONDARY OP, JOINING AND WELDING, HEAT AND/OR THERMOMECH. TREATMENTS → FINAL PRODUCT.
WE CAN PRODUCE A COMPONENT WITH A CERTAIN (CONTROLLED) LEVEL OF POROSITY.

WORKING TEMPERATURE: IT CAN WORK IN HIGH T SUCH AS FILAMENT OF TUNGSTEN; ALSO WROUGHT ALLOYS WORK AT HIGH T.

SURFACE FINISH: THE PRODUCT NEED A SURFACE FINISHING.

MECHANICAL RESISTANCE: MP. DEPEND MOSTLY ON LEVEL OF POROSITY, SECONDARILY ON CHEMICAL COMP AND SINTERING CONDITIONS; ITS STRENGTH AND TOUGHNESS ARE LESS THAN WROUGHT TECHN.

SHAPE COMPLEXITY: WE CAN PRODUCE COMPLEX GEOMETRY SHAPE PART WITH PM LIKE FILAM. OF W.

POSSIBLE DEFECTS: CRACK, BRITTLENESS.

- ADVANTAGES AND DISADVANTAGES OF PM TECHNOLOGY:

ADVANTAGES:
- NEAR NET AND COMPLEX SHAPES;
- NO WASTE;
- CONTROLLED LEVEL OF POROSITY;
- DIMENSION CONTROL;
- PM PRODUCTION METHOD CAN BE AUTOMATED; FOR ECONOMICAL PRODUCTION;
- PARTS OF UNUSUAL METAL (LIKE Cu+GRAFITE) ARE ALLOWED;

DISADVANTAGES:
- POWDER NOT EASY TO HANDLE;
- GEOMETRIC AND SIZE LIMITS;
- DENSITY VARIATION.

3. STAINLESS STEELS

- AISI 304, 316, 316L, 409L, 304L / 409, 446 / 410, 431, 440A, 604, 604L / 2304, 2205 / 17-4 PH SS

(IN ZIN)

AUSTENITIC SS

304 : BASIC GRADE : 18% CR - 8% Ni : EX : 0.08% C - 19% CR - 9% Ni - 2% Mm : σ_y = 205 [MPa] ; A% = 40%
EX OF APPL : CRYOGENIC VESSEL ; 304Ⓛ → LOWER % C σ_R = 515 [MPa]
ANNEALED

316 : 0.07% C - 17% Cr - 12% Ni - 2% Mm - 2% Mo : σ_y = 200 [MPa] ; σ_R = 500 [MPa] ; A% = 40%
316L : 0.03% C - 17% Cr - 12% Ni - 2% Mm - 2% Mo : σ_y = 170 [MPa] ; σ_R = 485 [MPa] ; A% = 40% (LOWER % C)

409L : SUPER AUSTENITIC SS (Ni > 20%) | 316L ALSO KNOWN AS: AISI 4406 OR 1.4406 | EX. APP: WELDING CONSTRUCTIONS

FERRITIC SS

409 : 0.08% C - 11.5% Cr - 0.5% Ni - 1% Mm - 0.75% Ti (ANNEALED) σ_y = 205 [MPa] ; σ_R = 380 [MPa] ; A% = 20%
EX. APPLIC: AUTOMOTIVE EXHAUST COMP, TANKS FOR AGRICOLTURAL SPRYS

446 : 0.2% C - 25% Cr - 1.5% Mm (ANNEALED) σ_y = 275 [MPa] ; σ_R = 515 [MPa] ; A% = 20%
EX APPL. : HIGH T APPL. VALVES ; GLASS MOLDS ; COMBUSTION CHAMBERS

MARTENSITIC SS

410 : 0.15% C - 12.5% Cr - 1% Mm (ANN, Q&T) : σ_y = 620 [MPa] ; σ_R = 825 [MPa] ; A% = 12%
EX. APPL. : RIFLE BARRELS, CUTLERY, JET ENGINE PARTS

431 : 0.2% C - 16% Cr - 1% Mm - 2% Ni

440A : 0.7% C - 17% CR - 1% Mm - 1% Mo (ANN Q&T) : σ_y = 1650 [MPa] ; σ_R = 1750 [MPa] ; A% = 5%
EX. APPL. : CUTLERY, BEARINGS, SURGICAL TOOLS

604 : 0.2% C - 1% Cr - 0.5% Mm - 1% Mo
APPL : HIGH STRENGTH AND HIGH T APPLICATIONS

DUPLEX SS

2304 : 23% CR - 4% Ni

2205 : 22% Cr - 5% Ni

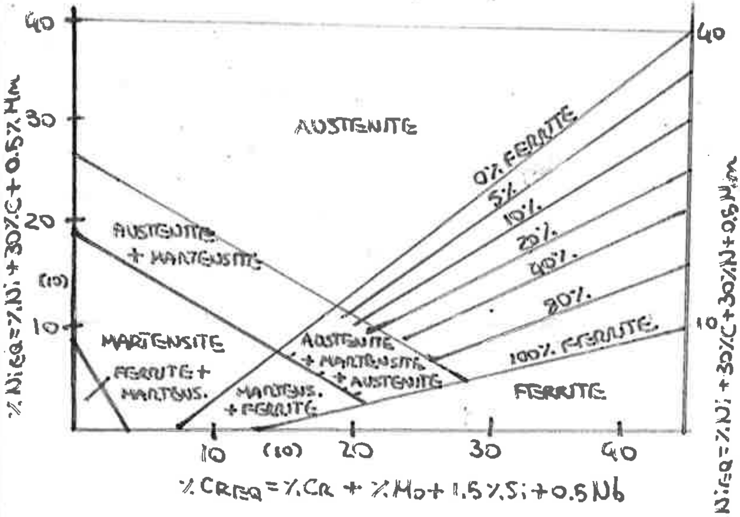
APPLICATIONS: PETROLEUM TANKERS, PRESSURE VESSELS, PROCESS EQUIPMENT

PRECIPITATION HARDENING SS

17-4 PH SS : 0.09% C - 17% Cr - 4% Ni - 4% Cu - 0.3% Nb | ALSO KNOWN AS GRADE 630

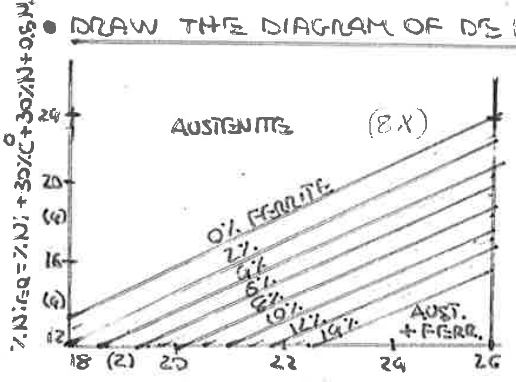
17-7 PH SS : 0.09% C - 17% Cr - 7% Ni - 1% Mm - 1% Al (PH) : σ_y = 1310 [MPa] ; σ_R = 1450 [MPa] ; A% = 1-6%
EX. APPL. : KNIVES, SPRINGS, PRESSURE VESSELS

- DRAW THE SHAEFFLER'S DIAGRAM.

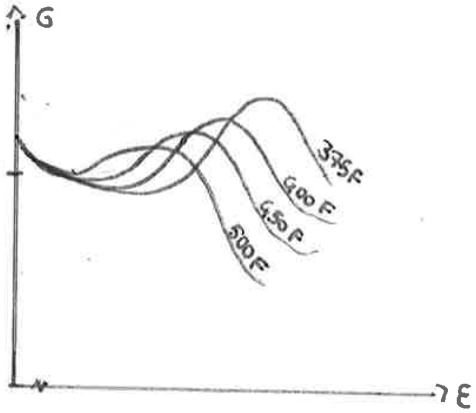


- IT IS USED TO UNDERSTAND WHAT HAPPENS WHEN WE WELD.
- WE HAVE TO CHOOSE ADDITIONAL ELEMENTS IN ORDER TO AVOID THE "CORNERS" IN THE S.D.
- MOST OF SS SHOW A CERTAIN % OF α ...

- DRAW THE DIAGRAM OF DE LONG



- DRAW THE TENSILE STRENGTH CURVE OF THE AA2014-T6 ALLOY FOR DIFF. AGING COND.

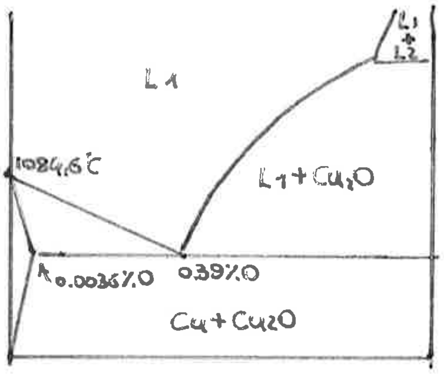


6. Cu-ALLOYS

NOTE: TO INCREASE THE WORKABILITY OF Cu WE ADD THE LEAD (Pb) IN ALLOY.

DESIGNATION: C 20 900 → 1 = PURE Cu
↓ COPPER ALLOY 2 = Cu-Zn
3 = Cu-Zn-Pb

Cu-Cu2O DIAGRAM



- OXYGEN HAS A VERY LOW SOLUBILITY IN Cu-ALLOY (MAX %O = 0.0036%)
- THEREFORE A LITTLE PERCENTAGE OF O INDUCES PRECIPITATION OF OXIDES (Cu2O)
- Cu2O DECREASES THE ELECTRICAL CONDUCTIVITY
- IT IS NECESSARY TO ADD A DEOXIDER: EX P (P CATCHES O AND THE RESIDUAL P CAN SOLVE)

DEOXIDERS:

