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IMMC 2018

STA'S
Session 1

Session Chairman / Oturum Başkanı: **C. HAKAN GÜR**

10.00 - 10.20	**Factors Influencing Mechanical Properties of Sintered Steels: Density and Carbon Content** **Nuray Beköz Üllen[1], Ceyda Yeşilay[2]** [1]İstanbul University-Cerrahpaşa, [2]GKN Sinter İstanbul Metals Industry and Trade Inc. Türkiye
10.20 - 10.40	**Efficient Special Steelmaking, a Technology Comparison** **Dennis Hüttenmeister, Michael Hohmann, Ulrich Biebricher, Gerhard Brückmann** ALD Vacuum Technologies GmbH Germany
10.40 - 11.00	**The Effect of Nitrogen-Containing Vanadium Alloying Element Additions on the Properties of S550MC Grade Steels** **Özcan Kaya[1], Kıvanç Çeitnkaya[1], Dilara Çimen[1], Zafer Çetin[1], Bora Derin[2]** [1]Ereğli Demir Çelik, [2]İstanbul Technical University Türkiye

STA'S
Session 2

Session Chairman / Oturum Başkanı: **C. HAKAN GÜR**

12.00 - 12.20	**Intelligent Cost Cutting Challenges in High Carbon Ferrochrome Operations While Diversifying Products** **Alparslan Malazgirt, Yavuzhan Kaya** Yılmaden Holding Inc. Türkiye
12.20 - 12.40	**Online Training and Certification of Non-Destructive Testing Personnel** **Ertuğrul Yılmaz** Ankalite Kalite Kontrol Türkiye

STA'S

Steelmaking Technologies and Applications Symposium
Çelik Üretim Teknolojileri ve Uygulamaları Sempozyumu

Factors Influencing Mechanical Properties of Sintered Steels: Density and Carbon Content

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Abstract

Powder metallurgy (PM) materials provide a cost efficient solution for a wide range of applications. As these materials and processes improve, they can be applied to components with tougher requirements. The mechanical properties of sintered materials depend mainly on the microstructure and density. Theoretical applicability of the experimental studies in this regard is not enough. The results of this study are obtained in mass production trials. The number of tested parts is more than usual. Sintered specimens having densities 6.9, 6.95, 7.0 g/cm^3 were produced from 0.5 and 0.8 wt. % carbon added Ni-Mo-Cu alloyed powders. The influence of manufacturing parameters such as density and carbon ratios on the mechanical properties of the sintered steels was investigated. Specimens were sintered at 1120 °C under endothermic atmosphere for 25 minutes in an industrial sintering furnace. Mechanical properties (hardness and tensile strength) were measured. Results show the mechanical properties increased by increasing density and carbon contents. Effect of the increased density is more prominent on the properties than carbon additive. Also the open and closed porosity contents of the specimens were determined and the effect was discussed.

1. Introduction

The advantages of the PM process compared with forging are that it is suitable for complexly shaped parts, the raw material utilization rate is high, and the production cost is reduced [1]. As stated earlier, the mechanical properties of PM parts are, to a great extent, dependent upon the density achieved in the part. Higher density is a key route for higher performance of PM components. With higher density strength and ductility of the sintered materials are improved. There are a number of possible routes for higher density such as high temperature sintering, copper infiltration, and liquid phase sintering and double pressing. It is however attractive if high density can be achieved by single press and single sintering process and thus avoiding large shrinkage during sintering in order to keep close tolerances [1-2]. The classification of density levels recognized by the Metal Powder Industries Federation [3]: R ranges from 6.4 to 6.8 g/cm^3; S ranges from 6.8 to 7.2 g/cm^3; and T ranges from 7.2 to 7.6 g/cm^3. The T density level is achieved by double pressing and sintering, and even S level may require double pressing and sintering. But, in addition, mechanical properties are also influenced by carbon and alloy content, and heat treatment. Carbon content is especially critical for sintered steels and it is essential that the carbon content be controlled within narrow limits, since the hardness of martensite strongly depends on its carbon content. In PM sintered steel, there is a threshold value of 1.0 wt. % for the carbon content. When the carbon content is higher than 1.0 wt. % the tensile strength of the parts will decrease, and sintering deformation is more likely to occur in the material. In addition, the alloying elements will also be segregated, leading to a reduction in the cutting performance and plastic properties of the material. Therefore, in this study, a range of 0.5-0.8 wt. % carbon was chosen to investigate the effect of carbon content on the mechanical properties [4]. The selection and use of pre-alloyed powders have many advantages over mechanical properties of sintered materials. Low alloyed steel powder commercially known as Distaloy AB is a partially pre-alloyed iron powder containing copper, nickel and molybdenum. High strength can be obtained after sintering with additions of graphite. This steel has for long time been one of the most commonly used alloying system for high strength components in the PM industry. [5]. A number of studies have been carried out on steel powder used in this study [6-8]. This is typically carried out experimentally in lab-scale. However, in this study, large-scale industrial application of this method was evaluated.

