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Comparison of Heat Treatments on the Toughness of 1.7Ni-1.5Cu-0.5Mo Pre-alloyed P/M Steels

Abstract: Effects of quenching plus tempering and intercritical annealing plus quenching heat treatments on the impact toughness properties of 1.7Ni-1.5Cu-0.5Mo pre-alloyed powder metallurgy steels with 0.2 (in mass%) graphite were investigated. Specimens were prepared by pressing at 670 MPa and sintering at 1250 °C. Different heat treatments, namely quenching and tempering, directly intercritically annealing and fully austenization plus intercritically annealing were carried out on the sintered specimens. The results showed that the impact toughness decreased with increasing intercritical annealing temperature in ferrite plus martensite dual phase powder metallurgy steels and with increasing tempering temperature in the quenched plus tempered specimens. Besides, impact toughness of fully austenizated plus intercritically annealed specimens was higher than those of quenched plus tempered and directly intercritically annealed specimens at the same hardness levels.

Keywords: impact resistance, powder metallurgy, microstructure, heat treatment

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1 Introduction

Powder metallurgy processing allows to produce parts with complex shape and extensive chemical composition tolerance [1]. Powder metallurgy parts are increasingly becoming more attractive in automotive industry and fabrication of lawn and garden mowers, tractors, lock and door hardware, sporting instruments [2] and implants as well [3]. Among the methods to improve the mechanical properties of powder metallurgy materials is addition of alloying elements made through various ways such as adding elemental powders, or pre-alloyed alloys [4] and application of different heat treatments. Heat treatment application to PM materials is desirable for high performance mechanical behaviours. To increase the strength and hardness of PM parts more, quenching plus tempering heat treatments are commonly used [5].

In hypoeutectoid steels, intrecrtically annealing heat treatments produce dual phase structures which have a microstructure consisting of hard martensite particles dispersed in the soft ferritic matrix [6]. In these steels, soft ferrite provides high ductility and toughness, while hard martensite particles supply enhanced strength [6, 7]. Many mechanical properties of dual phase steels are mainly controlled by martensite volume fraction, shape, size and morphology [8]. Previous investigations have shown that the impact toughness of dual phase steels with lower martensite volume fraction increases when the martensite content increases in the ferritic matrix [9]. However the properties could deteriorate with higher martensite fraction due to an increase in connectivity between martensite phases which are dispersed in the soft matrix.

The focus of this study is to make a comparison between conventional quenching plus tempering and intercrtically annealing heat treatments on the hardness, density and impact toughness properties of pre-alloyed powder metallurgy steels.

2 Experimental procedures

Diffusion alloyed ferrous based powders with 1.7Ni-1.5Cu-0.5Mo (in wt%) chemical composition were selected for this investigation. 0.2 wt% graphite was admixed to these powders as carbon source. A lubricant, Amide Wax PM in the amount of 0.9 wt% was also added to the powder mixtures. To test the impact toughness of the specimens having the standard of ASTM E-23, the powders were cold-compacted in the single act die under 670 MPa pressure. The compacted specimens were sintered at 1250 °C

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for 20 min. under extra purified argon gas atmosphere. After the sintering process, specimens which were intercritically annealed at 705, 735, 765 °C temperatures for 10 min. and then oil quenched were coded as D705, D735, D765 respectively and are called D series specimens in this study. The other specimens, which are referred to as A series, were fully austenizated at 890 °C for 8 min. and cooled down to intercritical annealing region at the same temperatures and for the same time and then oil quenched. The specimens which went through this heat treatment cycle were coded as A705, A735, A765 respectively. Another series of specimens, hereafter QT series in this study, were fully austenizated at 890 °C for 8 min. and oil-quenched plus tempered at 250 °C for 3 h and 180 °C for 2 h and coded as QT250 and QT180.

