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Improvement of Properties Jet Mechanics in A3S High Strength Steel

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ABSTRACT
The objective continued in this work is to improve the characteristics mechanical properties of high-strength A3S steel produced at the Panda Central Workshops of Gecamines. The steel grade studied contains quantities important manganese in proportions ranging from 2 to 4.6%. Various treatments thermal has summer realized in view to improve machinability while designing properties mechanics that meet the requirements of their use.
Samples in the raw casting state have presented a hardness of 407.8 HB and a resilience of 4.3 J/cm ^{2}. Annealing at 773°C followed by holding for 4 hours and slow cooling in the furnace to a speed of 20°C per hour helps to reduce hardness up to 200HB with increased resilience up to 28.3 J/cm ^{2}. A quench was then carried out and made it possible to retain a heating temperature of 900°C and water as a cooling medium; which allowed to increase hardness and resilience until values respective of 343 HB and 19.7 J/cm ^{2}. The final result obtained after tempering leads to a hardness of 217 HB and a resilience of 19.7 J/ cm^2.
It emerges from the tests realized that it is possible to modify and improve the hardness and resilience of the studied grade using thermal cycles appropriate.

Keywords: Steel, Hardness, Annealing, Tempering.

1. Introduction

Steels are of capital importance, since they are found in almost all fields. They are at the origin of all scientific and industrial revolutions. This progress is mainly due to the presence of a wide range of transformations that allow to vary considerably the mechanical properties of steels, by resorting to the addition of alloying elements in order to improve the different mechanical, thermal and chemical characteristics. The A3S steel grade is a high- strength steel developed at the Panda Central Workshops and used as a base material for the machining of parts mechanical (pinions attack, lifting bars, etc.) from the jets. Due to the severe conditions of implementation shape during machining and during use of the parts, thermal cycles are considered in view to modifying and improving properties mechanics of this last. The steel shade studied contains quantities important manganese in proportions ranging from 2 to 4.6 %. Manganese is present in steels, in part in form of impurities residual, in part as result of a deoxidation. A part of the manganese constitutes an element addition intentional to counterbalance the bad influence of iron sulfide, in producing manganese sulfide relatively less harmful (Bensaada, 2010). The improvement

considered will go through a treatment process thermal. Generally speaking, the treatments thermals do not change the chemical composition but brings changes from the point of view of constitution (carbon state, shape allotropic), structure (grain size, distribution of constituents) and stress state (Colombie, 2008). It consists of a number heating and cooling operation whose aim is to improve the characteristics of materials (breaking strength, increase in the limit elasticity, hardness etc.) for a better adaptation to service conditions; this will involve annealing, quenching and tempering.
The purpose of quenching is to harden the metal. It allows to obtain very hard steels but, in most cases, not very ductile (Chaussin and Hill, 2013). The tempering (quenching anisothermal) is in general treatment energetic leading to a metal with high Rm, Re, H due to the presence sought after martensite, but whose ductility (A%) and resilience (K) are very low for the same reason. It is intended to correct more or less completely these disadvantages and allows to mitigate the effects of tempering in making the part more ductile and more tenacious (Hantcherli, 2010).

2. Materials and Methods

This study was carried out on a jet cut into 5 parts, which were then machined in a machine tool workshop for the manufacture of 5 samples. The latter were ground in order to better sample the hardness and resilience and to carry out a microstructural analysis before proceeding to heat treatment.

2.1.Characterization

2.1.1. Chemical Characterization

A chemical characterization was carried out in the ACP foundry laboratory by the X-ray fluorescence method using the NITON XLT analyzer.

Figure 1: The NITON XLT Analyzer

2.1.2. Mechanical Characterization

1. Hardness

Hardness tests have summer carried out using a portable rebound durometer of the EQUOTIP 3 brand

Figure 2: Equotip 3 type rebound durometer

2. Resilience

The resilience tests were carried out using the Charpy pendulum impact tester on standardized specimens of length 55 mm and square section of 10 mm on each side, comprising in the middle of the length a V-shaped notch at 45°, of depth 2 mm with a radius at the bottom of the notch of 0.25 mm.

