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TUNGSTEN HEAVY METAL ALLOYS RELATIONS BETWEEN THE CRYSTALLOGRAPHIC TEXTURE AND THE INTERNAL STRESS DISTRIBUTION

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Summary :

Quite often the W-Ni-Fe-Co heavy alloys are subjected to a thermomechanical processing of swaging and aging in order to obtain the highest possible level of resistance. Within the framework of this plastic deformation on cylindrical parts, the swaging leads to the distribution of morphological and crystallographic texture as well as specific internal stresses. The resulting mechanical characteristics are correlated to structural and sub-structural variations.

Key words :

W-Ni-Fe-Co alloys – Swaging - Strain hardening -Texture – Internal stresses

1. Introduction :

The W-based alloys of the W-Ni-Fe-Co system are formed by liquid state sintering in accordance with the standard powder metallurgy procedure. The resulting microstructure is a biphase system composed of an α (W) phase of nodular form, surrounded by a γ ductile phase (Ni-Fe-Co-W) of which the chemical composition is dependent on the chemistry of the initial mixture.

This standard microstructure leads to a defined range of mechanical characteristics, of which the levels of resistance can only be increased by strain hardening such as swaging or rolling, according to the geometry of the product in question (1).

On these grounds, plastic deformation (more particularly by swaging) of the W-Ni-Fe-Co product of cylindrical geometry has been studied and the relations between the crystallographic texture and the distribution of internal stresses have been analysed.

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2. W-Ni-Fe-Co alloys – Generalities :

W-based alloys contain approximately 88 to 98 weight percentage of W, the rest constituted of alloying elements such as Ni, Fe and Co.

Most heavy alloys are produced by the process of liquid phase sintering in a reducing atmosphere (hydrogen) which leads to a biphase structure made up of (figure n°1):

- An α (W) phase in the form of more or less spherical nodules which are a result of the reduction of the W/liquid interface energy and the coalescence of W particles by Oswald coarsening. The crystallographic system of this phase composed of pure W is the body-centred cubic lattice.
- A ductile γ phase, solid solution (Ni-Fe-Co-W) upon thermodynamic equilibrium of which the W content is strictly dependent on the nature and proportion of alloying elements.

  The crystallographic system of this phase is the face-centred cubic lattice.

In correlation with this standard structure and after dehydrogenation heat treatment, alloys resulting from this system have density and mechanical properties, in tension, impact resistance, compression, bending and hardness that are homogenous and limited to a finite space.

For example, the levels of elastic limit and maximum tensile strength of these alloys cannot be superior to approximately:

- 800 MPa for the elastic limit,
- 1100 MPa for maximum tensile strength.

Owing to the fact that with this alloy system it is not possible to access hardening structural transformation such as martensitic transformation or hardening precipitation, plastic deformation is the only means to increase the levels of resistance and hardness of these materials. The strain hardening balance of the alloy which has plastic-elastic behaviour, and namely of the α phase at Young's high modulus (400 Gpa) should thus enable the alloy to accommodate more breaking stress energy

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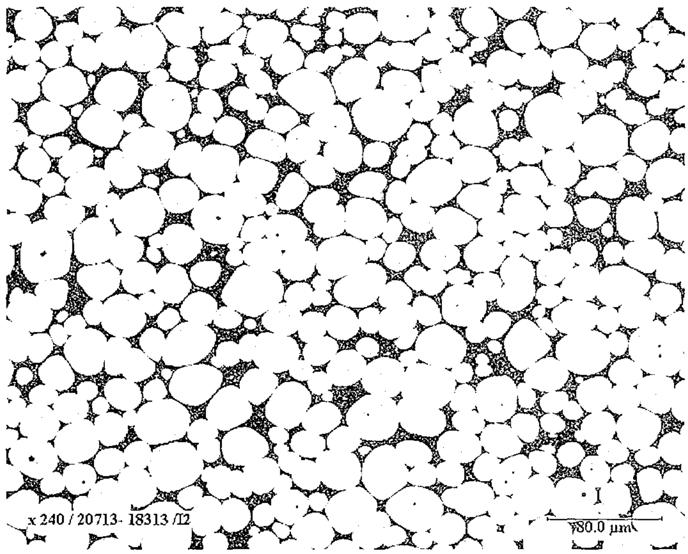
Fig 1 W-alloy (Ni-Fe-Co)
Standard microstructure (x 240) – Sintered state



Biphase alloy (e-back scattering):

- α (W) phase of nodular form
- γ phase (Ni-Fe-Co-W)

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3. Properties after thermomechanical processing :

Cold working has been studied by swaging round products using an axisymetric hammering device with 4 hammers (figure n°2). According to the intensity of work ratio and the rate of associated dislocation density (2), the following characteristics were taken into account:

- Morphological texture by metallographic observation,
- Crystallographic texture of the α phase by diffraction of X-ray,
- Mechanical characteristics:
  - Internal stresses by X-ray
  - Hardness measurement (HV30)
  - Tensile test

a) – Morphological texture

Cold working changes the morphology of the material microstructure to a large extent.

