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Microstructural Analysis of 400 Grade Maraging Steel
After Thermomechanical Treatment

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Abstract

Maraging steels 400 were developed targeting to reach high levels of mechanical resistance with a good toughness. Being maraging steels highly alloyed materials, they have the tendency to segregate some elements in its as-cast condition. This microsegregation is reduced when the material is homogenized at high temperatures for long time. Elements that more segregate are Ti and Mo. Microsegregation was investigated by means of scanning electron microscopy (SEM) with microanalysis by EDS. On the other hand, by means of electrical resistivity it was observed that the more dissolved are the alloying elements the higher is the electrical resistivity. In forging, the resistivity tends to increase and an additional thermal treatment for 835°C strongly reduces the electrical resistivity increasing simultaneously the microhardness. Through transmission electron microscopy (TEM) an intense precipitation was observed. Subsequent thermal treatments to higher temperatures, showed that the ideal solubilization of the maraging steel 400 occurs at 1050°C.

Keywords: microsegregation; macrosegregation; maraging steel, resistivity; precipitates

Introduction

In the sixties and early seventies maraging steels were developed, conforming to a class of steels of high resistance. These steels present mechanical resistance levels superior to 1700MPa allied with excellent toughness^[1]. Those steels usually contain 18% Nickel and other substitutional elements, such as Co, Mo and Ti. Traditional maraging steels are usually solubilized in the austenitic range, around 830°C, and cooled until room temperature to obtain a totally martensitic structure^[2-4]. The characteristic of those steels with high nickel content is that they are soft and ductile in the quenched condition and are hardened by means of an aging thermal treatment at 480°C for 3 to 4 hours, reaching high levels of mechanical resistance (microhardness)^[2].

Steels with high Mo and Ti contents tend to segregate them during the solidification. The goal of this work is to determine the microstructural characteristic during thermal and thermomechanical treatments, such as, segregation in the as-cast material condition, homogenization, electrical resistivity and Vickers microhardness.

Experimental methods

The material used in this work was a thick disk of maraging steel 400 with 150mm of diameter and 34 mm of thickness, cutted from an ingot manufactured by vacuum induction melting (VIM) and remelted by electroslag (ESR) to get satisfactory mechanical properties. The chemical composition of this alloy is shown in Table I.

Three samples of the ingot were removed, P1 (sample of the superficial area of the ingot), P2 (sample of the intermediary area or mid-radius) and P3 (sample of the central area), in which several techniques were used to determine the segregation degree, mechanical properties and electric resistivity of the material. The macrosegregation was determined using the X-ray fluorescence technique (XRF); microsegregation in the material was analyzed by means of scanning electron microscopy (SEM) coupled with microanalysis by EDS and electrical resistivity. Vickers microhardness technique was used to evaluate the mechanical resistance of the material.

Soon after, an homogeneization thermal heat was done in the ingot at 1200°C for 30 hours with the purpose to dissolve the segregated elements. After the homogeneization the material was thermomechanically treated (forging) at 1200°C reaching dimensions of 100mm of width, 15 mm of thickness and length of 400 mm.

To checking the microsegregation degree and the influence of the homogeneization thermal treatment the microsegregation index (I_s) defined according to the equation below was used:

$$I_s = C_M/C_m \quad (1)$$

Where: C_M is the maximum concentration
 C_m is the minimum concentration

The wrought material was submitted to thermal treatments at temperatures of 835, 900, 950, 1000 and 1050°C for 1 hour.

Characterization of the above-mentioned samples was done by using the techniques of transmission and scanning electron microscopies coupled with EDS to observe the structure and the microsegregation. Vickers microhardness and electrical resistivity techniques were used to investigate how microsegregation influences these properties.

Table I - Chemical composition of maraging steel 400.

