Avrupa Bilim ve Teknoloji Dergisi
Cilt. 5, No. 9, S. 44-47, Aralık 2016

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Vol. 5, No. 9, pp. 44-47, December 2016

Research Article

Effect of C Content on Microstructure and Mechanical Properties of Nb-V Added Microalloyed Steel Produced by Powder Metallurgy Method

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(First received 22 October 2016 and in final form 05 December 2016)

Abstract

In this work, the effect of C content on the microstructures and tensile behaviors of Nb-V added microalloyed powder metallurgy (PM) steels were investigated. The samples pressed at 700 MPa and sintered at 1450°C temperature in the sintering argon atmosphere for 1 h were produced. Nb-V added PM microalloyed steels with different carbon ratio were analyzed in terms of tensile test. Results indicated that the images of microstructure that as the proportion of the C in the PM samples increases, the volume of the perlite gets increase gradually and 0.35 wt. % C added Nb-V PM steel showed the highest values in yield strength (YS) and ultimate tensile strength (UTS).

Keywords: Powder metallurgy; powder metallurgy steels; Nb-V; Microstructure

1. Introduction

Steels are the material group having superior properties such as; high strength and toughness, low ductile-to-brittle transition temperature, excellent weldability and corrosion resistance which are obtained by applying various hardening mechanisms and proper thermomechanical procedures. The main roles of microalloying elements are to refine the grain size, prevent recrystallization and facilitate precipitate hardening. The effect of microalloying elements on the grain boundary movement and recrystallization is a result of carbo-nitride precipitates. (Erden et al., 2016a,b; Erden et al., 2014; Gladman ,1997).

Powder metallurgy (P/M) paves the way for the economical production of high quality and sophisticated tools. This production method turns the metal powders that are different in size, shape and packaging features into resistant, precise and high performance tools (Sage, 1986). Railway Tank Cars, Railway parts, nuclear power plants, aircraft parts, automotive components, armor-piercing materials, electrical connection components, orthopedic materials, high temperature filters, jet engines, clock parts, high power lightening are some of the areas that parts produced by powder metallurgy are used. PM method is preferred for its economy, manufacturability, homogeneity and quality as well as high performance and low cost of the produced parts (Wang et al., 2008, Rahimian et al., 2011)

In the present study, PM steel has been produced in the targeted compound by adding different proportions of C, Nb and V into the Fe matrix with the powder metallurgy method and the output microstructural mechanical features have been compared.

2. Materials and Experimental Procedure

In this investigation, having been added in different proportions, the effect of the C and Nb-V's amount on microstructural and mechanical properties is researched. Fe, C, Nb and V powders of ≤180, <20, <45 and <44 supplied by Aldrich were used. Analysis indicated that the purity of Fe, C, Nb and V was 99.9 %, 96.5 %, 99.8 % and 99.5 % respectively. Before the mixing process, powders were prepared in the proportions that had been given in Table 1 by weighing on a digital precision scale which has 0.0001 precision. The powders were mixed in an industrial conic mixer for 1 h. Graphite additions were 0.45 and 0.55 % to reach carbon concentration of 0.25 and 0.35 % in the test pieces after sintering. Additionally, Zn-stearate was used in all mixes as lubricant. Steel is produced by way of mixing in the chemical compounds given in the Table 1. Tensile test has been implemented on the produced samples after microstructural characterization is performed. The results have been compared. Having been mixed homogeneously, the powders were pressurized under 700 MPa unidirectional with Hidroliksan branded device, which has 96-ton pressure capacity. Samples of the tensile experiment were turned into blocks by squeezing with the mould which had been prepared according to ASTM (E 8M) standards of powder metal material tension sample.

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Table 1. *Chemical compositions of powder metal steels.*

Compound	C (%wt.)	Nb (%wt.)	V (%wt.)	Fe (%wt.)
Fe +0.25 C (Alloy 1)	0.25	-	-	rest
Fe +0.25 C+ 0.1 Nb-V (Alloy 2)	0.25	0.05	0.05	rest
Fe +0.25 C+ 0.15 Nb-V (Alloy 3)	0.25	0.075	0.075	rest
Fe +0.35 C (Alloy 4)	0.35	-	-	rest
Fe +0.35 C+ 0.1 Nb-V (Alloy 5)	0.35	0.05	0.05	rest
Fe +0.35 C+ 0.15 Nb-V (Alloy 6)	0.35	0.075	0.075	rest

The pressurized samples were sintered at argon atmosphere at 1450 ºC during 1 hour. After sintering, densimetry and pore values were measured. Sintered samples were made ready via traditional methods like sanding, polishing and searing for the metallographic examinations. Having been sintered at 1450 ºC, the microstructures of the PM steel tensile samples were examined under Nikon Epiphot 200 optical microscope which has X50-X1000 zoom capacity. Tensile test was carried out at 0.5 mm/min pulling speed with Shimadzu tensile device that has 50 KN capacity. The yield strength (% 0.2), tensile strength and % (percentage) values of elongation of the tensile test samples were determined. The density of the samples was determined using the densimeter and according to the principle of Archimedes. Besides, the pearlite proportions of the powder metal steels were calculated using Gladman and Woodhead's (1960) metallographic point counting method. Along with it NbC, VC, NbN, NbCN, VN and VCN sediments were detected by the help of the point and line EDS.