There are big differences between the parts produced in the laboratory and mass production. In this case, the results of the tests on the parts are different. The results of this study are obtained in mass production trials. The success and quality of findings obtained as a result of academic studies trials hinge upon observing the actual effect of the applied method on the appearance of the measured result. In the present study, different powder mixes produced to evaluate influence of carbon content and density on the mechanical properties. The results of this study are obtained in mass production trials. The number of tested parts is greater than for similar studies.

2. Experimental Procedure

Low alloy steel specimens were produced by powder metallurgy method using diffusion alloyed steel powders (Distaloy AB), which is a registered trademark of Höganäs Company, Sweden. The steel powder was mixed with different contents of fine graphite (UF4) to increase the hardness of the steel. The powder mixtures were prepared by weighing samples in Sartorious balance with 0.01 g sensitivity and then mixed homogeneously in a laboratory scale mixer for 30 min. The chemical compositions of the powder mixes prepared are given in Table 1. The pre-alloyed powders had a rounded but irregular shape. Typical morphology of steel powders revealed by scanning electron microscopy (SEM) is given in Figure 1.

Table 1. The chemical composition of the mixes (wt.%).

Base powders	**Cu**	**Ni**	**Mo**	**C**	**Lub.**	**Fe**
Distaloy AB	1.43	1.67	0.48	0.5 0.8	0.90	Bal.

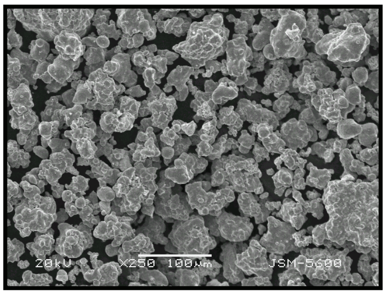

Figure 1. SEM image of the steel powder.

The parts were pressed under different pressures to obtain different densities. The sintering process was performed via a single normal-temperature sintering (1393 K and 30 min) route in a continuous furnace under an ammonia dissolving atmosphere. Ammonia dissolving is used as a protective atmosphere to protect the parts from oxidation during the sintering process. The carbon potential was controlled by the protective ammonia dissolving atmosphere so that the carbon content of the blank was maintained at the same level as the original ones. All of the part densities were well controlled by compacting. Density and porosity content of the sintered specimens were determined by employing Archimedes' principle in a Sartorius precision balance equipped with a density determination kit. At least five specimens were used for characterizing each porosity level. In order to find the correct amount of open porosity, the closed porosity was measured and then subtracted from the total porosity. PM parts used in this study produced by GKN Sinter Istanbul Metals Industry and Trade Inc. is shown in Figure 2. These parts are produced as tensile test specimens by GKN Sinter İstanbul.

Figure 2. The investigated parts.

All of the sintering tests were performed in mass production trials. Rockwell B (HRB) scale was used to measure the macrohardness of the specimens in Zwick hardness testing machine. Three different locations were selected on the surface of the specimens and the average of those values was used as the hardness measure of samples. Tensile test of the specimens were investigated at room temperature using the Zwick-Roell Z250 testing machine, with a strain rate of 1 mm sec^{-1}. Grease oil was used between the samples and the compression loads to minimize the friction. Each test was repeated ten times to ensure the repeatability of the results. Tensile testing was made according to ISO 6892 and hardness was evaluated according to ISO 7498.

3. Results and Discussion

Specimens having densities 6.9, 6.95, 7.0 g/cm^3 were produced after sintering. The specimens have porosities in the range of 10.25-11.50% and the total porosity of the specimens consists of 1.75-2.85% open and 8.50-8.65% closed porosity. The final porosity content was directly concerned to the compacting. Figure 3 shows tensile properties as functions of the sintered density of the specimens with 0.5% combined carbon. By increasing the density from 6.9 to 7.0 g/cm^3, the mechanical properties of parts increase significantly. The influence of density is clearly demonstrated. The ultimate tensile strength increases linearly with the density. All materials exhibit an average tensile strength that exceeds 460 MPa.

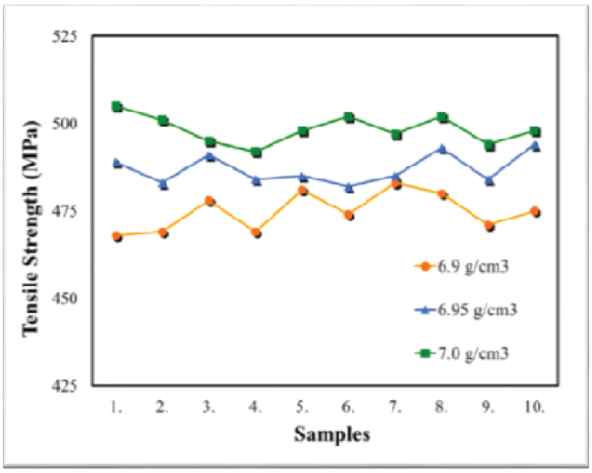

Figure 3. Influence of density on tensile strength.