Figure 3: Charpy pendulum hammer

2.1.3. Micrographic Characterization

A polishing mechanical with abrasive paper of different grits grain sizes of 120 mm, 320 mm, 600 mm, 800 mm, 1000 mm and 1200 mm respectively was carried out, then a final polishing using 2400 and 4000 grain papers. To study the constituents of the matrix metallic and carbides we have proceeded to an attack chemical with Nital prepared at 3 or 4 % for a time of approximately 5 to 90 seconds. Observation of the samples was made by a Euromex Holland type optical microscope equipped of a camera Computer - aided "CMEX" brand video taken at 200 magnifications.

Figure 4: Euromex Holland type optical microscope

2.2.Thermal Treatments

annealing to improve machinability, a martensitic quenching to increase hardness after machining and structural tempering to reduce the stresses generated by quenching.

These operations were carried out using a small BENET resistance furnace with the following characteristics : 220 voltages, parallelepiped shape, 1100°C max temperature, 2.3 KW max power and 50-60Hz frequency.

Figure 5: Treatment oven BENET type thermal

The fusion of metals ferrous has made in a three-phase STEIN type electric arc furnace with a 5-ton capacity of which the food in raw material is provided by the scrap metal park and ferroalloys (ferromanganeses, ferrochromes, ferromolybdenums and ferrosilicones). These latest serve mainly to the shading of the steel. The optimization of the heat treatment parameters consisted in determining the optimum heating temperature which will allow the hardness to be reduced to values of 175 to 210 HB, values which will allow the part to be machined, while maintaining good resilience. Secondly, a study of the cooling profile which will give the best compromise between hardness and resilience to the steel studied.

3. Results and Discussion

3.1.Chemical Characterization

Table 1Chemical composition of the samples

Elements	**Content**				
	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
Mo	0.44	0.63	0.4	0.56	0.47
Cu	0.08	0.10	0.2	0.17	0.13
Neither	0.30	0.33	0.40	0.43	0.31
Mn	**2.70**	**2.83**	**3.08**	**2.85**	**3.,41**
Fe	**93.3**	**87.6**	**90.00**	**90.98**	**89.07**
C	0.61	0.53	0.58	0.53	0.55
Cr	0.85	0.80	0.79	0.81	0.83
You	0.6	0.44	0.40	0.55	0.64

Grade A3S is a hypoeutectoid steel containing a carbon content of less than 0.77% and the manganese content is predominant compared to other elements present in the sample. It is therefore a steel with a low manganese alloy. This high proportion will impact the mechanical properties of this alloy.

3.2.Characterization Mechanical

Table 2: Properties mechanics of the sample in the raw casting state

Raw casting state	**Mechanical Properties**			
	Hardness	**Resilience**		
	HB	Section So	Energy	Resilience
		Cm2	Δw(j)	K(J/Cm2)
Sample1	410	0.8	3	3.75

Sample 2	413	0.8	3.2	4
Sample 3	400	0.8	3.6	4.5
Sample 4	410	0.8	4.0	5
Sample 5	406	0.8	3.3	4.13
Average	HBm : 407.8	Km : 4.3		

Hardness values are too high compared to those of resilience which are low on samples in the as-cast state. A hardness high could to explain by the presence of manganese in the sample which would form a solid solution with ferrite during uncontrolled cooling in the mold. On the other hand, the formation of manganese carbide improves hardness but decreases resilience, which consequently would affect ductility rendering thus making it difficult to machine the part in the raw casting state

3.3.Characterization Micrographic

this analysis is relevant a homogeneous structure containing perlite which consists of ferrite and lamellae hard in cementite. This explains the large hardness obtained in the A3S steel grade. Thus, the crystals pearlitic whole is surrounded by a network of cementite. The effect product on the structure is explain by the presence predominant manganese which promotes the formation of pearlite with the appearance of small lamellae.