	Chemical compositions (in Weight Percent)									
Steel	C	Si	Mn	P	S	Ni	Mo	Co	Ti	Al
M400	0,012	0,2	0,07	<0,01	<0,002	12,4	10	13,9	0,27	0,06

Results and Discussion

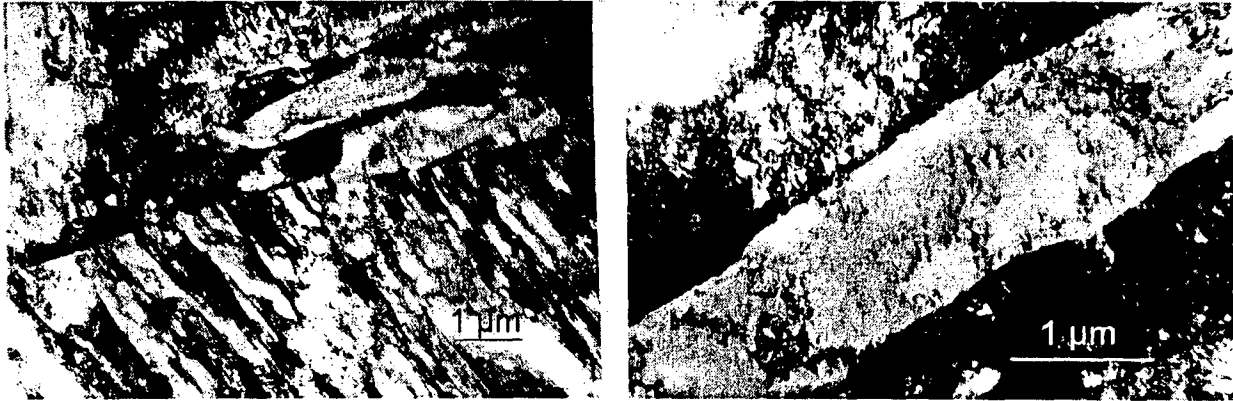
A) Determination of the macrosegregation

Results of the X-ray fluorescence analysis of the material in the as-cast condition, in the P1, P2 and P3 ingot regions are shown in Table II.

From the results, it is verified that the material doesn't shows tendencies of alloying elements macrosegregation. The small variations are in agreement with the accuracy of the used analysis technique, that is placed in the range from 1 to 2%.

E) Microstructural Studies

Figures 2a and 2b show transmission electron micrographies of the forged material where the structure martensitic is observed in laths form with a high density of dislocations, without evidence of precipitation.



Figures 2 (a–b). Transmission electron micrographies of the forged material; lath martensitic structure with a high dislocation density.

Figure 3a exhibits transmission electron micrograph of the forged material, that was thermally treated at 835°C for 1 hour. It is observed in this micrograph the presence of fine precipitate inside grains. Figure 3b exhibits the selected area diffraction pattern (SAD) where it was verified that the existing precipitates are Ni_3Mo and Ni_3Ti types.



Figure 3 (a–b). Transmission electron micrograph of the forged and thermally treated (835°C for 1 hour) material: a) fine precipitates inside grains, b) selected area diffraction pattern (SAD); precipitates are Ni_3Mo and Ni_3Ti types.

Figure 4 exhibits transmission electron micrograph of the forged material, that was thermally treated at 1050°C for 1 hour. This micrograph presents a lath martensitic structure, with a high dislocation density, without the presence of precipitates.

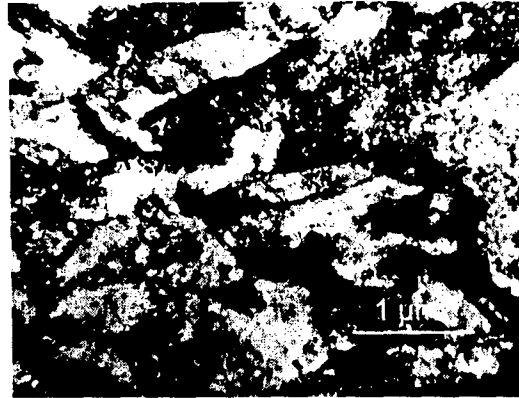


Figure 4. Transmission electron micrography of the forged and thermally treated (1050°C for 1 hour) material; lath martensitic structure showing a high dislocation density without the presence of precipitates.

By the results, it was verified that the forged material presented a martensitic structure, in lath shapes, without the presence of precipitates, even so when the material is thermally treated at 835°C it tends to form precipitates inside the grains, making that the material presents a smaller resistivity and an increase in the microhardness.