The Archimedes method was used to measure the density of sintered and heat treated specimens. For the microstructural investigation, specimens were ground and polished by using usual metallographic procedures. 2% nital etching was used to reveal microstructures. Scanning electron microscopy (SEM) (Jeol 6060 LV) was used to characterize the microstructure and fracture surface of the specimens. The amount of martensite phases were determined by means of linear intercept method. Rockwell C-scale hardness measurements were performed on heat treated specimens. All hardness measurements were carried out at least at 6 different areas of each specimen and average values were taken. Microhardness values of ferrite and martensite phases in microstructures were determined with a Vickers hardness tester using 10 g load. Charpy impact toughness tests were carried out at room temperature. The impact tests were conducted on a Universal Impact Machine with 150 J capacity.

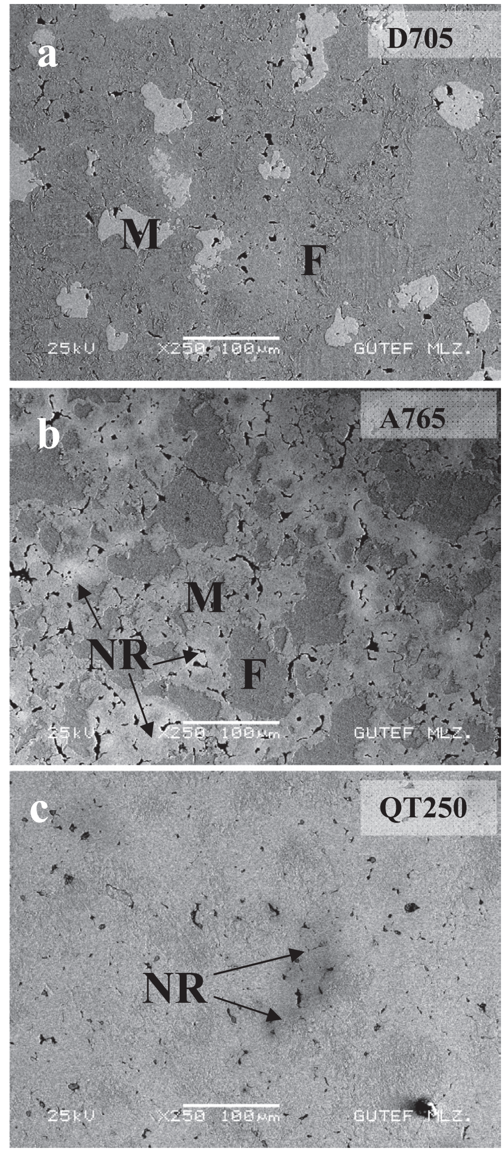

Fig. 1: SEM micrographs of the D705 (a) and A765 (b) specimens with ferrite plus martensite microstructure and of the QT250 (c) specimen with fully tempered martensitic microstructure (F: ferrite; M: martensite; NR: nickel rich)

3 Results and discussion

Fig. 1 presents SEM micrographs of the specimens. D and A series specimens contained martensite islands in the ferritic matrix (Fig. 1a and b). Martensite volume fraction increased with increasing intercritical annealing temperature as seen in Table 1. While the lowest martensite volume fraction was obtained in the D705 specimen, the highest martensite fraction occured in the A765 specimen. When intercritically annealed at 705 °C, the martensite islands dispersed discontinuously in the ferritic matrix of both D705 and A705 specimens. Continuous martensite network formed at the ferrite grain boundary in the specimens with higher martensite volume fraction as well as in the D765 and A765 specimens.