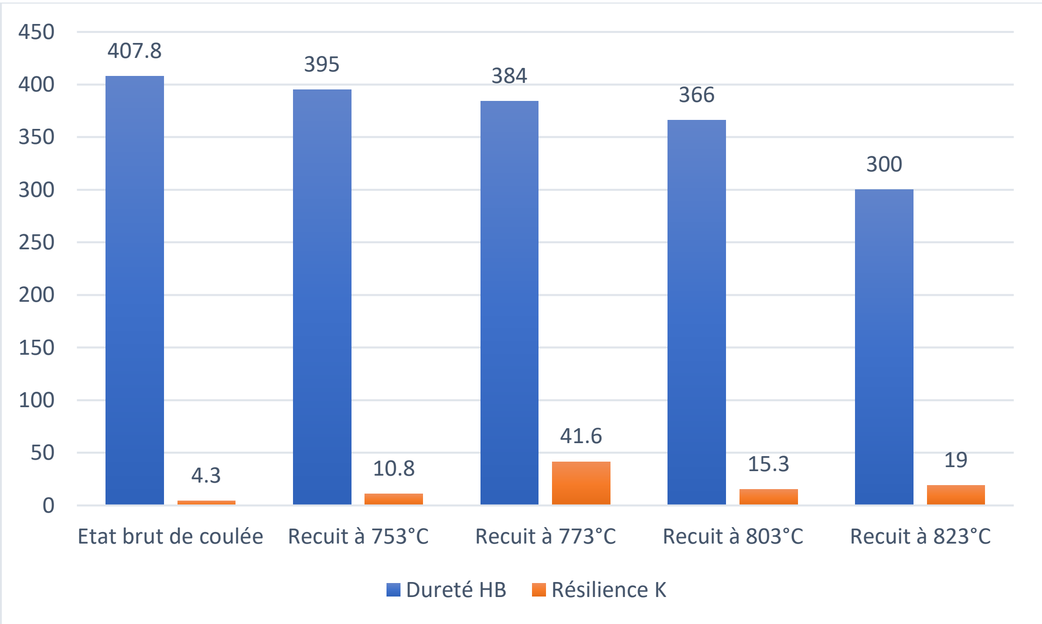
3.4.Treatments Thermals

3.4.1. Soft annealing

- **Heating Temperature**

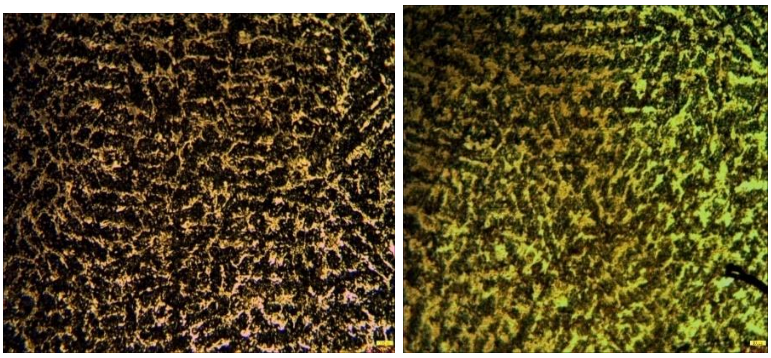
The temperatures have summer varied in the following range: AC1+30°C, AC1+50°C, AC1+80°C and AC1+100°C corresponding respectively at temperatures of 753, 773, 803 and 823°C. The cooling medium retained during these tests is the oven and the holding time has been set at 4 hours.

Figure 6: Influence of heating temperature on HB and K



The best heating temperature during soft annealing corresponds to AC1+50°C.

Figure 7: Micrograph of the shade heated to AC1+50°C (a); Micrograph of the shade heated to AC1+100°C (b)



(a) (b)

We note a presence of ferrite with a predominance of pearlite composed of cementite which tends to coalesce in the matrix and the network of iron carbides in excess. This structure is due to cooling in the furnace which causes the diffusion of iron carbides to the grain boundaries. It is so judicious to study the impact of the cooling profile on the structure of the A3S steel grade at the temperature AC1+50°C which gives a better trade-off between hardness and resilience.