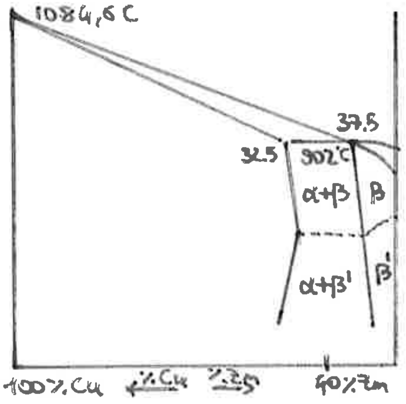
Li, Na, Be, Mg, B, Al, C, Si, P

Ca, Mg, Zn SOMETIMES; USUALLY OTHER ROLES

Cu-Sn ← P

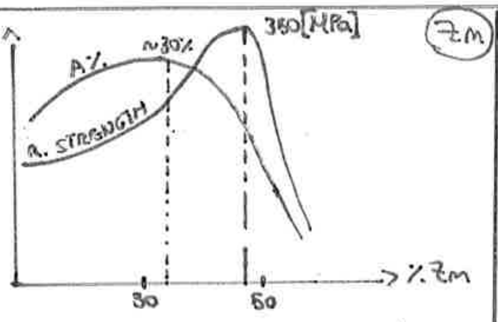
Cu-Cr ← Si

Cu-Zn DIAGRAM

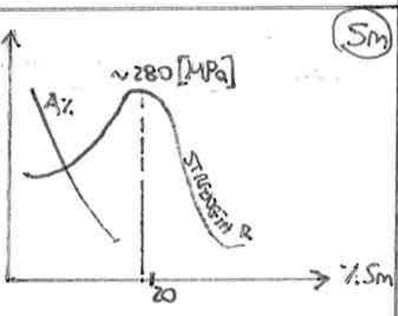


HIGH T: β → DISORDERED BCC (RANDOM DIST. OF Zn)
β' → ORDERED BCC: LOWER DEF, HIGHER STRENGTH
↓
BRITTLE

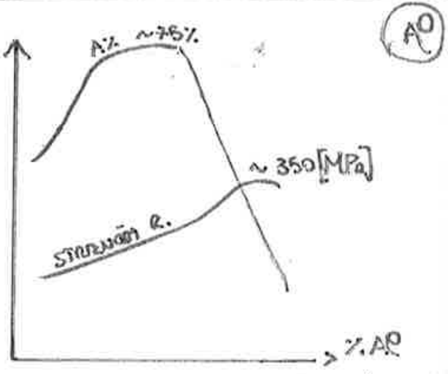
EFFECT OF:



- UNTIL ~35% Zn: Zn↑ ⇒ STR.↑; A%↑



Sn↑ ⇒ STRENGTH↑; A%↘



- UNTIL ~ 9÷10% Al: Al↑ ⇒ S↑; A%↑

7. Ti-ALLOYS

- 'IN THE CASE OF Ti-6Al-4V ALLOYS, HOW CAN HT AFFECT THE MP OF THE COMPONENT?

-> [7.28] ← ([B])

B. DEEP DRAWING STEELS

STRAIN HARDENING COEFF. (K), (m)

IN THE PLASTIC ZONE:

$\boxed{\sigma = K\varepsilon^m}$ HOLOMON EQ.

$\begin{cases} K = \text{S.H. COEFF.} \\ m = \text{S.H. EXP.} \quad (0<m<1) \end{cases}$
- $m = 0 \Rightarrow \sigma = K$ -> DEFORMATION WITHOUT STRAIN HARD. (BRITTLE CRACK)
- $m = 1 \Rightarrow \sigma = K\varepsilon$

RELATIONSHIP BETWEEN (ε) AND (m):

$P = \sigma \cdot A$

AT PMAX -> $dP = d\sigma \cdot A + \sigma dA = 0 \rightarrow \frac{d\sigma}{\sigma} = -\frac{dA}{A}$ (1)

$V = AL = \text{cost} \rightarrow dV = dAL + AdL \rightarrow \frac{dA}{A} = -\frac{dL}{L} = -d\varepsilon$ (2)

COMBINING (1) AND (2) WE OBTAIN:

$$\frac{d\sigma}{\sigma} = -\frac{dA}{A} = d\varepsilon \Rightarrow \frac{d\sigma}{d\varepsilon} = \sigma$$

IN CASE OF PLASTIC STRAIN: $\sigma = K\varepsilon^m$ AND SUBSTITUTING:

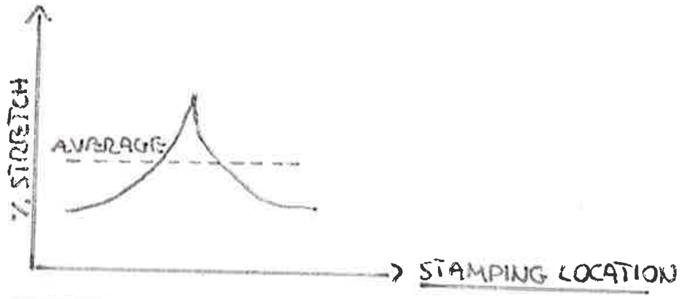
$$mK\varepsilon^{m-1} = K\varepsilon^m$$

AND THEN:

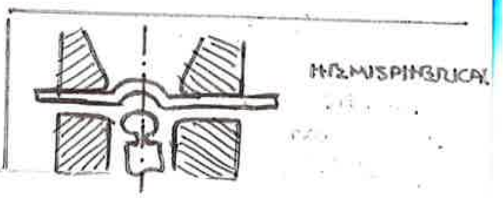
$\boxed{m = \varepsilon}$ ← THIS RELATIONSHIP INDICATES THAT IT IS POSSIBLE TO HAVE A MATERIAL WITH HIGH STRAIN ε, IF SUCH MATERIAL HAS HIGH m.

STRAIN GRADIENTS

THE METAL BECOME STRONGER IN THE HIGHER DEF. ZONE AND REDUCES THE TENDENCY FOR LOCALIZED THINNING, THE SURFACE DEFORM. BECOMES MORE UNIFORMLY DISTRIBUTED



STRAIN GRADIENTS GROW IN HIGH STRESS AREAS OF THE STAMPING.



ERIKSEN TEST

- IN THIS TEST A PLANE SHEET IS DEFORMED WITH A PUNCH IN ORDER TO OBTAIN HEMISPHERIC SHAPE.
- THE TEST STOPS WHEN A CRACK APPEARS IN THE SHEET (NORMALLY IN THE CENTRE) DURING THE DEFORMATION.
- THE RESULT IS THE VERTICAL DISPLACEMENT OF THE PUNCH IN [mm].

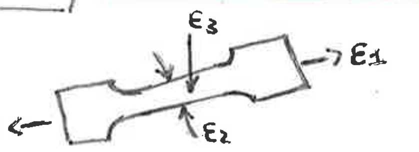
{IN TENSILE TEST -> ε_1

{~~IN ERIKSEN TEST -> $\varepsilon_2/\varepsilon_3$~~ = R F!

$\boxed{R = \frac{\varepsilon_2}{\varepsilon_3} = \ln\frac{(b/b_0)}{(a/a_0)}}$ COEFF. OF ANISOTROPY = SHRINKAGE = THICKNESS DECREASE

NW: FOR DEEP DRAWING AND HIGH STRENGTH STEELS IT IS REQUIRED THAT R>1

$\boxed{R_m = \frac{(R_0 + R_{45} + R_{90})}{4}}$ NORMAL ANISOTROPY RATIO (DETERMINED R ALONG 3 DIRECTIONS IN THE PLANE OF THE SHEET)

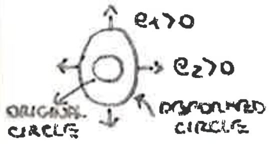


SHEET METAL FORMING

IN ORDER TO ANALYSE THE DEFORMABILITY OF THE SHAPE OF A METALLIC MAT, A NETWORK MESH IS PAINTED ON UNDEFORMED SURFACE.
THREE POSSIBLE CONDITIONS CAN BE OBTAINED:

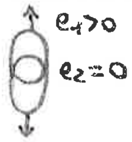
a) STRETCHING :

- WHEN THE SHEET IS POSITIVE STRAINED IN THE TWO DIRECTIONS IN THE PLAIN OF THE FOIL



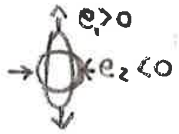
b) ONE DIRECTION DEFORMATION

- WHEN THE SHEET IS DEFORMED IN ONLY ONE DIRECTION.



c) DRAWING

- WHEN THE SHEET HAS A POSITIVE DEF. IN ONE DIRECTION AND A NEGATIVE ONE IN THE OTHER.



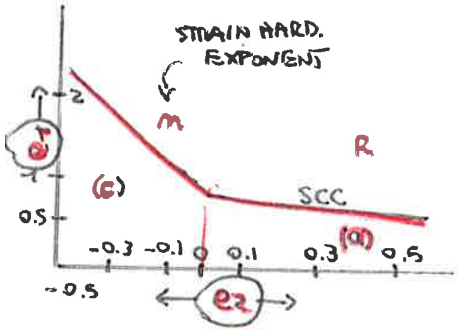
WE CAN DEFINE : $\boxed{\theta_1 = \frac{d-d_0}{d_0} > 0 \text{ ALWAYS}}$, WHILE THE SIGN OF θ_2 DEPENDS ON THE DEFORMATION TYPE. (a, b, c)

NAKAZIMA TEST

- IT PROPOSES TO INDUCE ON A METALLIC MAT. TO BE DEFORMED **ALL THE POSSIBLE TYPES OF DEF.** (a, b, c)
- A **PUNCH** WITH **HEMISPHERICAL SHAPE** IS ADOPTED TO DEFORM SAMPLES OF CONTROLLED GEOMETRY UNTIL THE TEARING APPEARANCE OR UNTIL CRACK STARTS IN THE MAT.
- **THE FIRST SAMPLE** HAS **SQUARE GEOMETRY** AND THE **BLANK** HOLDER ON THE **FOUR SIDES** (DRAW a, b, c)

THE SAFETY STRAINING CURVE (SSC)

- IT IS CONSTRUCTED WITH ALL THE COUPLED (e_1, e_2) VALUES OBTAINED IN MANY SAMPLE AFTER NAKAZIMA TESTS.
- THE **RIGHT** SIDE OF THE DIAGRAM IS THE **STRETCHING ZONE** (a) $(e_2>0)$
- THE **LEFT** SIDE OF THE DIAGRAM IS THE **DEEP DRAWING ZONE** (c) $(e_2<0)$
- THE SSC DEPEND ON THE THICKNESS AND ARE CHARACTERISTIC OF EVERY MATERIAL.
- THEY ARE VERY USEFUL TO DESIGNERS TO CHOOSE THE MORE APPROPRIATE MAT. FOR THE DIFFERENT COMPONENT (FROM THE POINT OF VIEW OF THE DEFORMABILITY).



- OVER SSC : THE MAT IS **DEFORMED** AND **REACHES THE NECK** THUS DAMAGING THE MAT.
- IMMEDIATELY BELOW SSC : THE MAT. IS NEAR THE NECKING CONDITIONS → **CRITICAL BAND**
- IT IS POSSIBLE TO OBTAIN A MATHEMATICAL RELATIONSHIP IN THE RIGHT SIDE (a) WITH COEFF OF ANISOTROPY Ⓡ, OR IN THE LEFT SIDE (c) WITH THE STRAIN HARDENING EXPONENT Ⓜ

C. SURFACE HARDENING

RECOMMENDED PRODUCTION CYCLE:

1. QUENCHING AND TEMPERING THE COMPONENT!
2. MACHINING!
3. SURFACE HARDENING: 3.1: HEATING, AUSTENITIZING OF SURFACE LAYER!
   3.2: QUENCHING -> MARTENSITE LAYER!
   3.3: LOW T TEMPERING -> STRESS RELIEVE!

