

CONTRIBUTION TO THE DEVELOPMENT OF HIGH-STRENGTH STEEL THROUGH RESEARCH OF THE RELATIONSHIP BETWEEN MICROSTRUCTURE AND PROPERTIES

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ABSTRACT

In this paper some results of the research related to high-strength Maraging steel 18Ni (250) and precipitation-hardening stainless steel 17-7 PH are presented. The research identified some mechanisms that take place in the microstructure depending on the heat treatment, which have direct affect on mechanical properties and exploitation characteristic. Particularly it was analyzed the reduction of ductility in Maraging steel 18Ni (250). The research has performed on experimental heats produced on pilot plants of the Institute. The static and dynamic mechanical properties were tested. Microstructural characteristics were investigated on the light, and on scanning and transmission electronic microscope.

Keywords: *high-strength steels, stainless steels, mechanical properties, microstructure*

1. INTRODUCTION

Aviation and automotive industry requiring high-strength materials with sufficient ductility initiated development of Maraging and precipitation-hardening stainless steel. These steels have certain advantages in making structural components such as hardening without quenching, and the absence of distortion and decarburization. Generally, the tensile strength of these steels is satisfactory, but it can not be said for the ductile properties. Therefore, the improvement of their ductility is still the subject of very extensive research. In this paper the microstructural factors having affects on ductile properties at Maraging and precipitation-hardening stainless steels are analyzed.

2. HIGH-STRENGTH STEELS

Maraging steels are high-strength steels in which relatively soft martensite are strengthened in the process of aging by the formation of fine precipitates of high density. The precipitates are intermetallic compounds of nickel with molybdenum, titanium and aluminum, which are formed depending on the type of steel. Precipitation-hardening stainless steels are high-alloyed steels that are strengthened by controlled transformation austenite in martensite and by subsequent precipitation of intermetallic compounds NiAl. Maraging steel 18Ni (250) and precipitation-hardening stainless steels 17-7 PH (UNS S17700) have the widest commercial application. The chemical compositions and mechanical properties of these steels produced for research purposes are given in Table 1 [1].

Table 1. Chemical composition and mechanical properties of the experimental heats of Maraging 18Ni(250) steel and precipitation-hardening stainless steel 17-7 PH steel

| Steel | Content of elements, wt. % | | | | | | | | | Heat treatment | Rm, MPa | A, % | KV, J | HRC | K _{IC} , MPa m ^{1/2} |
|------------|----------------------------|------|------|-----|-----|------|------|-------|-------|----------------|---------|------|-------|-----|--|
| | C | Cr | Ni | Co | Mo | Ti | Al | S | N | | | | | | |
| 18Ni (250) | 0,01 | - | 18,5 | 8,4 | 5,0 | 0,72 | 0,12 | 0,001 | 0,003 | T1 | 1950 | 9,5 | 29 | 53 | 76 |
| 17-7 PH | 0,06 | 16,5 | 7,7 | - | - | - | 0,95 | - | - | T2 | 1593 | 8,5 | - | 41 | - |
| | | | | | | | | | | T3 | 1645 | 5,5 | - | 46 | - |

T1 - Solution annealing 880°C/60min + Air cooling to room temperature + Aging 460°C/180min
T2 - Solution annealing 980°C/20min + Cooling to -75°C/120min + Aging 480°C/60min
T3 - Cold deformation (70%) + Aging 480°C/60min

2.1. Microstructure and mechanical properties relationships in 18Ni (250) Maraging steel

Maraging steel 18Ni (250) have relative soft low-carbon, iron-nickel lath martensite matrix (Figure 1) that is strengthened by precipitation of intermetallic compounds during precipitation aging [2]. This steel has very good hardenability if the austenite is completely transformed into martensite during cooling from solution annealing temperature to the room temperature throughout the cross section. In the case of proper performing of the heat treatment the presence of retained austenite is not expected in the structure.

Strengthening of Maraging steel is result of precipitation of fine and evenly distributed particles of intermetallic phase Ni₃(Mo,Ti,Al) in the martensitic matrix. Such particles are very efficient obstacle to dislocation slip, and since they are very small (up to 10µm), they are not suitable sites for nucleation and propagation of microcracks during fracture. This explains why the 18Ni (250) Maraging steel (250) has a very good combination of tensile strength and resistance to nucleation and propagation of cracks [3].