- **Cooling Profile**

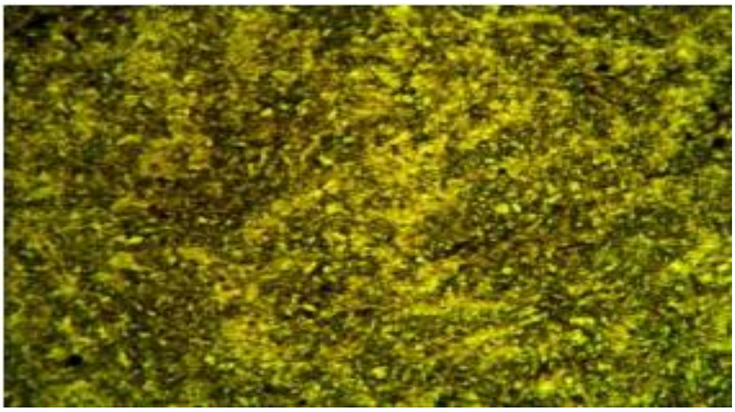
steel has been heated to a temperature of 773°C and cooled slowly in the oven. Cooling rates are 20 and 30°C per hour until approximately 600°C, the holding time is 4 hours to allow good heat penetration Then air cooled.

Table 3: Variation of HB and K in function of cooling rate

Quenching temperature °C	Cooling rate °C/hour	HB hardness	Resilience K (J/cm ^{2})
773	20	200	28.3
	30	270	19.2

A decrease in hardness in favor of resilience at a cooling rate of 20°C/ hour was observed, compared to those taken in the raw state of casting. The hardness increases and resilience decreases at the cooling rate of 30°C / hour.

Figure 8: Micrograph of the shade heated to AC1+50°C and cooled in the oven at 20°C/H



Analysis of the results revealed a homogeneous structure with a presence remarkable carbide, pearlite in which cementite and excess cementite network adopts a ball shape called cementite coalesced, which could lead to values moderate hardness and resilience.

3.4.2. Quenching

- **Quenching Temperature**

Heat rooms to temperatures corresponding to the state austenitic in the range following: AC3+40°C and AC3+80°C which corresponds to temperatures of 900°C and 940°C. In this series of tests, the constant parameters fixed are the cooling medium (Air) and the holding time of 30 minutes.

Table 4: Variation of hardness and resilience in function of quenching temperature

Quenching temperature °C	HB hardness	Section So (cm2)	Energy Δw (J)	Resilience K (J/cm ^{2})
900	280	0.8	14.96	18.7
940	170	0.8	16.24	20.3

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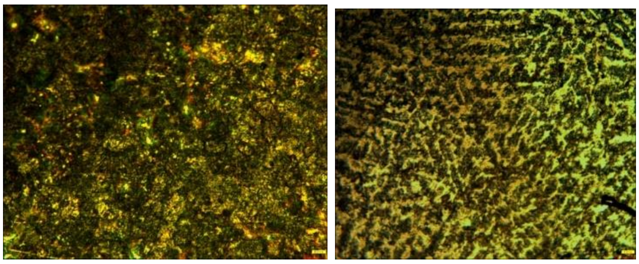
Figure 9: Micrograph of A3S heated to AC3+40°C (a) and air - cooled to AC3+80°C (b)



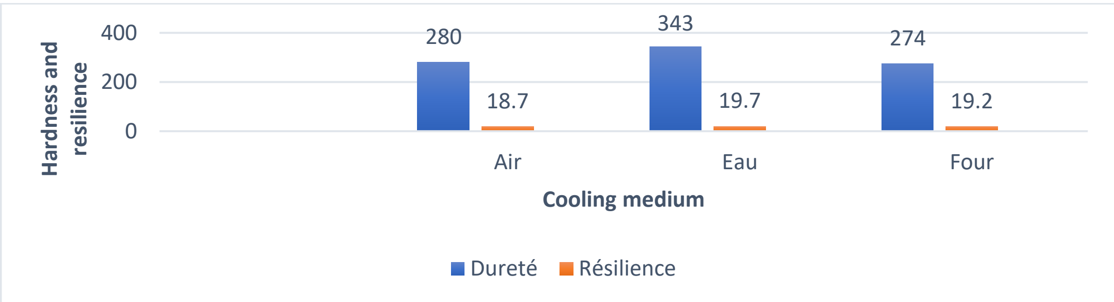
(a) (b)

At 900°C (AC3+40°C), the treatment applied caused the transformation of austenite in martensite with a precipitation of finer and well distributed carbides in the matrix but of a quantity less important, this has generated a small increase in hardness at value average resilience. The presence of carbides larger precipitates and a austenite residual coarse is observed at 940°C, this leads to the lowest hardness recorded after this quenching.