There is deformation of the α phase that evolves from a spherical shape to an ellipsoïd according to the work ratio intensity (figure n°3).

b) –Crystallographic texture of the α phase

The α phase develops a double crystallographic texture on each side of the half-radius of the cylinder (figure n°4).

- In the volume located between the surface and the half-radius of the part : texture {200} <100>.

- In the volume located at the core, from the half-radius of the part : texture {200} <110>.

The both <110> and <100> directions are parallel to the axis of the rod. The intensities of texture increase with the work ratio level (figure n°5).

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c) – Internal stresses

Internal stress measurements show that (figure n°6) :

- The material is subjected to an extensive field of internal stresses at the core and a compressive field of internal stresses on the periphery. The envelope of neutral fibre neighbours the crystallographic transition zone.

- Internal stresses increase with the work ratio and are dependent on the chemical composition of the alloy.

d) – Mechanical characteristics

Hardness and tensile characteristics show that in relation to structural characterisations, the following is noted:

- Peripheral values are higher than core values with regard to hardness gradient (figure n°7); this becomes increasingly true as the work ratio is intensified.

- Elastic limits and tensile strengths are higher at the external part than on the core part. Similarly, ductility is weaker on the periphery. (Table n°1)

Tab 1 W-Ni-Fe-Co alloy after cold working
Example of tensile mechanical characteristics according to samples taken from the core or the periphery of the part

	Sample	Tensile results		
		Rp (MPa)	Rm (MPa)	A (%)
Alloy 1	Core	1100	1190	9
	Periphery	1130	1210	7
Alloy 2	Core	1550	1550	10
	Periphery	1685	1690	6

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Fig 2 Schematic diagram of axisymetric hammering with four hammers

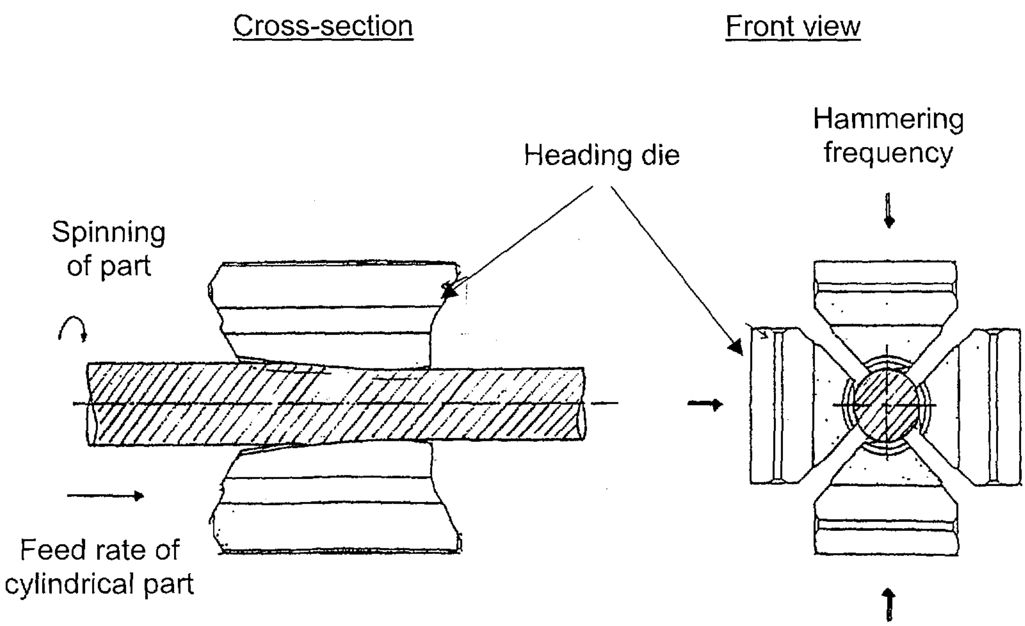

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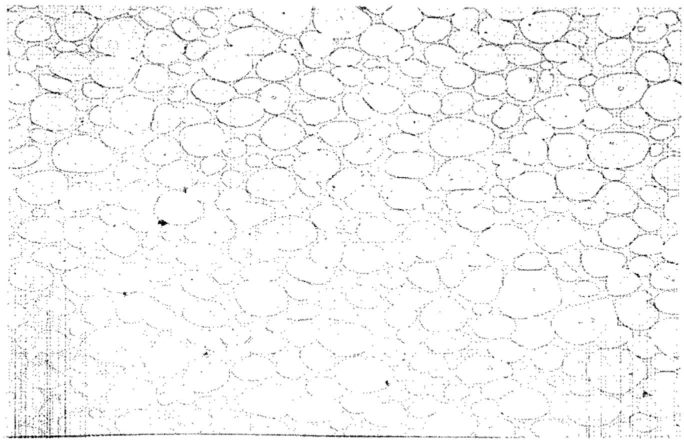
Fig 3 W-Ni-Fe-Co alloy after cold working
Variation of the morphological texture of the α (W) phase according to work ratio intensity
Metallographies (x 200) – longitudinal view after hammer hardening

