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STUDY OF AIR QUENCHING INFLUENCE ON VALVE SEAT INSERT OBTAINED WITH AISI M2 HIGH-SPEED STEEL

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Abstract. *This work aimed to heat treat sintered valve seat insert (VSI) in a fashion of improving the mechanical and physical properties of such component. The studied VSI was obtained from a powder mixture of AISI M2 high-speed steel, iron, manganese sulphide, niobium carbide, graphite, zinc stearate and copper. Such powders characterization consisted of determining its particle size distribution and morphological aspects. The VSI was air quenched and double tempered at seven equidistant temperatures, from 100 °C until 700 °C. A thermocouple type k attached to a data acquisition system was used to measure the temperature variation along the heat treatment. The mechanical and physical properties were analyzed by the VSI apparent density, apparent hardness and crush radial strength. The component's chemical composition was determined through gas analysis method and energy dispersive spectroscopy (EDS). The air quenching and double tempering at 600 °C provided the VSI best property according to the automakers' hardness requirements.*

Keywords: *Powder metallurgy, AISI M2 high-speed steel, Valve seat insert, Heat treatment*

1. INTRODUCTION

Automobile engines have undergone substantial changes, which have resulted in increased performance, reduced fuel consumption and environmental impact (Chang, *et al.*, 2013). Part of the mechanical set responsible for sealing the combustion chamber is constituted of valve seat and valve seat insert (VSI), as shown in Fig. 1.

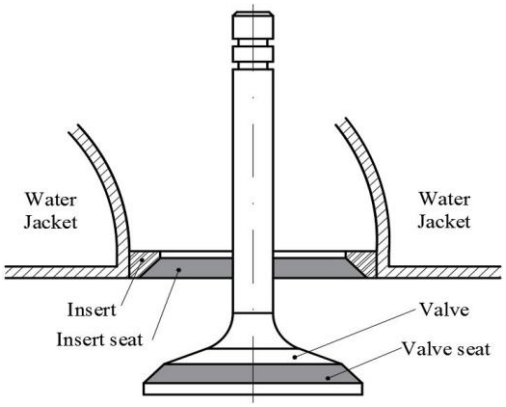

Figure 1. Schematic drawing indicating the valve and insert position in an internal combustion engine

The VSI for intake and exhaust of gases in the combustion chamber operate under severe conditions (Jesus Filho, *et al.*, 2005). The worst case occurs to the exhaust stroke when the temperature at the valve seat can reach 700 °C, and at the insert seat up to 350 °C (Sector Group of Powder Metallurgy, 2009). The use of powder metallurgy components have improved engine performance, as well as reducing its costs (Chang, *et al.*, 2013; Whittaker, 1998; Whittaker, 1999). The use of high-speed steel (HSS) for sintered parts is a consolidated option for this application due to its good mechanical properties, corrosion resistance, high thermal conductivity and good machining (Myers, 1999).

The aim of the present work was to heat treat and characterize valve seat inserts obtained through powder metallurgy technique with AISI M2 high-speed steel powder. The heat treatment consisted of air quenching and double tempering all the components. As any temperature up to the lower critical may be used for tempering (Krauss, 1990) all air quenched VSI were double tempered at seven equidistant temperatures, from 100 °C until 700 °C.

2. EXPERIMENTAL PROCEDURE

The VSI investigated along this work were obtained through the P/M technique. The powders mixtures consisted of high-speed steel (HSS) type AISI M2 plus iron powder and others additives such as manganese sulphide, niobium carbide, graphite and zinc stearate to reduce the die-wall friction. The HSS powder particle size distribution determination was based on the principle of laser multi angle analysis. The chemical composition of the powders mixture carried out along this work is shown in Tab. 1. (German, 1998).

Table 1. Nominal composition (mass %) of the studied powders mixtures.

Element	AISI M2	Fe	MnS	NbC	C (graphite)	Zn stearate	Cu (infiltration)
Alloy	43.6	43.6	0.5	2.0	0.3	0.8	10.0

All the powders mentioned in Tab. 1 were mixed in an intensive mixer for 300 s at 1,715 rpm, except copper because it was added by metallic infiltration, i.e., two compacts with dimensions of 32.5 x 25.5 x 5.9 mm^3 were pressed from the iron powders mixtures and cooper before the sintering process took place. These two compacts had to be put together, to mount one on top of the other. Green compacts were obtained from the powders mixtures compaction in a double action automated hydraulic press at a pressure of 700 MPa.