Figure 4 describes the apparent hardness as functions of the sintered density of the specimens with 0.5% combined carbon. By increasing the density from 6.9 to 7.0 g/cm³, the hardness of parts increase significantly as expected. The hardness increased from about 75 HRB at the lower density level up to 82 HRB for the highest density.

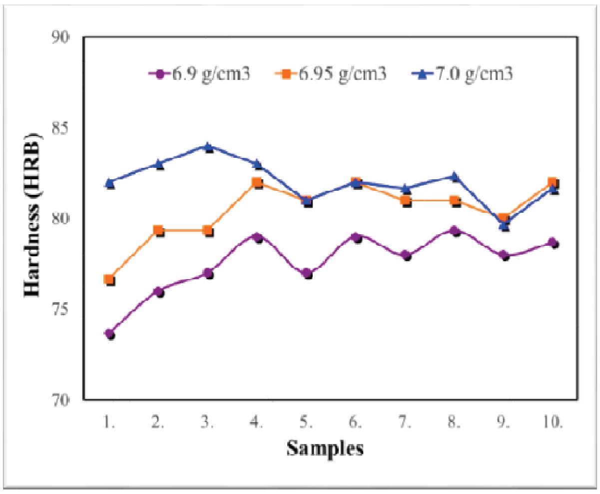

Figure 4. Influence of density on hardness.

The apparent hardness measurements as functions of the carbon content of the specimens with the density 7.0 g/cm^3 are shown in Figure 5. As expected, increasing the carbon content and density led to an increase in hardness. Hardness levels greater than 88 HRB were achieved at the highest carbon content level. Hardness is linear functions of carbon content. By increasing the carbon content from 0.5% to 0.8% the hardness of the materials is increased about 5%. This is due to the change in microstructure. At the lower carbon level the microstructure consists of bainite and some ferrite while at the higher level 0.8% carbon the microstructure is completely bainitic.

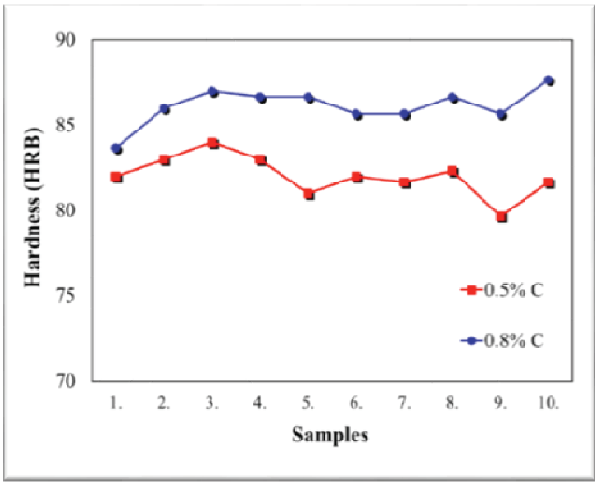

Figure 5. Influence of carbon content on hardness.

Improvements in powder processing have resulted in improved mechanical properties of PM steel parts, thus increasing the cost-effectiveness of PM processing. There is no significant effect on the results of increasing the number of investigated parts in this study. The strength and hardness of this type of material has been shown to be related to its content of martensite and bainite depending on carbon and density ratios. It should be pointed out that considerable higher hardness after sintering could be achieved by increasing the carbon content, [6] as is the case in this study. As mentioned above, the high tensile strength in the as-sintered stage of materials made from partially pre-alloyed powders containing Ni and Mo with additions of graphite is related to the occurrence of Ni martensite in the structure. Several studies have indicated the increasing carbon content of sintered steels increases strength, but decreases ductility and toughness. The increase in strength with increase in carbon content is more evident at higher density levels, but is generally proportional to density [9-10].

4. Conclusion

The conclusions that can be drawn from this study are the following:

▪ Mechanical properties of PM steels are strongly dependent on density. The increased density results in an improvement of the mechanical properties of 10-15 %. Increased density improves the strength thanks to the creation of a finer pore structure and the elimination of the large pores.
▪ Carbon as an alloying element is now as important in the sintering industry as in conventional steelmaking. By increasing the carbon content from 0.5% to 0.8% results in an improvement of the hardness of about 4-6 % due to changes in the microstructure.
▪ The work presented in this paper is the result of ongoing studies and more work is in progress. Comparison of theoretical and experimental studies should be studied.
▪ The better assessment of mechanical properties of PM products needs further laboratory tests and theoretical analysis.

Acknowledgment

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