It is noted that at the same intercritical annealing temperature, the obtained martensite volume fractions in the A series specimens were higher than the ones in the D series specimens. It is known that when a hypoeutectoid steel, like D series specimens, is heated to between Ac_1 to Ac_3 temperatures, denominated as intercritical annealing region, the austenite nucleates especially at the ferrite-pearlite boundaries as well as at pearlite colonies boundaries and grows up to reach equilibrium [9]. During initial isothermal holding, austenite volume fraction is expected to be less. However, when a single phase austenite, like in A series specimens in this study, is cooled to the two-

Table 1: The density, martensite volume fraction and hardness properties of specimens

Specimen	Sintered density (g·cm⁻³)	Heat treated density (g·cm⁻³)	Martensite volume fraction (%)	Hardness (HRc)
D705		7.253	31	24.6 (± 5.6)
D735		7.276	51	25.1 (± 5.9)
D765		7.254	62	32.4 (± 3.7)
A705	7.19	7.278	30	24.0 (± 7.3)
A735		7.258	57	29.0 (± 4.4)
A765		7.256	67	34.3 (± 5.2)
QT250		7.420	*	21.0 (± 4.0)
QT180		7.302	*	33.0 (± 6.1)

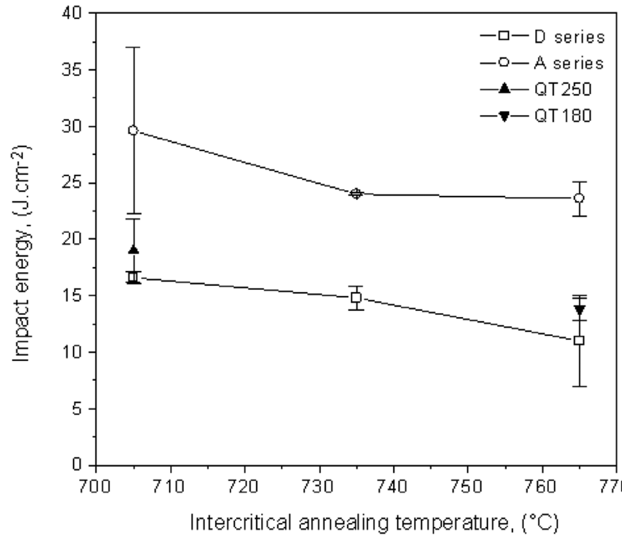

Fig. 2: Changes in the impact toughness of the specimens with intercritical annealing temperatures

phase region, ferrite nucleates at the grain boundaries of austenite and grows within the austenite grains [10]. As a result, at the same intercritical annealing temperature, ferrite and austenite rates were higher in A series specimens in comparison to D series specimens. In QT250 and QT180, typical tempered martensite microstructures were obtained. The microstructures of all the QT specimens include randomly Ni-rich retained austenite (Fig. 1c). However, the Ni-rich areas were seen in the centre of martensite islands in D and A series specimens.

The densities and hardness values of specimens are also given in Table 1. After the heat treatments, the densities of the specimens slightly increased. Highest density was obtained in QT specimens, which can be attributed to martensitic transformation upon quenching. The hardness increased with increasing martensite volume fraction in the intercrtically annealed specimens. Also, hardness in QT specimens increased with decreasing tempering temperature as expected. While lowest hardness values were obtained in the D705, A705, QT250 specimens, the highest ones were in the D765, A765, QT180 specimens at almost the same hardness levels.

Fig. 2 shows the impact toughness variations of the intercritically annealed specimens in comparison to those of quenched and tempered specimens. It is apparently seen that the impact toughness properties of D series specimens were higher than those of A and QT series specimens at similar hardness levels. However, the properties of A series specimens were slightly lower in comparison to the others. This could be attributed to lower micro hardness of ferrite and martensite phases in the A series specimens. In the D and A series specimens, average microhardness levels of ferrite phases were found as 191 ± 17 and 174 ± 19. Also martensite's microhardness values were evaluated as 635 ± 113 and 585 ± 83 respectively. The impact toughness decreased with the increasing intercritical annealing temperature in the D and A series specimens and with the decreasing tempering temperature of the QT series specimens. However, in a previous study, the impact toughness increased with the increasing martensite volume fraction in plain carbon PM steel [8]. In the present study, scaling up of martensite island connectivity with higher martensite volume fraction in the ferrite matrix was a detriment to toughness.