PARAMETERS:

- TYPICAL STEEL: 0.4-0.6% C LOW ALLOYED.
- AUSTENITIZED LAYER DEPTH FLUX ≈ 1 [mm]
- HEAT FLUX ≈ 2 [kW/cm^2]
- QUENCHING: ADDITIVE WATER.

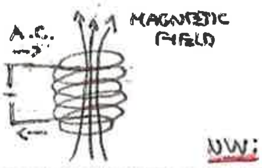
SURFACE HARDENING METHODS:

A) INDUCTION HARDENING
B) CARBURIZING
C) NITRIDING

A) INDUCTION HARDENING

- MAGNETIC FIELD AND INDUCED CURRENT PRODUCED BY AN INDUCTION COIL

A.C. CURRENT -> MAGNETIC FIELD -> EDDY CURRENT (THERMAL POWER)



NW: HIGHER FREQUENCY ↗ => LOWER DEPTH ↘

B) CARBURIZING

1. AUSTENITIZING (WHOLE SECTION); CARBURIZING (SURFACE LAYER) [T_{AUST}: 900÷950°C]
2. QUENCHING -> MARTENSITE LAYER!
3. LOW T TEMPERING -> STRESS RELIEVE!

CARBON CONTENT:

INITIAL/CORE 0.1-0.2% C
FINAL/CASE 0.8-1% C (IF HIGHER, RESIDUAL AUSTENITE!)

MICROSTRUCTURE:

- INITIAL: NOT IMPORTANT, USUALLY FERRITE + PEARLITE
- FINAL, CORE: USUALLY BAINITE, POSSIBLE MART/BAIN/FERR-PEARLITE;
- FINAL, CASE: MARTENSITE (POSSIBLY WITH SOME RETAINED AUSTENITE)

CARBURIZING AMBIENT

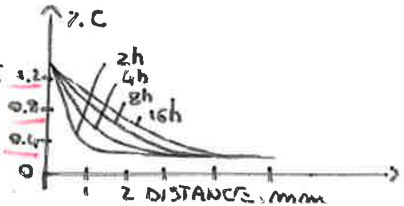
WE CAN CHOOSE BETWEEN:

- GAS CARBURIZING (MOST COMMON)
- LIQUID CARBURIZING;
- PACK CARBURIZING.

CONVENTIONALLY GAS CARBURIZING:

- PRESSURE = 1 [atm];
- GAS ATMOSPHERE: CO, CO_2, H_2, N_2 (FROM PARTIAL COMBUSTION OF METHANE);
- MAIN REACTION: $2CO \leftrightarrow C_{SOL} + CO_2$

CARBON % PROFILE VS TIME AT 925°C



D. HEAT TREATMENT

- WHICH ARE THE MOST IMPORTANT REASONS TO UNDERGO A STEEL TO QUENCH AND TEMPERING TREATMENT?

  –> TO INCREASE STEEL TOUGHNESS AND DUCTILITY

- DRAW THE CHANGE OF MECH. PROP. IN THE TEMPERING TREATMENT OF QUENCHED STEEL.

- PLOT THE QUENCH & TEMPER CYCLE OF THE AISI 4340 STEEL

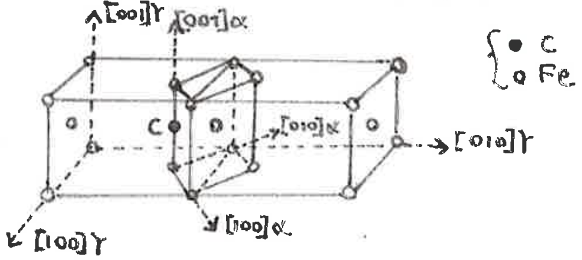
- PLOT THE THERMAL CYCLE IN ORDER TO QUENCH AND TEMPER A C70 STEEL

MARTENSITE

- IT FORMS WHEN AUSTENITE IS RAPIDLY (QUENCHED) TO ROOM TEMPERATURE.
- TRANSFORMATION FCC → BCT (MORE VOLUME!)
- LENTICULAR STRUCTURE
- VERY HARD AND VERY BRITTLE (INTERSTITIAL C) (800÷850 HV) (A%. ≈ 4%)

MARTENSITE TRANSFORMATION

- IT INVOLVES THE REORIENTATION OF C AND Fe ATOMS FROM THE FCC SOLID SOLUTION OF AUSTENITE (γ) TO A BODY-CENTERED TETRAGONAL (BCT) SOLID SOLUTION (MARTENSITE).
- IT IS AN ATHERMAL TRANSFORMATION (NO TERMAL ACTIVATION IS NEEDED; NO DIFFUSION) THE RAPID COOLING DOESN'T PERMIT THE TRANSF. FCC → BCC; THE C ATOMS DON'T HAVE TIME FOR DIFFUSION; THEREFORE THEY REMAIN IN INTERSTITIAL POSITIONS.
- IT IS NOT A CONDITION OF EQUILIBRIUM; INSIDE THE MAT. WE HAVE TENSION STATES.
- IF WE HAVE VERY LOW %C, WHEN WE COOL FROM AC_3^1 ($AC_3^1 = AC_3 + 50$) → T_{ROOM}, IT DOESN'T FORM MARTENSITE. WHAT WE OBTAIN IS SIMILAR TO α (BCC) WITH A HIGHER CONTENT OF C (→ LIGHT TENSION STATES)



- THEREFORE: HIGH T ($AC_3 + 50$) γ → (RAPID COOLING) → T' ≐ 200°C : MARTENSITE START
  IF %C OF THE ALLOY INCREASES ↗ ⇒ T' (T OF MART. START) ↘
  VICEVERSA, IF WE %C ↘ ⇒ T' ↗

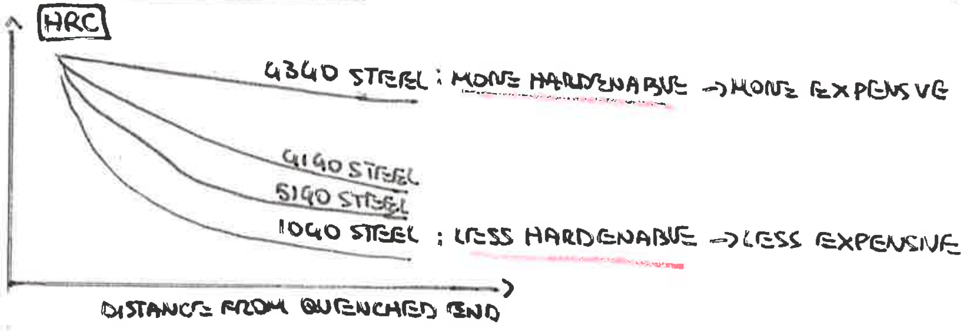
EFFECT OF ALLOYING ELEMENTS

- IF ALLOYING ELEMENT INCREASES ↗ ⇒ P+B NOSE SHIFT RIGHT
- THEREFORE, PLAIN C STEELS CAN'T BE HARDENED TO FORM MARTENSITE EXCEPT AT VERY HIGH COOLING RATES.

MEDIUM C STEELS

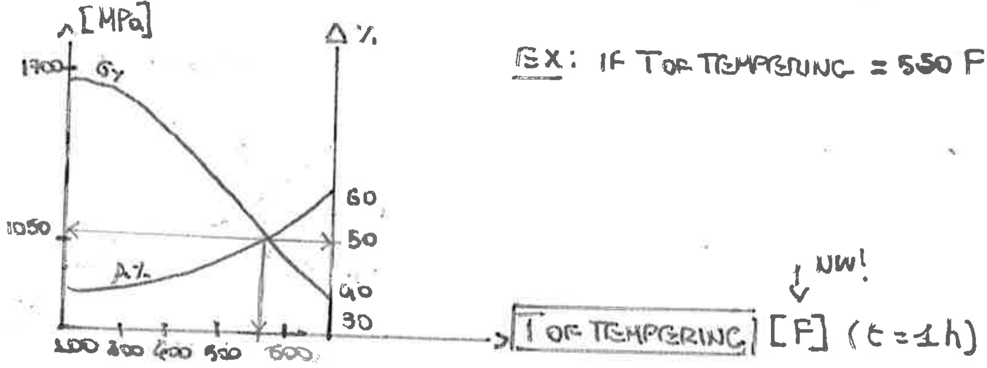
	BF TIME [S]
1040: 0.4%C + 1%Mn	800
5140: 0.4%C + 1%Mn + 0.9%Cr	200
4140: 0.4%C + 1%Mn + 1%Cr + 0.2%Mo	280
4340: 0.4%C + 1%Mn + 0.8%Cr + 0.3%Mo + 1.85%Ni	2000

TYPICAL JOMINY CURVES



TEMPERING

- MARTENSITE NEEDS TO BE TEMPERED TO INCREASE DUCTILITY.
- THIS HAPPENS WHEN Fe_3C IS ALLOWED TO PRECIPITATE.

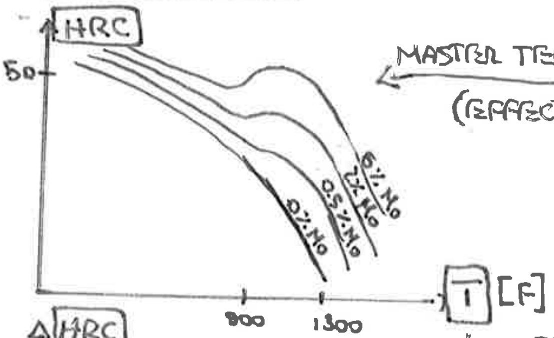


EX: IF T OF TEMPERING = 550 F → $\sigma_y \cong 1050$ [MPa] ; A% ≅ 50%

THE 4 STAGES OF TEMPERING:

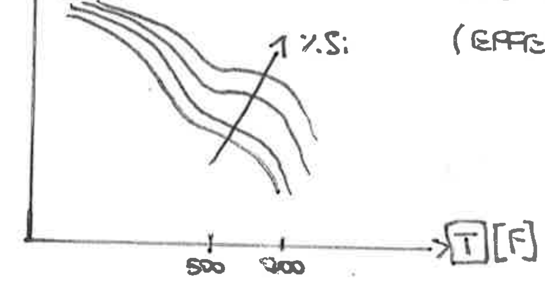
1) DURING 1ST STAGE, IF %C IS LOW (%C < 0.25%), THERE IS NO CHANGE IN HARDNESS.
   - ABOVE 0.25%C → HARDNESS OF MARTENSITE DECREASES.
   - EXAMPLE: T = 400 F (245°C)
   - E CARBIDES GO INTO SOLUTION AND THE STABLE IRON CARBIDE Fe_3C BEGINS TO SEPARATE FROM THE DECOMPOSING MARTENSITE.
   - THE ALLOYING ELEMENTS HAVE NO EFFECT ON FIRST-STAGE (EXCEPT C AND N).
2) - TRASFORMATION OF RETAINED AUSTENITE.
   - AUSTENITE TRANSFORMS IN BAINITE IN A PERCENTAGE THAT DEPENDS ON THE TTT CURVES.
   - THIS STAGE IS INFLUENCED BY ALLOYING ELEM.
3) - PRECIPITATION AND GROWTH OF Fe_3C FROM THE DECOMPOSED MARTENSITE THAT EXISTED AT THE END OF 1ST STAGE.
   - THIS STAGE IS INFLUENCED BY ALLOYING ELEM. (MOSTLY BY Si)
   - THE STEEL CAN EVIDENCE THE SO-CALLED "500F EMBRITTLEMENT".
4) - THIS STAGE INVOLVES THE PRECIPITATION OF ALLOY CARBIDES (WHEN THE STEEL CONTAINS THE ACTIVE CARBIDE-FORMING ELEMENTS SUCH AS, W, V, Mo AND Cr)
   - THIS INDUCES A INCREASE OF HARDNESS (RED HARDNESS) VERY USEFUL IN COMPONENT THAT MUST WORK IN HOT CONDITIONS. [800 ÷ 1300 F]!