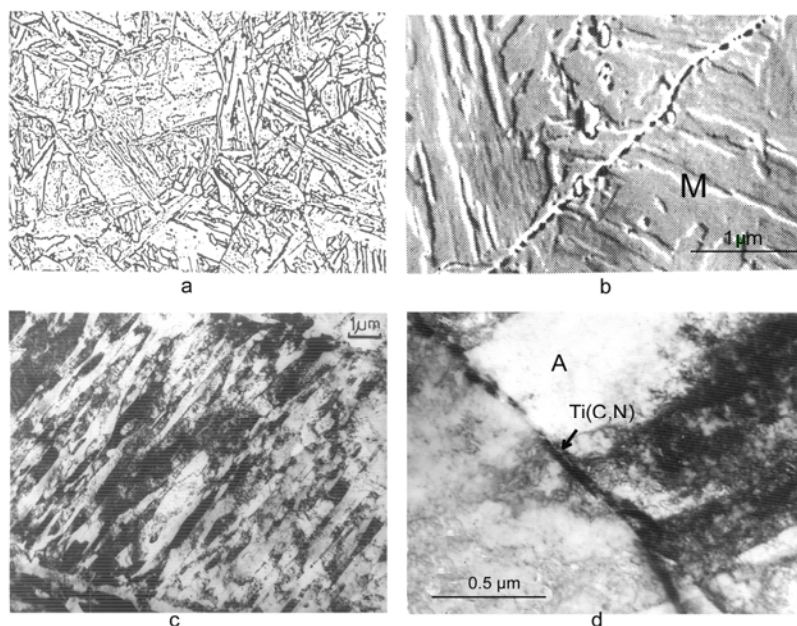


Figure 1. Microstructure of 18Ni (250) Maraging steel, a) lath martensite after forging - light microscopy, b) lath martensite - SEM, c) lath martensite - TEM, d) Ti(N,C) at austenite grain boundary - TEM

In the case of large cross-section the properties of Maraging steels are not always uniform. Also, there is a possibility of ductility decreasing. The main cause of the ductility decreasing is precipitation of titanium carbidenitrides at austenite grain boundaries causing intergranular fracture with reducing of absorbed energy values at impact test (Figure 1.d and Figure 2). Namely, ductile fracture occurs in

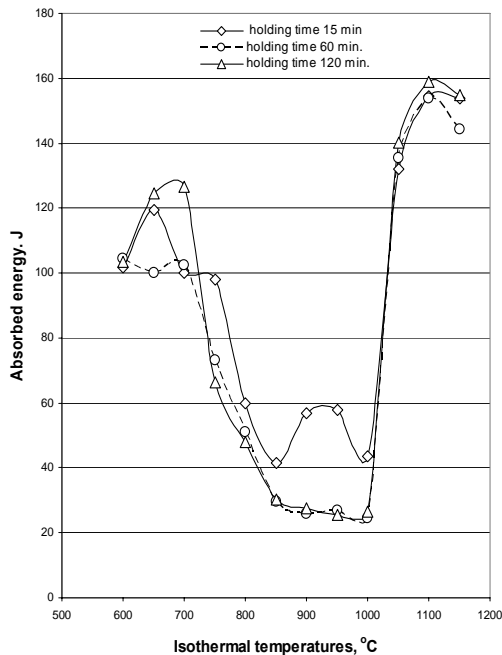


Figure 2. Dependence of the absorbed energy, isothermal temperature and holding time

three separate stages: nucleation, growth (propagation) and coalescence of microcracks. Suitable sites for the nucleation and propagation of microcracks in Maraging steels are secondary titanium carbonitrides and nonmetallic inclusions. Therefore the content of carbon and nitrogen in Maraging steels should be reduced to the minimum possible values. It can be achieved by a vacuum melting and subsequent electron beam remelting [4].

The experimental results of simulated phenomena of ductility decreasing at a gradual cooling of 18Ni (250) Maraging steel from temperature of 1200°C to temperatures 600-1150°C, with different times of isothermal holding at those temperatures are given on Figure 2. Values of absorbed energy at impact test have been used for estimation of the ductility decreasing. On the base of this results it was established the temperature range 750-1000°C in which 18Ni (250) Maraging steel shows the tendency to the reducing of ductility in the case of slow cooling. These experimental results can be used in determining the heat treatment to products with larger sizes.

