RESEARCH REGARDING THE ELABORATION OF ECOLOGIC SINTERED LOW-ALLOYED STEELS BASED UPON NANOSTRUCTURED POWDERS

Ph D Thesis Summary

The results of the research within the Ph D paper are lengthwise presented along 7 chapters, including final conclusions, the paper containing an important number of experiments synthesized in 59 tables and processed in 127 diagrams, according to the following research objectives proposed:

- replacing Ni and Cu from the chemical composition of sintered low-alloyed steels with elements such as Mn, Mo, Cr and B;
- elaborating, through mechanical alloying, nanostructured master alloys made of Mn, Mo, Cr, B and graphite in the form of nanometric powder, which in mixture with micronic Fe powder ensures the obtaining of homogeneous mixtures which furthermore bring chemical and structural homogeneity to sintered low-alloyed steels;
- the study of compressibility of homogeneous mixtures of micronic Fe powders and nanometric powders of nanostructured master alloys;
- approaching a new proceeding of sintering, namely sintering in two steps in order to ensure the variation of the granulation of sintered low-alloyed steels;
- the analysis of the interdependence between the structure and the utilization properties of the new ecologic sintered low-alloyed steels;
- the study of the tribological behavior of the new elaborated steels.

Chapter one comprises the results of the bibliographic research which represents a laborious; the bibliographic sources consulted being the newest ones.

Based upon the data from specialty literature, there are emphasized the importance and the effects of different alloy elements, such as Mn, Mo, V, Ni, Cu, W, B etc. on the structure and the utilization characteristics of low-alloyed steels elaborated through specific technologies of powder metallurgy. Under this circumstance, there are made a series of references regarding the possibility of replacing Ni and Cu with Mn, Mo and Cr. At the same time, there are broached a series of technological particularities, especially referring to he presence of B in the powder mixture to elaborate sintered low-alloyed steels on the technological parameters of the sintering operation, underlining the fact that B, in combination with Fe, forms an eutectic which technologically favors the sintering operation through the presence of the liquid phase.

There are made a series of considerations regarding the interdependence between the composition and the structure of sintered low-alloyed steels and the mechanical properties of these alloys, underlining the fact that Mn, Mo and Cr favor the growth in mechanical and shock resistance.

Based upon the data accumulated from bibliographic research, the research is orientated in the direction of replacing Cu and Ni with Mn, Mo and Cr, adding to these B in proportion of 0.5% to facilitate sintering with the presence of the liquid phase.

Under this circumstance, in the end of chapter one there are clearly presented the purpose and the objectives of the research and also the itinerary that is followed within the research.

Chapter two, called “Research regarding the elaboration through MA of nanostructured powders of master alloys and of mixtures of micronic Fe to elaborate sintered low-alloyed steels” comprises the results of the research regarding the elaboration of nanostructured powders which in mixture with Fe represent the raw material to obtain sintered low-alloyed steels.

Under this circumstance, it is emphasized the importance of the utilization of master alloys in the form of nanostructured powders with granules, which have alloy elements of steels in the chemical composition and, as originality element, it centers on the elaboration of these master alloys through mechanical alloy in high energy planetary mills.

The results of the research within this chapter underline the fact that after 20 hours of mechanical alloying, there are obtained nanostructured master alloys in the form of nanopowders with granulation around 700 nm. At the same time, it can be observed an interesting phenomenon, the fact that the presence of B in the mixture of elementary powders favors the smooth division of granules during the mechanical alloying, meaning that after 60 hours of mechanical alloying, the mixtures with B reach a smoother granulation, of 300 nm in comparison to the mixture without B, in which it reaches 600 nm.

Chapter three centers on the study of the technological problems which interfere when elaborating low-alloyed steels from Fe powders and nanopowders of master alloys mixture, which was sintered through mechanical alloying. Under this circumstance, it is enterprised laborious research regarding the compaction and sintering of a number of 14 grades of powder mixtures. There are presented in this context the parameters of the samples resulted from compaction of these mixtures at 600 MPa pressure and, by processing the experimental results, it can be observed that when the mechanical alloying time grows, the compressibility of nanopowders decreases.

In this chapter is remarkable a notable originality element which the author of the paper brings in the research, namely the sintering in two steps. This proceeding is used to ensure a granulation as smooth as possible to the sintered low-alloyed steels. The way in which sintering in two steps is thermally conducted influences granulation, so in order to obtain smooth granulation, there are necessary thermal conditions to ensure diffusion to consolidate the aggregate of nanopowders resulted at compaction.