The compacted VSI was pre-heated up to 600 °C (0.3 °C/s) for 2,100 s to ensure the zinc stearate elimination. Then, it was sintered at 1,150 °C (0.2 °C/s) for 2,400 s. By last, the VSI was cooled until room temperature with a rate of 0.3 °C/s. The sintering process have been performed in a continuous commercial belt furnace under a hydrogen-based (90% H_2 + 10% N_2) atmosphere.

The sintered VSI heat treatment consisted of austenitizing it at 1,150 °C (heated at a rate of 0.5 °C/s) for 1,200 s in a laboratory muffle. In order to avoid decarburization, the VSI were wrapped in a blick white sulphite drawing paper and put inside a cast iron box containing a mixture of 50% C (graphite) + 50% Al_2O_3 (aluminum oxide). Then, this box was put inside the muffle for heat treatment. A thermocouple type k was attached to the samples and a data acquisition system was used to measure the cooling rate of the VSI samples. The austenitized samples were at that time air quenched until room temperature. All air quenched VSI were double tempered till room temperature, for one hour each at seven equidistant different temperatures, ranging from 100 °C up to 700 °C.

The components physical and mechanical properties were determined through three main tests. The apparent hardness of all heat treated VSI was determined in accordance with the standard ASTM E 10-01 (2004). This test method covers the determination of the Brinell hardness of metallic materials. Then, the as sintered densities were measured immersing the inserts into water using the Archimedes method, in agreement with the standard ASTM C 373-88 (2004). By last, the crush radial strength test was performed in agreement with the standard MPIF 35 (2009). This standard test consists of radially compress the VSI until its first crack appear.

The chemical composition analyses were carried out using two techniques, gas analysis and energy dispersive X-ray fluorescence spectrometry (EDXRFS). The gas analyzer equipment determined the content of light elements, such as carbon and sulfur within the samples. This apparatus uses an induction furnace and measures the amount of each element by infrared absorption (Moura, *et al.*, 2013). The others elements were measured using the EDXRFS technique (Warren, 1990; Cullity, 2014; Girolami, 2016).

3. RESULTS AND DISCUSSION

The graphical particle size distribution of AISI M2 HSS powder is shown by means of Fig. 2. It can be observed a bimodal asymmetric distribution. Due to the method of obtention, which was by gas atomization (German, 1994), the AISI M2 powders had a spherical shape.

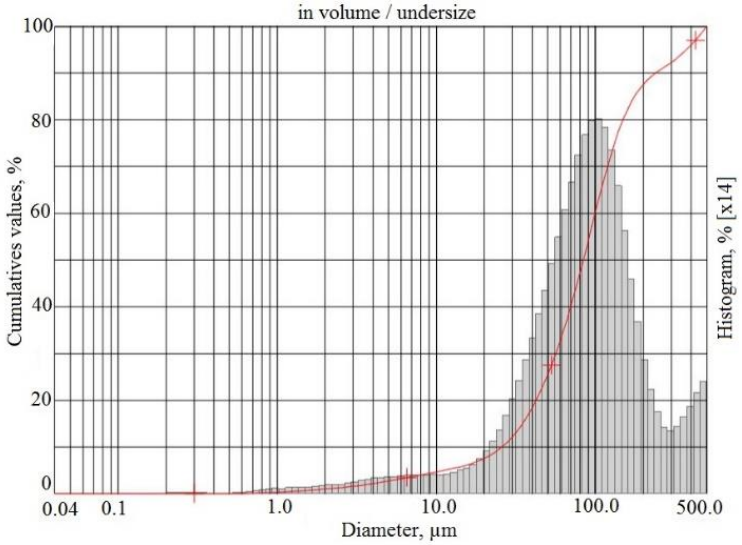

Figure 2. Graphic of the high-speed steel AISI M2 powder particle size distribution measured by laser diffraction

The Brinell hardness (HB 2.5/187.5) variation for the VSI taking into account the as sintered and the heat treated one, one hour each at the specified temperature and then air-cooled, ranging from 100 °C up to 700 °C, is shown in Fig. 3.