2.2. Phase transformation in 17-7 PH stainless steel with controlled transformation

The main reason for the development of precipitation-hardening stainless 17-7 PH steel, is the fact that Maraging steels, despite of very high degree of alloying, have not satisfactory corrosion resistance. Therefore, PH steels have been developed. These steels have high values of strength and fracture toughness, very close to Maraging steel, but with greater resistance to corrosion.

Precipitation-hardening stainless steel 17-7 PH is steel in which the required structure and properties are achieved by controlled transformation. After heating at temperatures up to 1050°C and cooling in air steel structure has around 70% austenite and 30% ferrite (Figure 3a). Maximal hardness of steel in that state is around 220HV.

Strengthening of the steel is achieved by the transformation of austenite into martensite and subsequent precipitation of intermetallic compounds. Complete transformation of austenite into martensite can be achieved with heating the steel to temperature 780°C and subsequent cooling to temperature -70°C or with cold deformation in amount higher than 50%. Annealing of 17-7 PH steel at 780°C causes very intensive precipitation of $M_{23}C_6$ carbides and reducing of carbon content in austenite matrix. It increases of the martensite transformation temperature and enables complete transformation of austenite into martensite. It is possible combine the heat treatment with cold deformation with the aim of achieving complete transformation of austenite into martensite (Figure 3b and 3c). It means that microstructural characteristic and appropriate mechanical properties can be regulated by transformation austenite into martensite since that the transformation determines amount of austenite and martensite in structure. In any case presence of δ ferrite is undesirable so its content should be as little as possible.

After partial or complete transformation austenite into martensite these steels are additionally strengthened with precipitation aging. This strengthening with precipitation of intermetallic phase NiAl (Figure 3d) is very simple and effective [5].

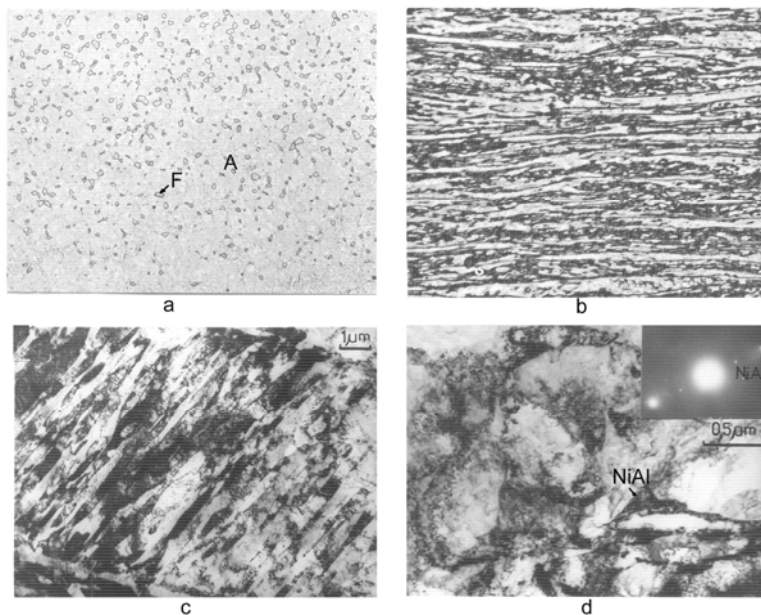


Figure 3. Microstructure of 17-7 PH steel, a) Austenite+Ferrite – light microscopy, b) cold-deformed (Martensite+Austenite+Ferrite) – light microscopy, c) cold-deformed (Martensite+Austenite+Ferrite) –TEM, d) cold-deformed and aged (Martensite+Austenite+Ferrite) –TEM

3. CONCLUSION

This paper describes the effects of heat treatment and cold deformation, in the case of 17-7 PH steel, on the microstructure and mechanical properties of the considered steels. It was found that in 18Ni (250) Maraging steel in the temperature range of 750-1000°C, in the case of slow cooling, the decreasing of ductility occurs as result of precipitation of titanium carbonitrides at austenite grain boundaries. This should be taken into account in the case of the heat treatment of products with larger sizes. Maraging steel 18Ni (250) has very good properties but its manufacturing technology is very complicated and expensive. Precipitation-hardening stainless steels with a simple system of alloying and possibility of the microstructure and properties control, with relatively high tensile strength and hardness, and also good corrosion resistance, are increasingly used.

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