RED HARDNESS



← MASTER TEMPERING CURVES (EFFECT OF Mo)

↳ OF TEMPERING

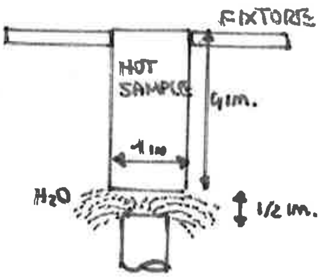


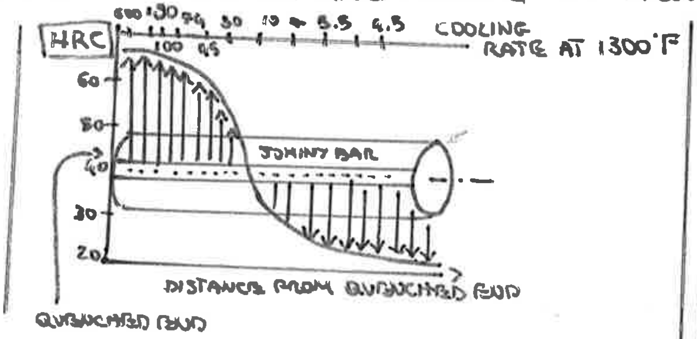
(EFFECT OF Si)

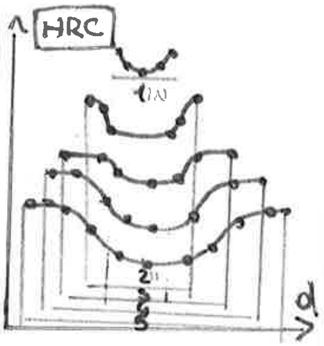
JOMINY METHOD

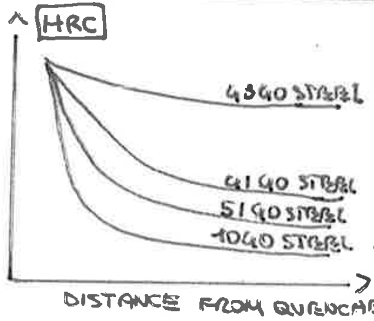
- BAR 1 [INCH] DIAMETER, 4 [INCHES] LENGTH;
- PLACE IN FIXTURE;
- WATER QUENCH OF SPECIMEN;
- AFTER COOLING → GRIND FLAT;
- MEASURE Rc ALONG LENGTH OF THE BAR;
- SECTION AND EXAMINE METALLOGRAPHY ALONG LENGTH TO DETERMINE MICROSTRUCTURE;
- CORRELATE MICROSTRUCTURES AND PROPERTIES;
- NOW → KNOWN COOLING RATE NEEDED TO GET A GIVEN PROPERTY.

→ CAN MAKE CCT DIAGRAM WITH QUANTITATIVE MICROSTRUCTURE AND HARDNESS.







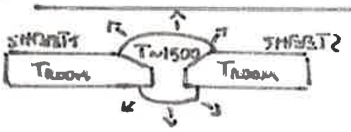


→ LESS HARDENABLE
→ LESS EXP.

⦿ WELDING :

$$\%C_{EQ} = \%C + \frac{\%Mn}{6} + \%\frac{(Cr+Mo+V)}{5} + \frac{(Ni+Cu)}{15}$$

- MOST IMPORTANT INFORMATION ON STEEL WELDING



- TO EVALUATE THE COOLING RATE : GROSSMAN INDEX $H = \frac{h}{2k}$

$H = \frac{h}{2k}$ h : GLOBAL CONDUCTION COEFF.
k : THERMAL CONDUCTION OF THE SHEETS

IN THIS CASE THE QUENCHING MEDIUM ANS THE 2 SHEETS ;
THEREFORE $h = k \Rightarrow H = 0.5$ (SIMILAR TO OIL QUENCHING + AGITATION)
A PROBLEM THAT CAN ARISE IS THE FORMATION OF MARTENSITE → CAN LEAD TO WELDING QUENCHING CRACKS.
THIS PROBLEM ARISE WHEN WE HAVE HIGH %C → HIGH PROBABILITY TO FORM M.

$\%C_{EQ} < 0.41$ GOOD WELDING PROPERTY
$0.41 < \%C_{EQ} < 0.45$ (WE HAVE TO DO ATTENTION TO THE H CONTENT)
$0.45 < \%C_{EQ} < 0.60$ WE HAVE TO PRE-HEAT THE SHEETS, AND USE ELECTRODES WITH LOW CONTENT OF H.
$\%C_{EQ} > 0.60$ WE MUST USE SPECIAL TECNIQUES !!

⦿ TOOL STEELS

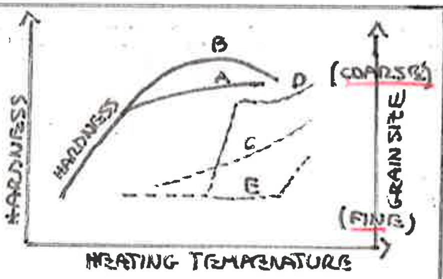
- WHAT IS MARAGING STEEL ?

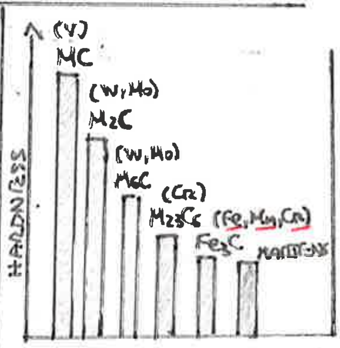
- THEY ARE IRON ALLOYS KNOWN FOR POSSESSING SUPERIOR STRENGTH AND TOUGHNESS WITHOUT LOSING MALLEABILITY.
- THESE STEELS ARE A SPECIAL CLASS OF LOW %C ULTRA-HIGH STRENGTH
- THEIR STRENGTH DERIVES NOT FROM CARBON (C) BUT FROM PRECIPITATION OF INTERMETALLIC COMPOUNDS.
- PRINCIPAL ALLOYING ELEMENT : $\boxed{15 \div 25\%\ Ni}$
- OTHER ALLOYING ELEMENTS : Mo, Co, Ti : TO PROVIDE INTERMETALLIC PRECIPITATION

- WHICH IS THE CRITERION OF AUSTENITIZING T. CHOICE IN TOOL STEEL TREATMENT ?

- THE AUSTENITIZING T INFLUENCES :
  - HARDNESS AFTER QUENCH.
  - AUSTENITE GRAIN SIZE;
  - MARTENSITE FORMATION;

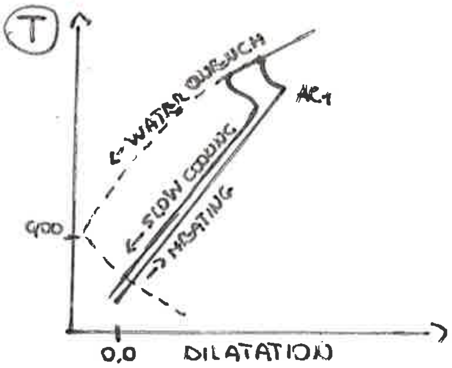
A) IN SOME CASES THE HARDNESS EVIDENCES AN ASYMPTOTIC TREND,
B) IN OTHER CASES IT REACHES A MAXIMUM AND THEN DECREASES
C, D, E) THE GRAIN SIZE CAN GROW ACCORDING THE DASH LINES.

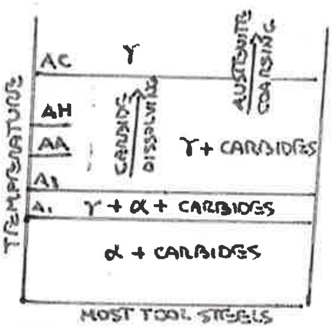




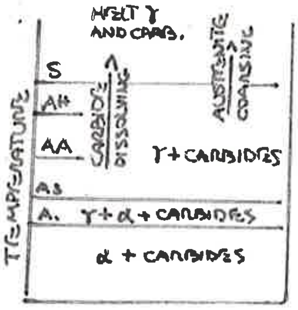
DILATATION CURVES

- AUSTENITE IS DENSER THAN ANY OF ITS TRANSFORMATION PRODUCTS
- THEREFORE STEEL UNDERGOES A VOLUME EXPANSION WHENEVER γ TRANSFORMS.