Level 1 work ratio intensity
Slight deformation of the α (W) phase nodules



Level 2 work ratio intensity
Significant deformation of the α (W) phase nodules

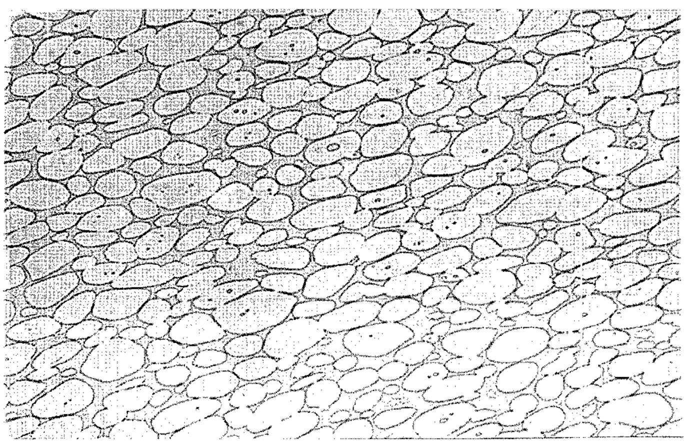


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Fig 4 W-Ni-Fe-Co alloy after cold working
Display of the fibre texture in a cylinder

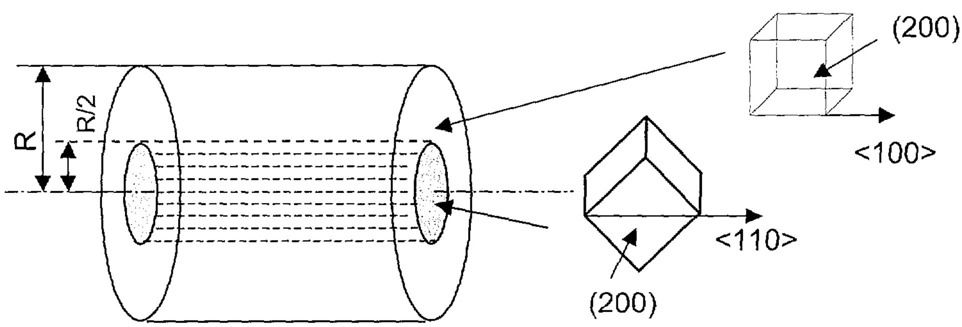

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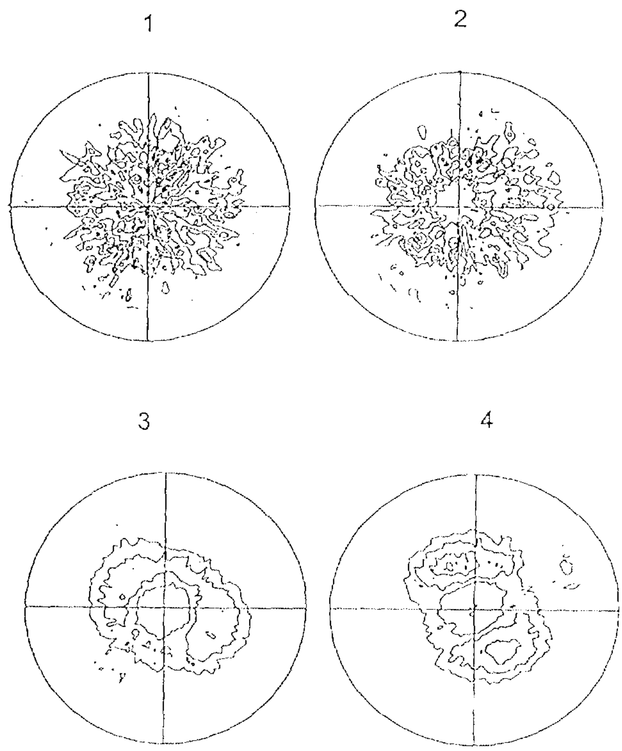
Fig 5 W-Ni-Fe-Co alloy after cold working
Pole figures {200} and fibre texture <110>

Evolution of the pole figures according to the work ratio intensity (levels 1 to 4)