Thermal treatments at temperatures above 835°C results in precipitation (835°C), precipitation and beginning of coalescence (900°C), precipitation and coalescence (950°C), coalescence and dissolution of the precipitates (1000°C) and finally, solubilization (1050°C), showing that in the maraging steels 400, the solubilization temperature is higher than that of the traditional maraging steels where the solubilization occurs at 830°C.

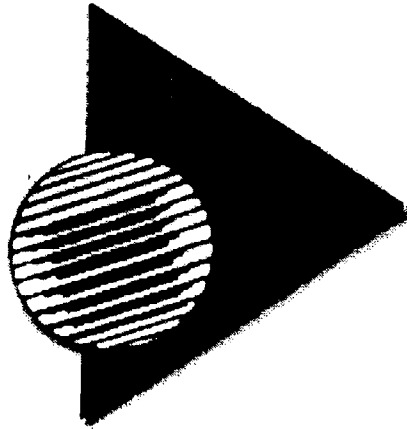
Conclusion

It is concluded that:

- 1) As-cast material presents intense inter-dendritic segregation of the elements Mo and Ti;
- 2) Homogeneization at 1200°C for 30 hours was not too effective;
- 3) Thermal treatment at 835°C causes precipitation, increase of the microhardness and a drop in the electrical resistivity;
- 4) Thermal treatment at 1050°C causes the ideal solubilization of the material, making that a decrease in the microhardness and an increase in the resistivity occur.

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Preface

We are glad to present you with the Proceedings of THERMEC 2000, the International Conference on Processing and Manufacturing of Advanced Materials, held in Las Vegas, NV, USA, during December 4-8, 2000. As in the earlier conferences, the Conference was very well attended by about 500 participants from 35 countries, making this a truly international event. This Conference was co-sponsored by and jointly organized with The Minerals, Metals and Materials Society (TMS), The Japan Institute of Metals, The Iron & Steel Institute of Japan, The Japan Institute of Light Metals, The Society of Materials Science of Japan, The Japan Society of Technology for Plasticity, The Korean Institute of Metals and Materials (KIMM), The Indian Institute of Metals (IIM), The Chinese Society for Metals, Verein Deutscher Eisenhüttenwesen, Germany, and Society Francaise de Metallurgie et Materiaux, France.

Thermomechanical Processing (TMP) is a key processing technology in the development of materials with improved properties and performance, in addition to cost saving of both ferrous and non-ferrous materials. Today the scientific and practical knowledge has reached a level that, in a number of cases, permits the planned development of advanced materials by suitable processing/fabrication techniques. Consequently, THERMEC 2000 focused its emphasis on the processing, fabrication, properties, and applications of a wide variety of advanced engineering materials. The THERMEC 2000 conference was successful in bringing together leading experts from the industry, academia, and national laboratories from all over the world and provided an important

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Conference Information

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platform for the exchange and discussion of the science and technology of advanced materials. The conference, spread over five days, consisted of 55 sessions devoted to Steels (7), High Nitrogen Steels (2), Stainless Steels (2), Thermomechanical Processing (2), Superplastic Deformation (2), Aluminum Alloys (4), Magnesium Alloys (4), Titanium Alloys (2), Intermetallics (4), Superalloys (2), Composites (2), High Temperature Superconductors (2), Bulk Metallic Glasses (1), Novel and Smart Materials (3), Ultrafine Grained Materials (3), Modeling (5), Textures (4), Coatings (3), and Residual Stresses (1). Leading authorities presented Keynote Lectures in many sessions giving a clear exposition of the present status of the field. These were followed by the invited and contributed papers in the different sessions.

In keeping with the revolution in book production technology, for the first time the THERMEC 2000 proceedings are published as a CD-ROM. We sincerely hope that the participants of THERMEC 2000 and the readers of these Proceedings welcome this idea and, with the approval of the audience, we wish to follow this trend for future Conferences as well. In addition to the CD-ROM, the keynote papers are also presented as a special issue of the *Journal of Materials Processing Technology*. vol 117 / issue 3

A conference of this magnitude requires the help and assistance of a number of people and we were fortunate in receiving that in abundance. The coordinators of the various session topics had devoted a lot of their time, energy, and expertise in contacting potential authors and soliciting abstracts for presentation at the Conference. The Chairpersons of the different sessions did a wonderful job in

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