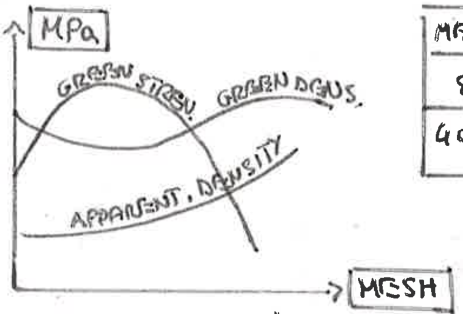


MOST TOOL STEELS
AA : AUSTENITIZING TEMP.
AH : QUENCHING T TO OBTAIN HARDENING



HIGH SPEED STEELS

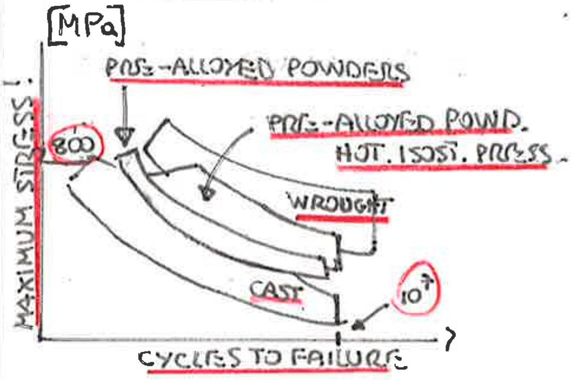
1. POWDER METALLURGY

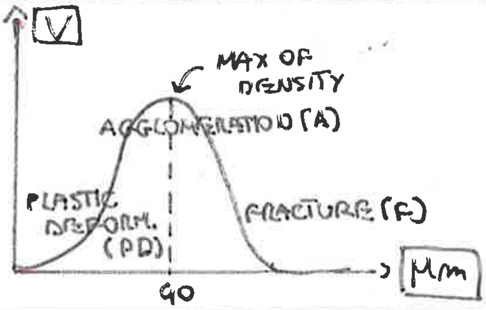


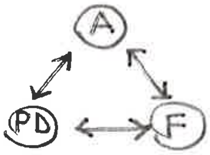
MESH	MICROMETERS
80	177
400	37

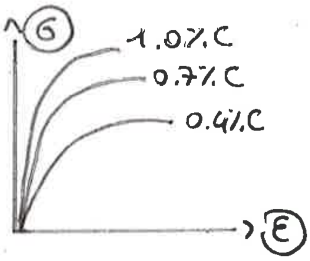
$$\text{PARTICLE SIZE} = \frac{1}{\text{GREEN STRENGTH}}$$

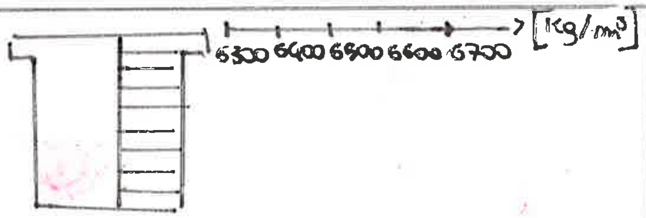
COMPARISON !!!!!!

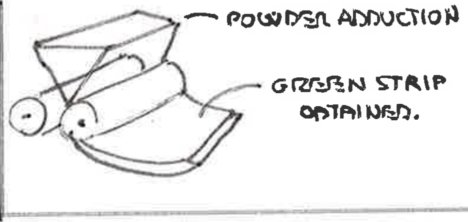




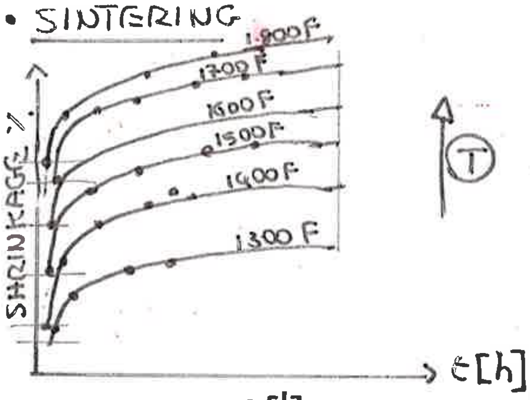




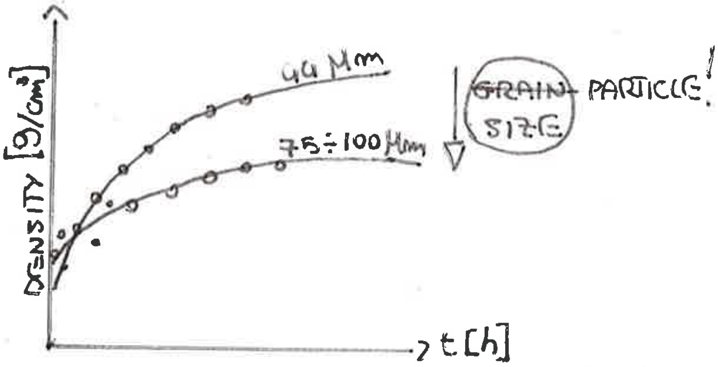




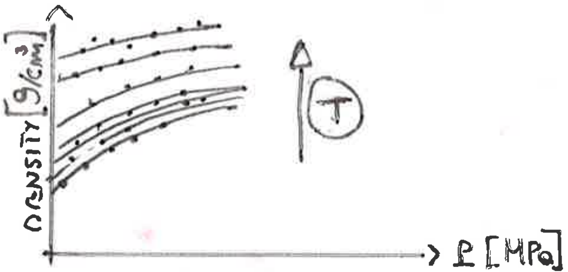
- SINTERING



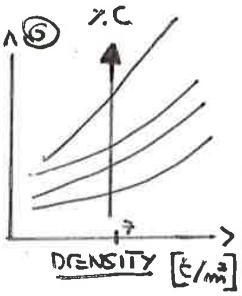
SHRINKAGE % - TIME [h] ; f(t,T)

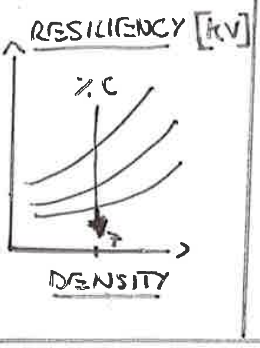


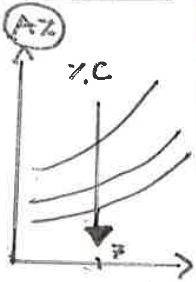
DENSITY [g/cm³] - TIME [h] ; f(t, SIZE)



DENSITY [g/cm³] - PRESSURE [MPa]; f(P,T)