Material : Alloy 2

Cold working level	Work ratio (%)
1	10
2	15
3	20
4	25

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W-Ni-Fe-Co alloy after cold working
Internal stresses and hardness gradient

Fig 6 Internal stress gradient (MPa)

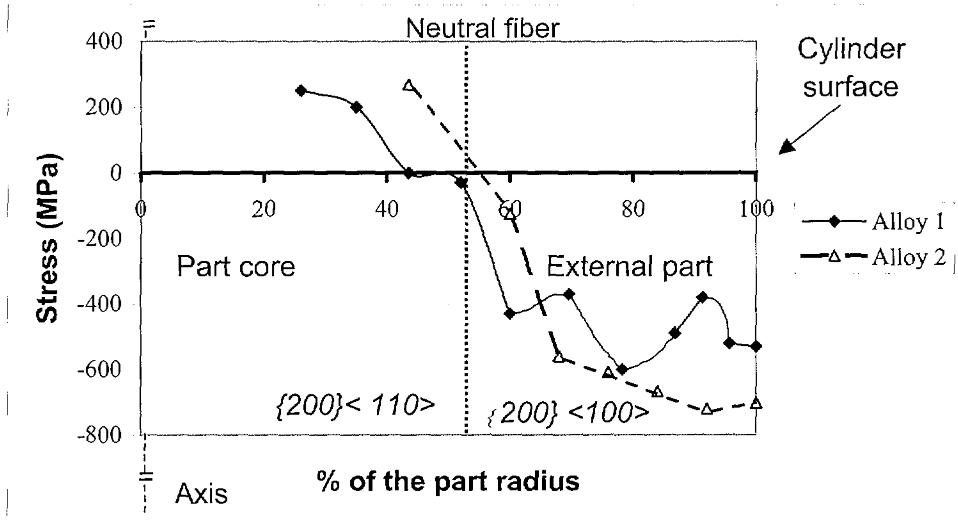
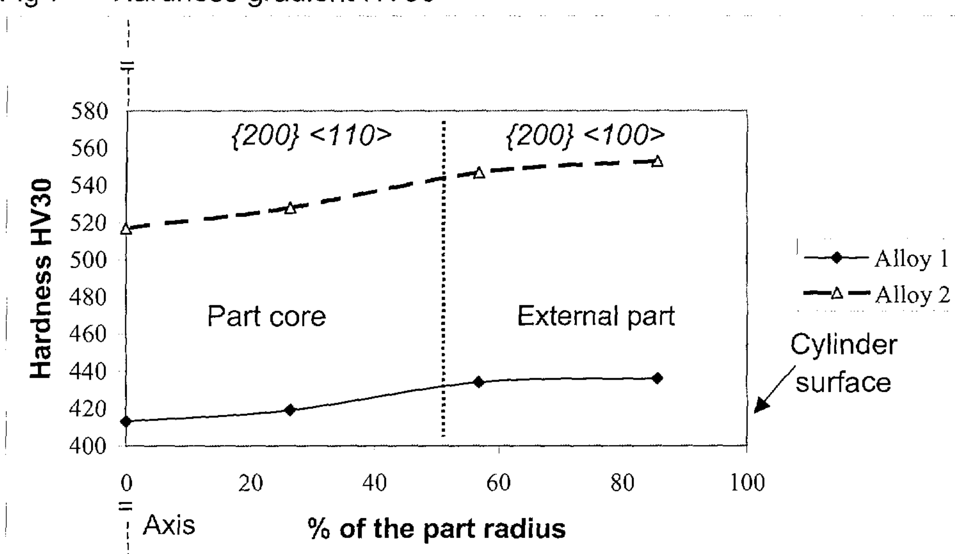


Fig 7 Hardness gradient HV30



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4. Conclusion :

It is determined that heavy alloys, W-Ni-Fe-Co based system have to be cold worked in order to increase the strength and the hardness. Typically for a rod, cold working is achieved by swaging and it generally leads to specific distribution of morphological and crystallographic texture as well as of internal stresses.

The swaging of the W-Ni-Fe-Co based cylinder results in:

- A morphological texture with a deformation of the α phase according to the work ratio intensity.

- An α (W) phase crystallographic texture, distributed in two main parts :

  ⇨ For the external part, between the half radius and the surface of the cylinder, the α (W) texture is :

  Plan {200} – direction <100>

  In this field, the internal stresses are in compression

  ⇨ For the core part, between the half radius and the axis of the cylinder, the α (W) texture is :

  Plan {200} – direction <110>

  With an internal stresses distribution in tensile

- The both intensities of texture and internal stresses for each part increase with the work ratio level.

- In relation to these distributions, a gradient of hardness and tensile characteristics are recorded, with an higher level for the external part.

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