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Effect of Heat Treatment on the Microstructure of Spray Formed AISI M2 High-Speed Steel

R. M. Lima, E. R. B. Jesus, J. L. Rossi

Instituto de Pesquisas Energéticas e Nucleares - IPEN
P. O. Box 11 049 - CEP 05422-970 - São Paulo - Brazil

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Abstract. The effect of heat treatment on the microstructure of spray formed AISI M2 high-speed steel is under evaluation. The objective of this work was to optimise the heat treatments aiming further mechanical working. The M2 steel used in the present work was obtained in a spray forming plant in Brazil, built for processing billets preforms of light alloys and steels. The typical microstructure of spray formed materials, i.e., fine and equiaxial grains, allowed the optimisation of the M2 spheroidization heat treatment. The heat treatment at 1160 ± 10 □C for 12 hours was effective in producing microstructure and hardness suitable for further mechanical working.

Introduction

High-speed steels can be obtained by three distinct methods, casting, powder metallurgy and spray forming. The casting route usually leads to a microstructure with alloying elements segregation and poor carbide size distribution. This may affect the material performance but, can be minimised by further thermomecanical treatments, at a cost penalty. Powder metallurgy methods can overcome such problems. The result is the obtainment of materials with improved performance. Nevertheless, the removal of any remaining porosity can be highly expensive, e.g. by hot isostatic pressing. In the early 1970, the development of spray forming introduced a new process. One of the outstanding features of this process is the capability to produce alloys that are normally difficult to cast by conventional techniques. This capability is due to the rapid solidification phenomenon involved in the process. The technique is very useful for the production of alloys with extensive freezing range, which impairs solidification and microstructure control during casting.

Tool steels are characterised by long freezing range and complex eutectic reactions, resulting in alloying elements segregation and formation of several different types of carbides during solidification [1-5]. The spray forming process minimises these effects and is effective as the powder metallurgy process, having the advantage of obtaining material in one single fabrication step. Therefore, it may offer substantial cost reduction [2].

Regarding high-speed steels, the more often observed carbides are MC, M_2C and M_6C, depending on the cooling rate and alloy composition [2,4,5]. The mechanical properties of the high-speed steels are affected by the carbides type, size and distribution [2]. For molybdenum high-speed steels obtained by continuous casting, the M_2C carbide formation by eutectic reaction impairs hot workability and toughness [2].

Carbide formation and microstructure changes after reheating M2 high-speed steels, obtained by casting in sand and chill moulds have been presented in the literature [6]. This work shows that M2 steel solidification leads to coarse precipitation of M_2C particles at the centre of the dendrites resulting from a peritectic decomposition of δ-ferrite. Subsequent enrichment of solute atoms around the growing austenite dendrites leads to MC, M_2C and M_6C formation. Further cooling, below the solidus line, results in the precipitation of small M_2C and MC carbides, but reheating leads to rapid dissolution of the ultrafine carbides. The M_2C particles decompose rapidly to form MC and M_6C in less than one hour at temperatures between 1150 and 1200 °C. Further reheating causes spheroidization of M_6C eutectic carbide and coarsening of M_6C and MC.

Literature results indicate that the microstructure of M2 casting obtained in chill moulds is slightly finer than that obtained in sand-cast [7]. Consequently reheating the material at higher temperatures, show faster reaction kinetics. The aim of the present work was to evaluate the spheroidization heat treatment of a much-refined M2 high-speed steel microstructure, i.e. those obtained by the Osprey spray forming process.

Experimental

Material

The material under evaluation is spray formed AISI M2 high-speed steel. The burden charger for the spray forming processing was standard commercial M2 cast steel. The chemical composition (wt. %) of the spray formed M2 high-speed steel is shown in Table 1 in comparison to nominal composition [8].

Table 1. Chemical composition of AISI M2 high-speed steel investigated (wt. %).

AISI M2	C	Mn	Si	Cr	Ni	Mo	W	V	P	S
Nominal	0.78 - 0.88 0.95 - 1.05	0.15- 0.40	0.20- 0.45	3.75- 4.50	0.30 max	4.50- 5.50	5.50- 6.75	1.75- 2.20	0.03 max	0.03 max
Spray formed	1.03	0.18	0.22	3.29	0.29	4.98	6.19	1.87	...	...

... Not measured.

Heat treatments

The conditions of the heat treatments used in this work (annealing and spheroidization) are presented in Table 2. All samples were heat treated inside a box filled with black carbon and alumina powders, in order to avoid sample decarburization. The samples were slowly cooled inside the furnace.