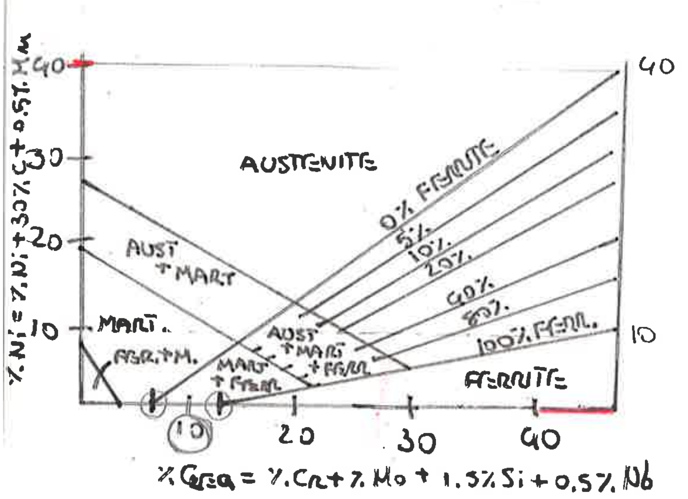




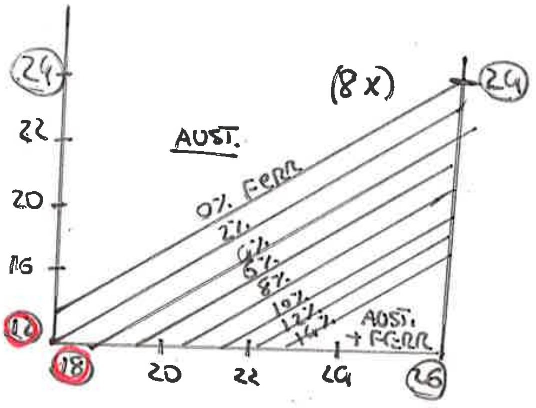


3. SS

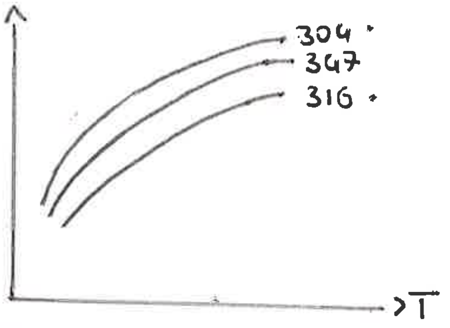
• SHAEFFLER'S DIAGRAM



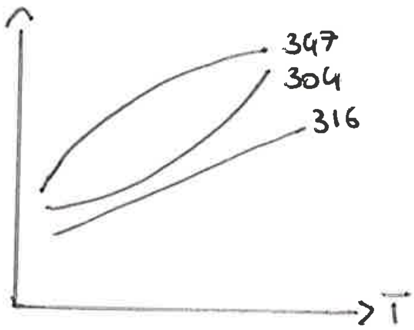
• DIAGRAM OF DE LONG



• THERM. COND. - T

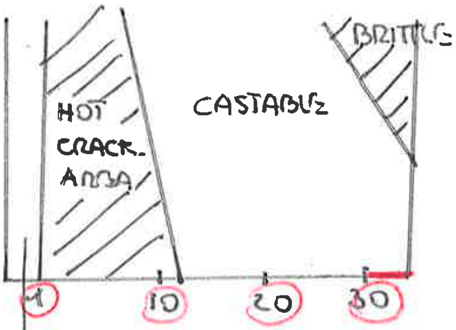


• THERMAL DIL. - T



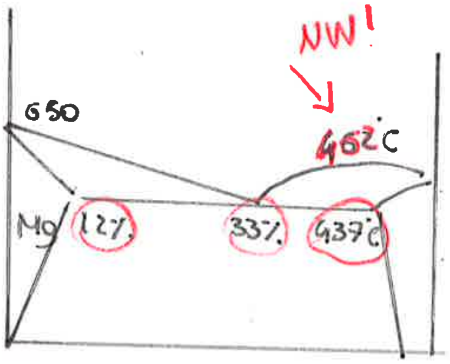
5. Mg - ALLOYS

• DIE-CASTING Mg-ALLOYS



↳ CASTABLE AZ91 D

• Mg - Al DIAGRAM

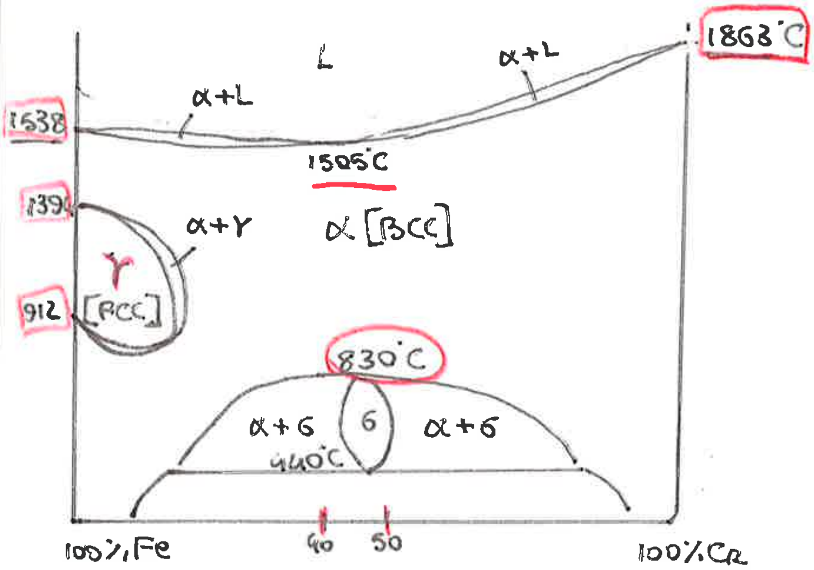


- Mg: T_M = 650°C
- Al: TM = 660,45°C
- T_E = 437°C $COMP_E$ ≅ 33%
- Mg MELT AT MOST 12% Al
- SOLID SOLUTION β

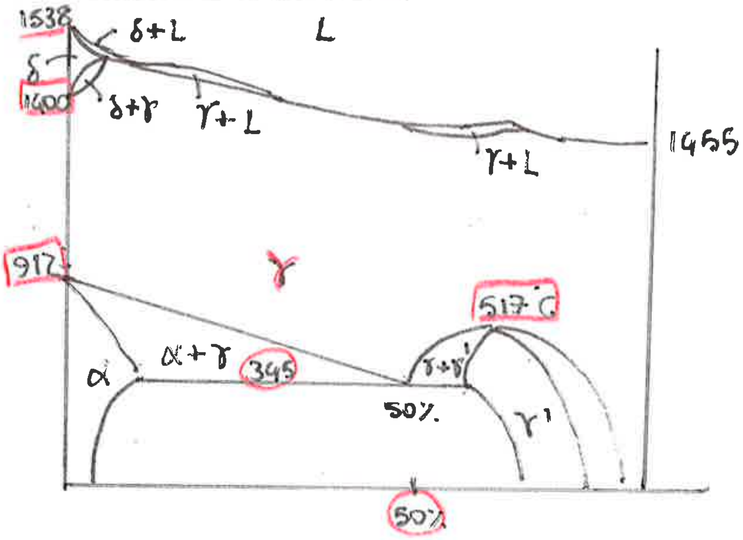
OTHERS

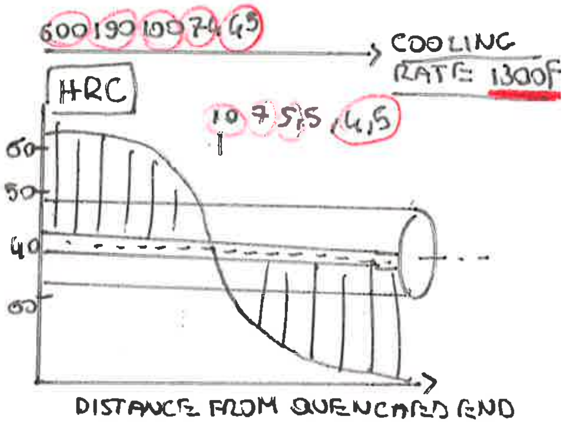
SS

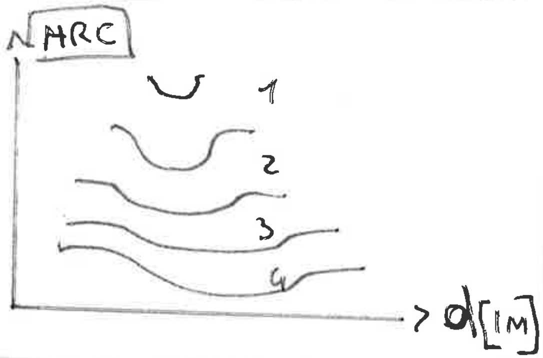
- Fe-CR DIAGRAM

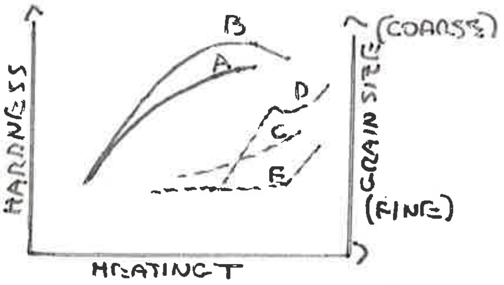


- Fe-Ni DIAGRAM

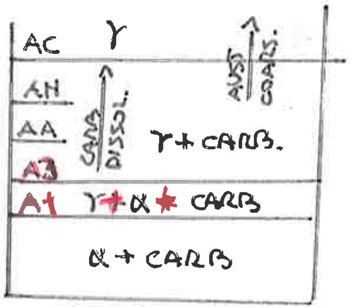








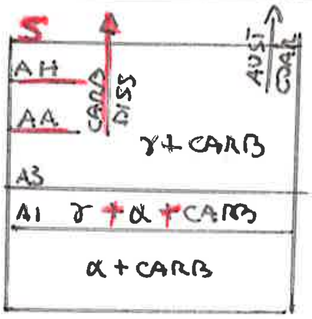
TOOL STEELS



MOST TOOL STEELS

AA : AUST.T

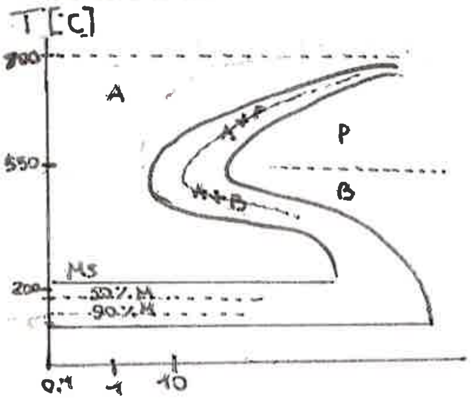
AH : QUENCH T TO OBT. M

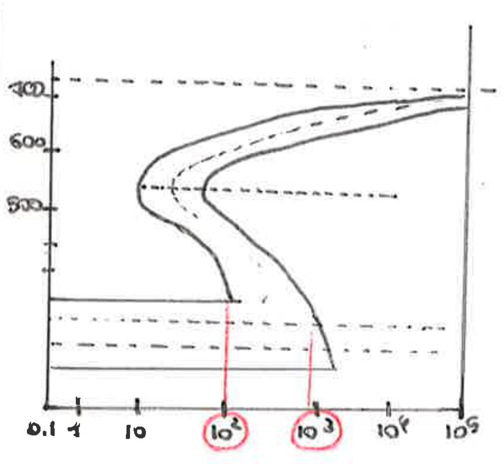


HIGH SPEED STEELS

D. HEAT TREATMENTS

TTT DIAGRAM





SPHEROIDITE

- SPHERICAL "GLOBS" OF Fe_3C
- THIS STRUCTURE IS OBTAINABLE WHEN: LONG TIME TEMPERING
- SPHERES OF Fe_3C FORMS AND GROW IN A FERRITIC MATRIX
- VERY SOFT, EASY TO MACHINE

PEARLITE

- LAYERS OF FERRITE (α) AND CEMENTITE Fe_3C;
- COARSE PEARLITE OR FINE PEARLITE

BAINITE

- IT'S NOT A PHASE: TWO MICROSTRUCTURES: $\alpha + Fe_3C$
- IT IS OBTAINABLE WITH MEDIUM COOLING RATE (NOT TOO FAST NEITHER TOO SLOW);
- IT IS SIMILAR TO PEARLITE BUT IT'S STRONGER
- OBTAINABLE T RANGE: 250÷550°C
- UPPER BAINITE: (550÷350°C) $\alpha + Fe_3C$: RODS OF Fe_3C
- LOWER BAINITE: (350÷250°C) $\alpha + Fe_3C$: ACICULAR STRUCTURE.

STEEL:	B_F time [S]
1040	~ 800
5140	~ 200
4140	~ 280
4340	~ 2000

1040: 0.4% C + 1% Mn
5140: 0.4% C + 1% Mn + 0.9% Cr
4140: 0.4% C + 1% Mn + 1% Cr + 0.2% Mo
4340: 0.4% C + 1% Mn + 0.8% Cr + 0.3% Mo + 1.85% Ni

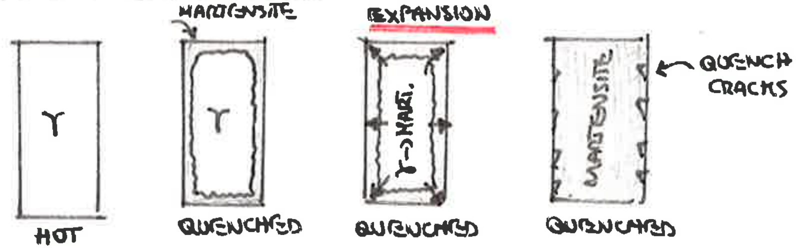
MARTENSITE

- IT IS NOT A STABLE PHASE. IT IS OBTAINABLE BY RAPID COOLING (QUENCHING) FROM AUSTENITE γ TO ROOM T.
- TRANSFORMATION: γ (BCC) → M (BCT) [BCT = BODY CENTERED TETRAGONAL ~~STRUCT.~~] (MORE VOLUME)
- LENTICULAR STRUCTURE.
- VERY HARD, VERY BRITTLE; HV ≅ 800÷850; A% ≅ 4%.

MARTENSITE TRANSFORMATION

- IT INVOLVES THE REORIENTATION OF THE ATOMS OF Fe AND C FROM THE FCC STRUCTURE OF THE SOLID SOL. γ TO THE BODY CENTERED TETRAGONAL SOLID SOLUTION (MARTENSITE)
- IT IS AN ATHERMAL TRANSFORMATION (NO THERMAL ACT. IS NEEDED, NO DIFF.)
- THE RAPID COOLING DOES NOT PERMIT THE TRASF.: FCC → BCC : THE ATOMS OF C HAVE NO TIME FOR THEIR DIFFUSION, SO REMAIN IN INTERSTITIAL POSITION.
- IT IS NOT A CONDITION OF EQUILIBRIUM: INSIDE THE MAT. → TENSION FIELDS ⇒ STRENGTH ↗
- IF % C IS VERY LOW WHEN WE COOL FROM AC3+50 → T ROOM WE DON'T OBTAIN MART. BUT SOMETHING SIMILAR TO α (BCC) WITH HIGHER CONC. OF C. (LIGHT TENSION FIELDS)
- THEREFORE: AC3+50 → RAPID COOLING → 220°C ~ Ms. IF %C ↘ ⇒ TMs ↘

QUENCHING CRACKS



HARDENABILITY

IT IS THE PROPERTY THAT DETERMINES THE DEPTH AND DISTRIBUTION OF HARDNESS INDUCED BY QUENCHING FROM AUSTENITE. IT DEPENDS ON:

- CHEMICAL COMP.
- AUST. GRAIN SIZE
- STRUCTURE OF STEEL BEFORE QUENCHING

IT IS DETERMINED BY

- GROSSMAN TESTING
- JOMINY METHOD

VOCABULARY:

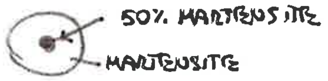
H = QUENCH SEVERITY FACTOR (OIL = 0.2 ; BRINE + AG. = 5)

D_0 = ACTUAL CRITICAL BAR DIAMETER TO OBTAIN 50% M IN THE CENTRE, KNOWN THE H

D_i = IDEAL CRITICAL BAR DIAMETER TO PRODUCE 50% M IN THE CORE WITH $H = \infty$ (IDEAL QUENCH).