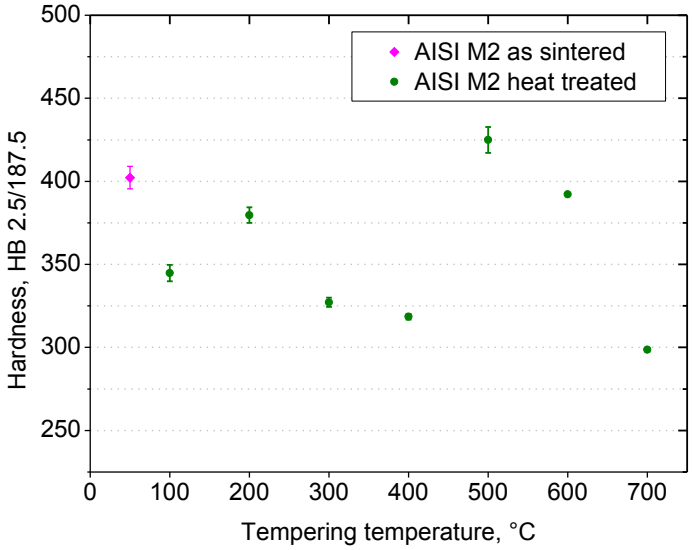

Figure 3. Brinell hardness (HB 2.5/187.5) variation for the VSI as sintered, quenched (1,150 ˚C quenched in air) and double tempered at seven equidistant different temperatures

It can be observed a substantial variation of the component's hardness. According to the VSI final commercial application requirements, the hardness should be between 370 HB till 410 HB (2.5/187.5). Fig. 3 also shows that the heat treatment that most got close to a hardness between 370 HB till 410 HB, is the Alloy (AISI M2 mixture) double tempered at 600 °C. Hence, it worth mention that all the following given results and discussion of the present work are focused on these heat treatment. Although the apparent hardness is a very important property, the apparent density and crush radial strength (CRS) are as important as the VSI apparent hardness. Briefly, the results of the properties mentioned previously is shown in Tab. 2.

Table 2. Physical and mechanical properties of the valve seat insert obtained with the Alloy (AISI M2 powder mixture) air quenched and double tempered at 600 °C

Property	Apparent density (g/cm^3)	Hardness (HB 2.5/187.5)	Crush radial strength (MPa)
Alloy	7.4 ± 0.3	392 ± 1	579 ± 92

In comparison with the work developed previously by Santos *et al.* (2014a, 2014b, 2016), only with as sintered components, the apparent density can be considered the same, 7.4 g/cm^3. The apparent hardness values measured by Santos (2014a) was lower, 345 ± 21 HB, than the one obtained in the present work, 392 ± 1 HB. Additionally, the CRS values obtained by Santos (2014a) was a little bit higher, 595 ± 48 MPa, than that shown here, 579 ± 92 MPa. Although the CRS values obtained in the present work are lower when comparing to that one developed by Santos (2014a), this property is only necessary when assembling the VSI into the engine block. Therefore, there is no minimum level requirement for the CRS, the component just need to withstand the assembly step.

The measured chemical composition of the VSI in shown in Tab. 3. The carbon and sulfur contents were determined through the gas analysis method; all the other elements were determined using energy dispersive X-ray fluorescence spectrometry (EDXRFS).

Table 3. Valve seat insert chemical composition (mass %) determined by gas analysis and energy dispersive X-ray fluorescence spectrometry (EDXRFS). The carbon and sulfur contents were determined using gas analysis.

Element	Fe	Cu	Mo	W	Cr	Nb	V	C	Mn	Si	S
Alloy	73.52 ± 0.02	15.04 ± 0.01	2.77 ± 0.01	1.62 ± 0.01	2.09 ± 0.01	2.03 ± 0.03	0.79 ± 0.01	0.97 ± 0.03	0.78 ± 0.06	0.27 ± 0.07	0.12 ± 0.02

From the results shown in Tab. 3 it can be noticed, regarding the copper concentration, a considerable variation from the nominal value (see Tab. 1). This value should be 10%, but the measured value was 11.79%. Such copper variation can be justified by not precisely measuring the copper ring's mass, which should be ten percent of the insert's mass, *i.e.*, the insert and the copper ring should be precisely paired. The cooling rate during air quenching for the studied VSI was measured with a thermocouple type k attached to the sample and to a data acquisition system, and it was 0.6 °C/s

4. CONCLUSIONS

The heat treatment proved to be efficient regarding the desired mechanical and physical change, resulting in a wide variation of such properties.

It can be inferred from the mechanical properties results that as higher as the hardness is attained, the lower the crush radial strength of the VSI tends to be.

Regarding the hardness variation, which is a very important mechanical property, the components reacted in a good way and showed to be sensitive to the different temperatures applied while been heat-treated.

5. ACKNOWLEDGEMENT

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7. RESPONSIBILITY NOTICE

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