Table 2. Spray formed M2 heat treatments condition used in this work.

heat treatment	condition
annealing	880 ± 5 °C for 1 h
spheroidization	annealing + 1160 ± 10 °C for 12 h

Microstructural characterisation and mechanical testing

Samples of M2 high-speed steel after spray forming, annealing and spheroidization were prepared for microstructural characterisation and hardness testing. The samples for metallographic examinations were mounted in resin, polished and etched (Nital 3 %). The grain size was measured using the mean intercept length method (mean lineal intercept) in the optical microscope. The samples for hardness testing were milled from both sides for a better settling in the hardness machine.

Results And Discussion

Hardness testing

The material hardness may give an insight of the mechanical workability of the material. The hardness testing results are shown in Table 3. The spray formed tool steels in the as fabricated condition showed high hardness that can result in difficult machining operations such as sawing. The literature hardness of M2 steel in the as annealed condition values vary from 16 to 23 HRC [8,9]. The results obtained in this study were similar to the literature-reported values. The spheroidization heat treatment produced soft spray formed M2 steel.

Table 3. Hardness values after different heat treatments for the M2 high-speed steel.

Condition	HRC
as spray formed	41 ± 5
annealing	25 ± 3
spheroidization	20 ± 3
annealing [8,9]	16 - 23

... Not measured.

Microstructural characterisation

M2 high-speed steel samples after proper polishing and etching were observed by optical microscopy. The spray forming of the M2 high-speed steel resulted in a fine microstructure with equiaxial grains, mean size of 57 μm, see fig. 1. The heat treatment of the spray formed M2 steel at 1160 □C for 12 h produced a microstructure with characteristics typical of strong destabilisation of the carbides plates, i.e., spheroidization, see fig. 2. The literature indicates that carbides spheroidization and ferritic matrix is adequate for further mechanical working [8].

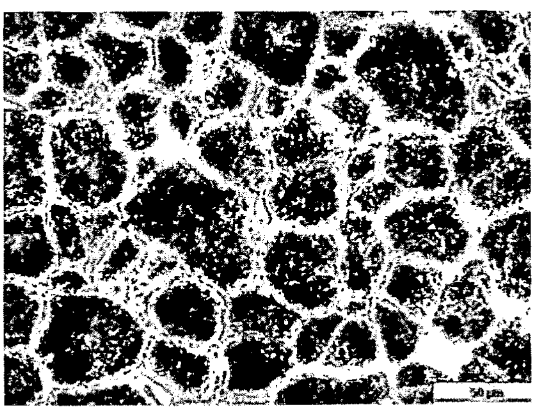

Fig. 1. Optical micrograph of M2 high-speed steel as spray formed. Nital etched.

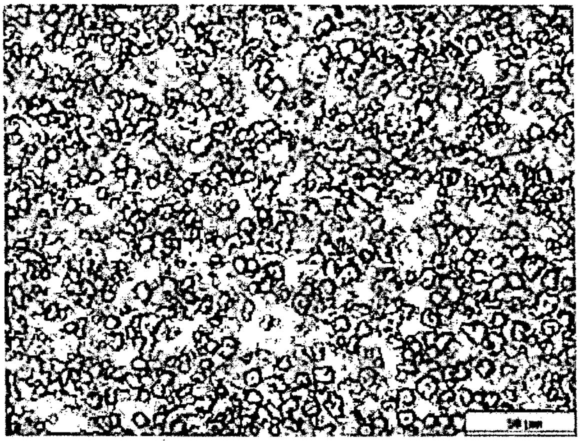

Fig. 2. Optical micrograph of the spray formed M2 high-speed steel, after spheroidization at 1160 □C for 12 hours. Nital etched.

Literature showed that carbide spheroidization stops after 100 hours, due to the impingement mechanism of the already spheroidized carbides [7]. For M2 casting in sand moulds, the impingement mechanism starts after 10 hours at 1200 □C and the amount of spheroidization of the grain boundaries eutectic carbides type M_6C is around 60 %.

The spray forming process is characterised by a finer microstructure of equiaxial grains in comparison to casting in sand and chill moulds. Therefore, this fine microstructure may lead to faster spheroidization kinetics. A preliminary analysis suggests that the amount of carbides spheroidization of spray formed M2 steel in 12 hours heat treatment, is superior to that of the same material obtained by sand-cast.

Conclusions

The high cooling rate intrinsic of the spray forming process led to a partial hardening of the tool steels obtained. Annealing of the preforms, before any further cutting operation, is therefore necessary.

The fine spray formed microstructure lead to a rapid carbide spheroidization in the M2 high-speed steel. The heat treatment sequence (annealing and spheroidization) was effective in the obtainment of microstructure and hardness adequate to mechanical working.

The fine microstructure, homogeneity, equiaxial grain structure and the short spheroidization times are striking characteristics that makes the spray forming process very attractive in relation to other fabrication techniques.

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