- **Cooling Medium**

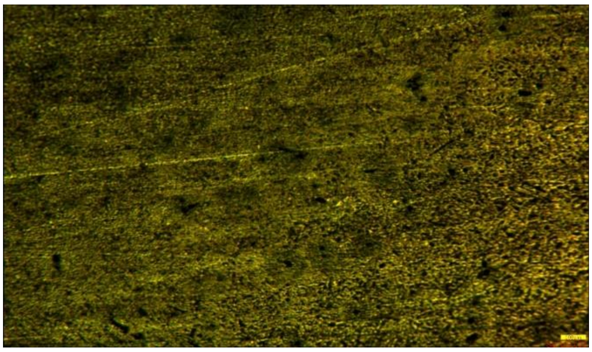
cooling medium is a parameter that allows to fix the cooling speed and to evaluate the hardenability of the materials. The heating was done in two stages, the first at 650°C with 30 minutes of holding and the second with increase of the temperature to 900°C followed by a new holding at 30 minutes. The environments studied are: the oven (which gives weak cooling rates) and water (which gives cooling rates enough fast).

Figure 10: Evolution of characteristics mechanical according to the quenching media



The characteristics mechanical favorable are those obtained when cooling in water. In fact, under these conditions the hardness and resilience are of the order of 343 HB and 19.7 J/cm ^{2}.

Figure 11: Micrograph of A3S heated to AC3+40°C and cooled with water



Microstructure analysis reveals that the carbides precipitated are more numerous, thin and distributed throughout the matrix. It is observed the presence of finer martensite and a quantity of austenite residual after an austenitization at 900°C.

3.4.3. Tempering

After a quenching treatment at the temperature optimum of 900°C, the parts have had returned to temperatures of: 250, 350, 450, 550 and 650°C in order to reduce the internal stresses induced in the parts. The heating was carried out during a two- hour hold followed by cooling in open air.

Table 5: Results of hardness tests after tempering

Income Temperature °C	250	350	450	550	650
HB hardness	343	347	351	296	217

Hardness increases at temperatures weak in the steel grade and finally decreases at higher temperatures, more precisely from 550° C.

4. Conclusion

The objective of this work was to study the impact of heat treatments of high-strength A3S steel on its mechanical properties with a view to modifying its behavior in the face of stresses undergone during forming and its subsequent use.

In order to achieve the assigned objective, several heat treatments were carried out on the A3S steel grade test pieces in order to soften the jets produced and improve their machinability and on the other hand with the aim of improving the hardness and resilience after machining to meet the conditions of use of these parts.

The results obtained showed that the A3S steel grade has a hardness of 407.8HB and a resilience of 4.3 J/cm ^{2} in the as-cast state and that a soft annealing with variation of the heating temperature improved its performance. Indeed, at a temperature of 773°C, the steel grade had a hardness of 200HB and a resilience of 28.3 J/cm ^{2}.

The results obtained after austenitization heat treatment at 900°C with variation of the cooling medium showed that the best results are 343HB and 19.7 J/cm ^{2} obtained after cooling in water. Low performances were recorded with cooling in a furnace (280HB and 18.7J/cm ^{2}) and in air (274 HB and 19.2 J/cm ^{2}). Finally, a tempering heat treatment was carried out in order to eliminate the internal stresses noted after quenching and led to opting for a heating temperature of 650°C with two-hour maintenance followed by cooling in open air. The hardness and impact strength of the grade obtained after tempering are 217HB and 19.7 J/cm ^{2} respectively.

To future researchers, we suggest to continue the present work by studying the impact of the different alloying elements at high temperature in order to foresee a probable improvement of the mechanical properties of the A3S steel grade beyond the temperature zone chosen in this work.

5. Conflict of interest

The authors have no conflicts of interest to declare.

6. Thanks

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