The SEM micrographs of the fracture surface morphologies of the specimens are given in Fig. 3. The D specimens showed some cleavage fracture and tended to increase as the intercritical annealing temperature increased (Fig. 3a). The increase in this fracture could be attributed to high martensite volume fraction as less cleavage fracture found in A specimens compared to D specimens (Fig. 3b). The fracture surface morphologies of low density materials like PM materials frequently occurred as micro dimple between inter powder particles [11]. This can be explained with the tie line rule according to which the hard and brittle martensite phases in the intercritically annealed materials displayed cleavage fracture due to the increase in the carbon content of austenite (after quenching martensite) phase during annealing in two phase region. However, as can be seen in Fig. 3c, in QT specimens, there were no cleavage areas despite their fully tempered martensitic structure due to the tempering process and decreasing carbon content and soft nickel rich region dispersed in the matrix structure.

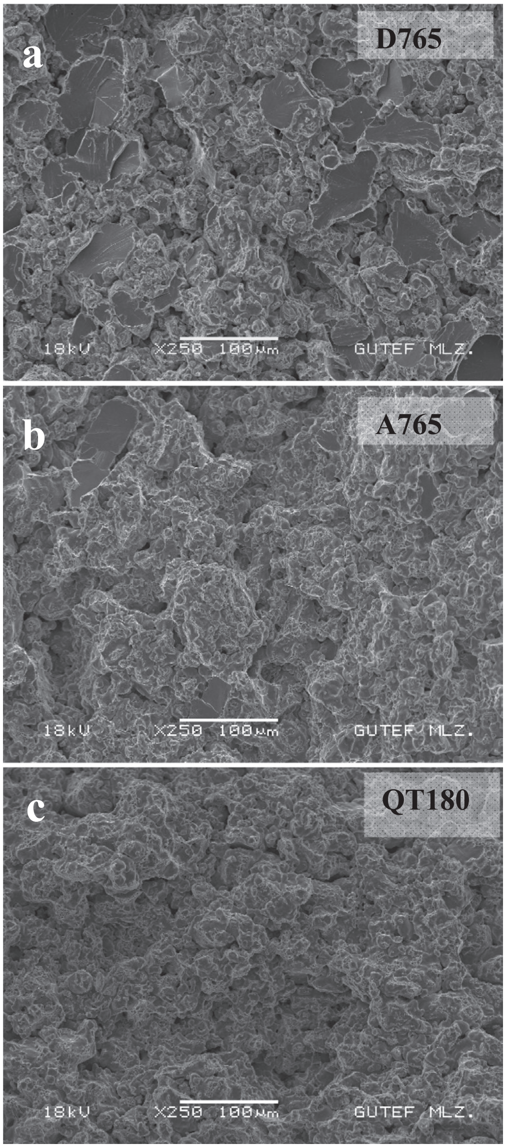

Fig. 3: SEM micrographs of the fracture surface morphologies of the specimens D765 (a), A765 (b) and QT180 (c) specimens

4 Conclusions

The effects of conventional quenching plus tempering and intercrtically annealing heat treatments on impact toughness properties of 1.7Ni-1.5Cu-0.5Mo pre-alloyed powder metallurgy steels are compared. The results are as follows.

1. When the steel was intercritically annealed at 705 °C, the martensite islands dispersed discontinuously in the ferritic matrix. Continuous martensite network formed at the ferrite grain boundaries in specimens with higher martensite volume fraction.
2. The hardness increased with increasing martensite volume fraction in the intercritically annealed specimens and decreasing tempering temperature in the quenched and tempered specimens as expected.
3. The impact toughness properties of D series specimens were higher than those of A and QT series specimens at similar hardness level. The impact toughness decreased with increasing intercritical annealing temperature in the D and A series specimens and with decreasing tempering temperature of the QT series specimens as less cleavage fractures were found in A specimens in comparison to D specimens.

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