Based upon the results obtained, it can be observed that this sintering proceeding, in comparison to classic sintering, is more favorable, because it ensures a higher rate of chemical and structural homogeneity and, at the same time, it leads to a growth in density of the sintered material.

Chapter four comprises the results of the research regarding the structural characteristics of sintered low-alloyed steels with Mn, Mo and Cr, with or without B.

At the beginning of the chapter there are structurally analyzed the steels from the point of view of porosity and also considering the measured values in the precedent chapter, it is observed that the presence of B in the mixture of powders leads to a decrease in porosity and sintering in two steps is favorable from this point of view in the case of nanometric powders. In the case of micronic powders, it is necessary to grow the maintaining time at sintering temperatures at over 60 hours to record comparable porosity values.

In what regards the microscopic structure of the steel samples, it is observed that it is ferrito-perlitic and that the homogeneity of the distribution of structural constituents grows together with the growth in smoothness of the powders used to elaborate sintered low-alloyed steels. An important role in this direction has the proceeding of sintering in two steps, meaning that it leads to a better structural homogeneity of the steels.

Referring to the granulation of sintered steels, it is emphasized the fat that it is influenced by the maintaining time at sintering in two steps, meaning that granulation grows together with the growth in the maintaining time at sintering temperature.

Next, it is made the connection between the structure and he mechanical properties of sintered steels and in this context it is analyzed the hardness of these steels, also considering the fact that furthermore their tribological behavior is subject to preoccupation.

In the light of hardness measurements and of data processing, it can be concluded that the hardness of steels depends on the nature and the granulation of the powders used, the optimum values being obtained in the case of powders resulted from the mixtures with nanometric powders of nanostructured master alloys, adding B powder.

Chapter five presents the results of the measurement regarding the friction coefficient of steel samples obtained through compaction at different pressures, of 600, 700, 800 MPa, of powder mixtures.

Based upon the results of the measurement ad the graphic evolution of these values for different types of powder mixtures used to elaborate steels, the author of the paper observes that the steels resulted from the powders resulted through mechanical alloying have the most reduced friction coefficient.

At the same time, comparatively analyzing the steels that come from the same powder grades, but are differently sintered, it can be observed that sintering in two steps allows the elaboration of steels with a more reduced friction coefficient in comparison to those obtained through classic sintering.

Chapter six centers on the optimization of elaboration proceeding of sintered low-alloyed steels, basing upon the results of the experimental research enterprised in order to elaborate this Ph D paper.

○ **Chapter seven** of the Ph D thesis presents the final conclusions and the elements of originality of the research. In this context are to be underlined the following original contributions:

- elaboration, through mechanical alloying, of Mn-Mo-Cr-Graphite master alloys from elementary Mn, Mo, Cr powders, with or without B, destined to realize sintered low-alloyed steels;
- elaboration, through mechanical alloying, of nanostructured composite powders and nanopowders destined to realize sintered low-alloyed steels;
- elaboration of sintered low-alloyed steels without Ni and Cu in order to realize ecological technological proceeding and to reduce the costs of sintered low-alloyed steels;
- establishing interdependence between the nature and granulation of powders of master alloy, respectively nanostructured composites, on the

structural and utilization characteristics of the steels elaborated through the research;

- determining the influence of some technological parameters, especially of the compaction pressure, on the structural and utilization characteristics of the steels elaborated;

- approaching a new proceeding of sintering, namely sintering in two steps, to elaborate sintered low-alloyed steels;

- elaborating sintered low-alloyed steels with remarkable tribological characteristics and which are part of the antifriction material class.

As a consequence of the unrolling of experimental research, there have been obtained a series of experimental results, based upon which the following conclusions can be drawn:

- The mechanical alloying time to obtain nanostructured master alloys is situated around 20 hours when the master alloy powder reaches lower values than 700 nm;
- The homogeneity of the distribution of alloying elements in granules of nanostructured master alloy powders grows together with the growth in MA time;
- The granulation of the powders obtained through the mechanical alloying of the micronic Fe with nanostructured master alloy powders is reduced together with the growth in mechanical alloying and the homogeneity of powder granules from the point of view of the distribution of master alloys in the mixture, grows together with the growth in mechanical alloying time;
- In the case of composite powders with the Fe-3Mn-1Mo-1.5Cr-0.45Graphite contents, with or without B adding, the granulation evolution is different, meaning that in both cases granulation decreases together with the increase in mechanical alloying time, but it has been obtained that the presence of the B powders favors the smooth division of

composite powder granules. It is observed that at 60 hours mechanical alloying time, the composite powders with B contents reach around 300 nm, while the composite powders without B reach dimensions about 600 nm;