GROSSMAN HARDENABILITY

- BARS OF DIFFERENT DIAMETERS QUENCHED IN DIFFERENT MEDIAS.
- THE BAR THAT WILL PRESENT 50% OF M. IN THE CORE WILL BE SELECTED AS THE BAR WITH THE CRITICAL DIAMETER D_0



- WE CONVERT $D_0 \rightarrow D_i$ IN ORDER TO ELIMINATE THE COOLING RATE VARIABILITY.
- $D_i = D\,(D = f(\%C, \text{GRAIN SIZE})) \cdot MF_1 \cdot MF_2 \cdot \ldots MF\,(MF = f(\%\ \text{ALLOYING ELEM}))$; MF = MULTIPLYING FACTOR (CONVENTIONALLY: +0.3%Si, 0.7%Mn)

IF %C ↑ ⇒ HARDENABILITY INCREASES

IN GENERAL IF ALLOYING ELEM. ↑ ⇒ HARD. INCREASES (EXCEPT FOR : S, Co, Ti)

S → (MnS); Co → (INCREASES THE RATE OF NUCLEATION AND GROWTH OF P.); Ti → (TiC)

JOMINY METHOD

1 - BAR 1 IN DIAMETER, 4 IN. LENGTH ;
2 - PLACED IN FIXTURE;
3 - WATER QUENCH OF SPECIMEN;
4 - AFTER COOLING → GRIND FLAT ;
5 - MEASURE RC ALONG LENGTH OF THE BAR;
6 - SECTION AND EXAMINE METALLOGRAPHY ALONG LENGTH TO DETERMINE MICROSTRUCTURE;
7 - CORRELATE MICROSTR. - PROPERTIES ;
8 - NOW → KNOW COOLING RATE NEEDED TO GET A GIVEN PROPERTY;
9 → CAN MAKE CCT DIAGRAM WITH QUANTITATIVE MICROSTR. AND HARDNESS;

40) The Aluminum alloy have high strength to density ratio **(T)**
41) The Mg alloy have high strength to density ratio. **(T)**
42) By continuous cooling of plain carbon steel 100% of bainite can be obtains **(F)**
43) The adding of Zn in Cu alloy increases their price. **(F)**
44) The deep drawing steel should have low n and r parameters. **(F) (For DDS gamma>1)**
45) The cast Al-Si alloys is generally used to produce engine piston. **(T)**
46) The cast Al-Si alloy is generally used to produce oil gear. **(F)**
47) The pitting corrosion is favored from Na$^+$ ions in solution. **(F)**
48) The pitting corrosion is favored from Cl$^-$ ions in solution. **(T)**
49) The normalizing treatment in steel is affected to improve deformability. **(F)**
50) The annealing treatment in steel is affected to improve deformability. **(T)**
51) The GP1 and GP2 metastable precipitations are detected in die casted Al-Si alloys. **(F)**
52) The GP1 and GP2 metastable precipitations are detected in sand casted Al-Si alloys. **(F)**
53) The AZ91 T5 is the designation of a magnesium alloy. **(T)**
54) The AM100 T5 is the designation of a magnesium alloy. **(T)**
55) There is define relationship between melting temperature and yield strength/ young's modulus. **(T)**
56) The pure metallic components generally evidence lower corrosion resistance than alloyed one. **(F)**
57) The pure metallic components generally evidence higher corrosion resistance than alloyed one. **(T)**
58) Which is the main roll of Zn in copper alloy.
   - It guarantees an anodic protection.
   - Stabilizes the FCC lattice arrangement at room temperature (With Zn %> 35)
   - **Reduce the price of the material**
   - Favors the cast-ability of brass alloy
   - **Increase Hardenability (Almost a certain percentage)**

59) Which is the main roll of Sn in copper alloy.
   - **It guarantees an anodic protection.**
   - It Stabilizes the FCC lattice arrangement at room temperature (S%)
   - It Reduce the price of the material
   - It favors the cast-ability of brass alloy
   - It Increase strength and deformability (Almost a certain percentage)
   - **It enhance the mechanical properties in solute heat-treating and ageing process**

60) In the case of wrought alloy which of the following assertions are true?
   - The wrought alloys are produced to evaluate steel hardenability
   - The cooling rate in casting affect the final wrought product properties
   - All the wrought components have to be quenched before being used
   - **This production technology reduces the component not homogeneity and porosity**
   - **These components can undergo to forging process**
   - The components product with wrought technology is cheaper than those from casting one

61) Which is the main role of Si in cast Iron?
   - **It is a graphite-forming element**
   - Increase the cast ability of cast iron alloys
   - It is the easiest way to increase the corrosion resistance
   - Stabilize FCC crystal lattice at room temperature
   - Enhance hardenability after quenching
   - Reduce the price of the grey cast iron alloys
   - **With Mg it enhance the toughness by optimizing C graphite shape and distribution.**

62) The σ_y of artificial aged 7XXX Al alloys are generally higher than that of 2XXX ones. **(T)**
63) Which is the main role of Cr in low alloy steel?
   - It is the easiest way to increase the corrosion resistance of steel
   - Stabilize austenite at room temperature
   - Increase the surface finishing properties
   - **It is a carbide-forming element**
   - **Enhance hardenability in solute heat-treating and quenching process**
   - Reduce the price of the steel

64) Which is the main role of Cr in stainless steel?
   - **It is the easiest way to increase the corrosion resistance of steel**
   - Stabilize austenite at room temperature

79) What is the technology application of this equation

$$\% \mathrm{Ceq} = \%\mathrm{C} + \%\mathrm{Mn}/6 + \%(\mathrm{Cr} + \mathrm{Mo} + \mathrm{V})/5 + \%(\mathrm{Ni} + \mathrm{Cu})/15$$

- In case of gray cast iron component production
- To define the family of stainless steel
- **In case of welding procedure**
- To evaluate the hardness of steel
- To define the types of copper alloy
- To evaluate the carbon percentage in plain C steel

80) What is the technology application of this equation

$$\%C\ eq = \%C + \%Si/3 + \%P/3$$

- In the case of welding procedure
- **In case of gray cast iron component production**
- To define the family of stainless steel
- To define the hardness of steel
- To define the types of copper alloy
- To evaluate the carbon percentage in plain C steel

81) The Nakazima technological test is affected to build the safe straining curve. **(T)**
82) The Ericksen index is the measure of anisotropic coefficient of sheet. **(F)**
83) What is the main role of Si in Al-Si cast alloy?

- It guarantee high deformability
- It favor the eutectic modification phenomena
- **It increase the cooling rate (certain percentage)**
- It is one of the most important deoxidizer
- **It enhance the toughness by optimizing Si particles shape and distribution**
- It reduce the price of metal

84) The TRIP steel have a certain amount of martensite that act as a "shock absorber" **(F)**
85) The cottrel atmosphere justifies the Luder's band in low C plain steel. **(T)**
86) The interstitial free steel has low C and Ti higher than 0.5 %. **(F) (Ti higher than 0.3%)**
87) The krupp problem are not connected with stainless steel production. **(T)**
88) In welding the filler material of stainless steel is plain carbon steel. **(F)**
89) The yield strength of AISI 410 SS in Q and T conditions reached the 600 MPa. **(T)**
90) Austenitic stainless steel has higher corrosion resistance than Martensitic SS. **(T)**
91) The duplex SS have the austenitic and bainite phase (50%-50%). **(F)**
92) The AISI 316L SS generally evidence pitting corrosion resistance. **(T)**
93) The austenitic SS evidence ferromagnetic properties. **(F)**
94) The inoculation procedure in commonly adopted in cast Cu alloy. **(F)**
95) The aluminum alloy has highest specific strength than as compare to (Ti, Fe, Cu alloy). **(F)**
96) The elements are highly deplete the electrical conductivity of Cu are Ag and Zn. **(F)**
97) The galvanic corrosion is avoided in single-phase components. **(T)**
98) Natural and artificial ageing is commonly apply to 3XXX, 4XXX and & 5XXX alloys. **(F)**

Some important point

- Alloying with 2% molybdenum (Mo) great increase pitting corrosion.
- Adding Al in bronzes (Cu-Sn) increase ductility and increases strength
- To increase the workability of Cu we add the lead (Pd) in copper alloy.
- Interstitial elements in Ti (Fe, C, N, O) increase the strength but also they decrease toughness.

8) What are the HSLA steels? Which are their most important features?

High strength and low alloy steel (HSLA) is types of alloy steel that provides better mechanical properties or greater resistance to corrosion than conventional carbon steel. They are designed to meet specific mechanical properties, such as yield strength greater than 275MPa rather than to obtain a specific chemical composition. They have a carbon content between 0.05–0.25% to retain formability and weldability.

9) Which are the strain hardening properties of Austenite, Ferrite and Martensitic stainless steel?

10) Can you explain the Martensitic transformation? Which mechanical properties can be obtained?

Martensite forms when austenite is rapidly cooled (quenched) to room temperature. The martensitic transformation involves the sudden reorientation of C and Fe atoms from the FCC solid solution of γ-Fe (austenite) to a body-centered tetragonal (BCT) solid solution (martensite). Since martensite is metastable non-equilibrium phase. The austenite-martensite does not involve diffusion → no thermal activation is needed, this is called an athermal transformation.

Martensite is the hardest, strongest and the most brittle. The strength of martensite is not related to microstructure. Rather, it is related to the interstitial C atoms hindering dislocation motion.

11) Wrought Aluminum alloy. Which are their characteristics and properties?

12) Which is the criterion of austenitizing temperature choice in tool steel treatment?

The austenitizing temperature influences the hardness (continuous line) after quench and the austenite grain size (dash line). In some case the hardness has an asymptotic trend (A) while in others it reaches a maximum a then decrease (B). The austenite grain sizes can respectively growth, according the lines C, D or E.

13) What is the influence of compaction pressure in the part proceed in powder technology?

Increase Compaction pressure provides better packing of particles and lead to decrease porosity. At higher pressure, the green density approaches density of bulk metal.

21) What does it happen in the artificial ageing of the 2024 aluminum alloy?

22) What does it happen in the artificial ageing of the 2014 aluminum alloy?

23) How do strength and elongation change it Zn wt. % increase in copper alloy?

Maximum solubility of Zn in copper is 37%. 3 alloys: α (cold working alloys), α + β, β (hot working alloys), Strength increases a lot in the α+β' region, Ductility drops – β' more brittle

– high strength,

– high ductility

Higher Zn amount suddenly drop Mechanical properties and also start to decrease deformability (elongation) and adding Zn in Cu corrosion resistance decrease.

24) How do strength and elongation change it Sn wt. % increase in copper –Tin alloy?