- The density of the sintered samples grows together with the growth in mechanical alloying time, meaning that the highest values, of about 7.4 g/cm^3, are obtained in the case of powders elaborated through mechanical alloying for 60 hours, while the samples sintered classically reach 7.2 g/cm^3 for the powders resulted from mechanical alloying for 20 hours;
- Using the powders mechanically alloyed for a longer time to elaborate sintered low-alloyed steels is favorable from the point of view of the chemical and structural homogeneity and therefore, from this point view, sintering in two steps is favorable;
- Comparatively to classic sintering, the density of the sintered samples record values continuously growing at the growth in mechanical alloying time in the case of sintering gin two steps;
- An interesting observation is that at the sintering in two steps, the density of the samples with B contents is higher, comparatively to the same samples, but without B contents, but at the samples mechanically alloyed for 60 hours, the densities of the two categories of samples are equalized;
- In what regards the chemical homogeneity of the distribution of alloying elements, in the case of sintered steels elaborated, from the two categories of powders, it is observed that using mixtures of micronic Fe powders with nanostructured master alloy powders obtained through mechanical alloying for 20 hours is favorable in what regards the Mn distribution, the other alloying elements having the same distribution regardless of the nature of the powder mixture;

- The structural and mechanical characteristics of sintered low-alloyed steels depend on the nature and the granulation of the powders used. In this direction, the lowest porosities are those of the steels from nanostructured composite powders obtained though mechanical alloying for 60 hours, thus with the smoothest granulation;
- The chemical composition of the fabrication powders of steels influences the structural and mechanical characteristics and in this context research has emphasized that sintered steels coming from powders with 0.5% B have a higher homogeneity and increased hardness in comparison to the same steels, but elaborated from powders without B;
- The sintered proceeding adopted to elaborate sintered low-alloyed steels highly influences their structure and resistance characteristics and in this context the results of the experimental research have emphasized the superiority of the same steels, but realized through classic sintering;
- In what regards the porosity of sintered low-alloyed steels, the lowest one, of 5.37%, belongs to the steels elaborated from composite nanopowders with B (MA 60+B), sintered in two steps, in comparison to the porosity of 8.72% of the same steels, but classically sintered;
- From the point of view of structural homogeneity, the most homogeneous structures are those of the steels elaborated from the MA 60+B nanopowders sintered in two steps;
- From the point of view of the hardnesses of the sintered low-alloyed steels, the highest ones, both at classic sintering and at sintering in two steps, are those of the steels coming from nanometric MA 60+B powders, i.e. 342 HV in the case of classic sintering and 417 HV for sintering in two steps. These values emphasize the influence of the sintering proceeding on the characteristics of sintered steels;

- From the point of view of the nature and granulation of powders, the best values of the friction coefficient are those of the steels elaborated through composite nanopowders with B, resulted from MA;
- From the point of view of the technological parameters of elaboration, it can be observed that the values of the friction coefficient decrease together with the increase in compaction pressure, regardless of the nature and granulation of the powders used to process them;
- From the point of view of the sintering proceedings adopted, it can be observed that at sintering in two steps, the friction coefficient is much lower, of 0.116, for the steels elaborated from composite nanopowders with B (MA 60+B), in comparison to the value of the friction coefficient of 0.158 for the same steel, but obtained through classic sintering;
- From the point of view of the contents, for the mechanical characteristics determined – hardness, their highest values and also a very low friction coefficient are for the steels from powders containing B;
- The compaction pressure positively influences these mechanical characteristics determined. Together with its growth and also of the density, the HB hardness of the sintered low-alloyed steels grows and reaches the maximum at 800 MPa; also, the friction coefficient in sintered state reaches the maximum at 800 MPa, too;
- The sintering temperature influences mechanical characteristics in this way: from the point of view of hardness wear, it is favored by superior sintering temperatures;
- Sintering in two steps favors the growth in hardness of sintered steels and the reduction of the friction coefficient in comparison to classic sintering.