Precipitation of a second phase

34) Draw the Fe-Ni diagram (in the iron rich side)

35) Write some features of the Mg alloys?

Lattice structure is HCP. The melting temperature is 650 °C. The density is 1.738 kg/m3. The elastic modulus is 42 GPa. Mg has a lower corrosion resistance than Al. It is flammable and explosive (was used in bombs). Some alloys can increase strength if solute heat-treated and aged.

36) AISI 304- which type of material is it?

It is austenitic stain less steel with wt.% of composition are Cr 19%, Ni 9%, Mn 2% and 0.08% C. Tensile strength is 515MPa, yield strength 205MPa and percentage of elongation is 40%. It's typical used in chemical and food processing equipment, cryogenic vessels.

37) Which are some methods to prevent corrosion in metallic materials?

Electrically insulate dissimilar metals
Use non-absorbing gaskets
Use welding rather than bolted or riveted joints
Lowering the fluid temperature/ velocity usually produces a reduction in the rate at which corrosion occurs
Use inhibitors
Physical barriers to corrosion are applied on surface in the form of films and coatings.

38) Describe the main features of powder metallurgy in comparison to wrought technology?

Basic principle of PM: Metal processing technology in which parts are produced from metallic powders. In the usual PM production sequence are Powder-Mixing-forming-sintering-machining-heat treatment- final products and we can produce a component with certain level of porosity.

Working temperature: It can work in high temperature such as using filament of tungsten but also wrought technology work in high temperature.

Surface finish: The product needs a surface finishing

Mechanical resistance: Mechanical properties depends upon the chemical composition of powder, level of porosity, gran size, compacting and sintering condition but its strength and toughness is less than wrought technology

Shape complexity: We can produce complex geometry shape part with powder metallurgy like filament of tungsten

Possible defect: Crack, Brittleness

39) Describe the 2nd phase particles hardening mechanism.

Precipitation hardening, also called age hardening or particle hardening, is a heat treatment technique used to increase the yield strength of materials. The heat treatment process consists of three steps.

(1) Solution treatment, in which the alloy is heated to a temperature T_0 above the solvus line into the alpha phase region and held for a period sufficient to dissolve the beta phase.

(2) Quenching to room temperature to create a supersaturated solid solution.

(3) Precipitation treatment, in which the alloy is heated to a temperature T_2, below T_0, to cause precipitation of fine particles of the beta phase. This third step is called aging, and for this reason the whole heat treatment is sometimes called age hardening.

47) Plot the Jominy curve of the following steel?
AISI 1060, AISI 4140, AISI 4340

48) To represent the impact test graph for some of the studied metallic materials.

49) Tensile test plot. (Influence of chemical composition, strain rate and temperature)

50) Plot the quench & temper cycle of the AISI 4340 steel.

56) Nitring process. Which are the procedures and the results?

Gas nitriding is a surface hardening process, where nitrogen is added to the surface of steel parts using dissociated ammonia (NH_3) as the source. Gas nitriding develops a very hard case in a component at relatively low temperature, without the need for quenching.

57) What can your write on crack problem in martensite transformation?

58) What is maraging steel?

Maraging steels (iron alloys) that are known for possessing superior strength and toughness without losing malleability, although they cannot hold a good cutting edge. These steel are a special class of low carbon ultra high strength that drive their strength not from carbon but from precipitation of intermetallic compound. Principal alloying elements 15% to 25% weight % nickel and secondary alloying elements, which are included molybdenum, cobalt, titanium to provide intermetallic precipitation.

6) Which are the hardening mechanism?

7) What does it happen in the artificial aging of the 2024 aluminium alloy?

8) How do strength and elongation change in Zn wt. % increases Copper alloys?

9) When the plastic deformation of Cu could be defined "hot deformation"? If the temperature is higher than:

- ○ 584 °C
- ○ 410 °C
- ○ 315 °C
- ○ 185 °C

10) What is pearlite?

11) Which are some methods to prevent corrosion in metallic materials?

17) Which is the main role of Cr in stainless steels? (Mark with an X sign the right answer)

- ○ It is the easiest way to increase the corrosion resistance of steels
- ○ Stabilize austenite at room temperature
- ○ Increase the surface finishing properties
- ○ It is a carbide forming element
- ○ Enhance hardenability in solute heat treating and quenching process
- ○ Reduce the price of the steel

18) Explain why are surface compressive residual stresses a benefit for fatigue resistance in case of cycle bending load? Draw a picture or scheme.

19) Calculate the percentage of pearlite in a plain carbon steel annealed with C=0.40%. Graph.

20) Materials with HEX lattice (only chemical symbol).

21) Which is the main role of Ni in stainless steels? (Mark with an X sign the right response).

- ○ It is the easiest way to increase the corrosion resistance of steels
- ○ Stabilize austenite at room temperature
- ○ Increase the surface finishing properties
- ○ It is a carbide forming element
- ○ Enhance hardenability in solute heat treating and quenching process
- ○ Reduce the price of the steel

27) Which is the technological application of the relation?

$$\%C_{eq}=\%C+\%Si/3+\%P/3$$

- ○ In case of welding procedures
- ○ In case of grey cast iron component production
- ○ To define the family of stainless steel type
- ○ To evaluate the hardenability of steels
- ○ To define the type of copper alloy
- ○ To evaluate the carbon percentage in plain C steels

28) Plot the Jominy curves (proportionately) of the following steels:

- AISI 1060
- AISI 5140
- AISI 4340

29) Mark with an (X) sign if the following assertions is true:

- ○ The adding of Zn in Cu alloys increases the corrosion resistance
- ○ The Titanium alloys have a cheap price
- ○ The solidification and cooling rate affect the final properties od annealed cast alloys
- ○ The adding of Zn in Cu alloys decreases their deformability
- ○ The adding of Sn in Cu alloys decreases their deformability
- ○ The $\%O_{eq}$ relationship is adopted to evaluate the influence of Oxygen in Cu alloys
- ○ The "L" type of stainless steels must be used to avoid sensitization problem
- ○ Natural and artificial aging is commonly applied to 2XXX, 6XXX and 7XXX Al alloys

30) Equation and reaction in wet corrosion. Graph.

31) Draw the Shaffler diagram.

38) Draw the Fe-Cr diagram (in the iron rich side)

39) Impact test curve (Influence of lattice type and chemical composition. Graph.

40) I.4406-Which type of material is it ?

41) Draw the Fe-Ni diagram (in the iron rich side)

42) Tensile test plot. (Influence of chemical composition, stain rate an temperature) Graph

49) Materials with FCC lattice (only chemical symbol):

50) Which is the main role of Cr in stainless steels?

- ○ It is the easiest way to increase the corrosion resistance of steels
- ○ Stabilize austenite at room temperature
- ○ Increase the surface finishing properties
- ○ It is a carbide forming element
- ○ Enhance hardenability in solute heat treating and quenching process
- ○ Reduce the price of the steel

51) Explain why are surface compressive residual stresses a benefit for fatigue resistance in case of a cyclic bending? Picture or scheme.

52) Calculate the percentage of pearlite in a plain Carbon Steel annealed with C=0,40%.

53) Materials with HEX lattice.

54) Which is the main role of Ni in stainless steels?

- ○ It is the easiest way to increase the corrosion resistance of steels
- ○ Stabilize austenite at room temperature
- ○ Increase the surface finishing properties
- ○ Is a Carbide forming element
- ○ Enhance hardenability in solute heat treating and quenching process
- ○ Reduce the price of steel

55) From the crystallographic point of view draw the lattice transformation of austenite into martensitic during quenching. Which are the properties of the martensitic?

61) To draw the Shaffles diagram.

62) Impact test curve.

63) AISI 316L-Which type of material is it?

64) Draw the Fe-Cr diagram (in the iron rich side):

65) 1.4406 Which type of material is it?

66) Draw the Fe-Ni diagram (into the rich side)

70) Some important features of high strength low alloys steels:

71) Wet corrosion: which are the possible reactions?

72) Write some advantages by adopting power metallurgy technology (in respect to wrought and cast technology):

73) Describe the solid solution strengthening mechanism.

74) Which are the hardening mechanism?

75) What does it happen in the artificial aging of the 2024 aluminium alloy?

TRUE/FALSE

	True	False
The Mg alloys manifest mainly an anodic behaviour in corrosion in sea water		
The Mg alloys manifest mainly a cathodic behaviour in corrosion in sea water		
Natural or artificial aging is commonly applied to 5XXX Al Alloy		
Natural or artificial aging is commonly applied to 6XXX Al Alloy		
The adding of silicon is very important for white cast iron component		
The adding of silicon is very important for grey cast iron component		
The corrosion resistance of the ferritic SS is higher than that of Cu		
The corrosion resistance of the martensitic SS is higher than that of Cu		
There is a relationship between σ and ε for the deep drawing steel		
The eutectic modification phenomenon is typical for AlSi alloy		
The eutectic modification phenomenon is typical for AlCu Alloy		
The C_{eq} equation is commonly used for cast iron		
Cu enhance sintering process of steel component		
Austenitic stainless steel brace higher corrosion resistance than martensitic one		
The duplex SS have the austenitic and bainite P(50-50)		
In welding the filler material of SS in a plain carbon alloy		
The yield strength of AISI 410 SS in Q and T condition reach 60 MP		
The AISI 316 L SS does not generally evidence pitting corrosion resistance		
The SS in the active surface state evidence lower corrosion resistance than Cu alloy		
The deep drawing steels are generally used to produce oil gear		
The adding of Zn in Cu alloys decreases the corrosion resistance		
By continuous cooling of plain carbon steel 100% of bainite can be obtained		
The solidification and cooling rate affect the final properties of annealed cost alloy		
The adding of Zn in Cu alloys decreases their deformability		
The % O_{eq} relationship refers to the influence of Oxygen in Ti alloy		
The σ_y of artificial aged 7XXX Al alloy are generally higher than that of 2XXX one		
The Al alloy have a high strength density ratio		
The L type of SS must be used to avoid sensitization problem		
The Titanium alloy have a cheap price		
The adding Sn in Cu alloys decreases their deformability		
The %O_{eq} relationship is adopted to evaluate the influence of Oxygen in Cu alloys		
The anisotropic coefficient r is very important for deep drawing steel		
The Grossman Index is a measurement of quenching bath quantity		
The adding of interstitial element (C,w) is a benefit for Fe alloy deformability		
The Knepp's problem are connected with the SS production		
The austenitic SS do not evidence ferromagnetic properties		
To be defined Stainless the steel has to contain almost 11-12% of Ni		
The cottnell atmosphere justifies the Lüder's bands in low C plain steels		
The interstitial free steels have a low C and Ti higher than 0,3%		
The TRIP steels have a certain amount of martensitic that act as shock absorbed		
The Nahashima technological test is affected to build the safe straining curve		
The Ericksen index is a measure of the anisotropy coefficient of sheets		