3. Results and Arguments

3.1. Microstructure results

The images of the microstructures of the samples are demonstrated in the Figure 1. As can be seen from the figure, the structure comprises of ferrite and pearlite phases in the whole alloys. When the images of the microstructure in the Figure 1 are examined, it is detected that there are partially uncovered pores on the borders of the grains. Although it is stated that porosity affect the strength of many welds negatively, it is reported that tiny and spherical pores do not reduce the strength (Misra et al., 2003) It is inferred from the images of microstructure that as the proportion of the Nb and V alloys in the PM samples which contents 0.25 % wt C increases, the size of the grain gets smaller gradually. For instance; the size of the grain decreased to 35.7 µm and 31.3 µm respectively with 0.1 and 0.15 percentage of weight increase in the amount of the (Nb-V) while the average size of grain in the nonalloy P/M steel sample in the Fe+0,25C compound is 43.5 µm. It is inferred from the images of microstructure that as the proportion of the C in the PM samples increases, the volume of the perlite gets increase gradually. For instance, the volume of the perlite increased to % 25.1 and % 26.7 respectively with 0,1 and 0,15 percentage of weight increase in the amount of the (Nb-V) the volume of the perlite in the nonalloy P/M steel sample in the Fe+0,25C compound is % 23.3.

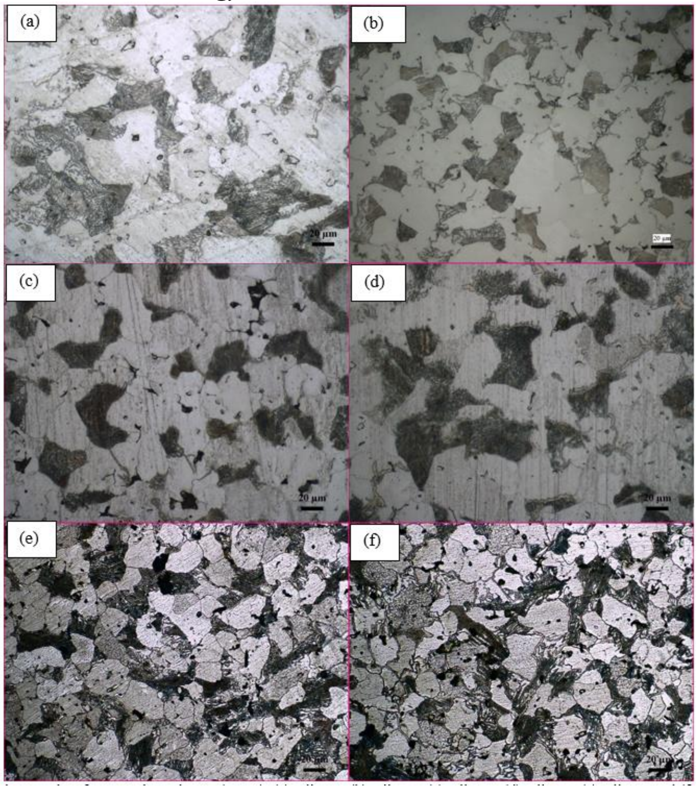

Figure 1. *Micrographs of PM steel specimens (500 x). (a) Alloy 1, (b) Alloy 2, (c) Alloy 3, (d) Alloy 4, (e) Alloy 5 and (f) Alloy 6.*

Table 2. *Relative density, mean linear intercept grain sizes and volume fractions of ferrite and pearlite phases in PM steel specimens*

Alloy	Relative Density (%)	Porosity (%)	Pearlite (%)	Grain Size (µm)
Alloy 1	93.7	6.3	23.3	43.5
Alloy 2	93.4	6.6	25.1	35.7
Alloy 3	93	7	26.7	31.3
Alloy 4	93.3	6.7	26.2	43.9
Alloy 5	93.1	6.9	33.1	35.4
Alloy 6	92.9	7.1	35.3	30.7

In the table 2, it is seen that the average size of grain decreases with a % 0.15 of increase in the proportion of the (Nb-V). This situation emerges when NbC, NbN, VC, VN, VCN and NbCN precipitates that develop in the sintering process prevent the austenite grains from getting bigger. One of the features of microalloy elements is that they restrict grain size by creating carbide and nitride.in the austenitizing or sintering processes. Development of little sediments during the austenitizing process prevents austenite grains from growing and leads to the development of small ferrite grains (Scade et al., 2012a,b; Xiang-done et. al., 2013).

3.2. Mechanical properties

While the figure 2 shows the tensile-elongation diagrams of the sintered samples, table 3 shows the yield, tensile, elongation and toughness as percentage. The yield and tensile strength with the elongation and toughness values as percentage (%) are observed to increase when (Nb-V) proportion increases to % 0.15 as weight. Being created by the niobium and vanadium elements, the carbide, nitride and carbonitride sediments ensure the material to be small grained by way of restricting the size of the austenite grain and re-crystallisation of the austenite. The improvement of the resistance is fulfilled thanks to the more grain borders in the small grain structure and the prevention of dislocation move by this grain borders. The decrease of the grain size also contributes to the elongation of the material as percentage (%). Along with these, the developed sediments contributed to the increase of the yield and tensile strength via various resistance booster mechanisms like sediment hardening, dispersion hardening and aggregation hardening (Rahimian et al., 2011; Scade et al., 2012a,b; Xiang-done et. al., 2013).

It is inferred from the tensile tests that as the proportion of the C in the PM samples increases, mechanical properties such as yield strength and tensile strength of PM steels gets increases. For instance, the tensile strength in the 0.15 % wt. Nb-V added microalloyed P/M steel sample in the Fe+0.25C and Fe+0.35C compound 434 MPa and 454 MPa respectively.

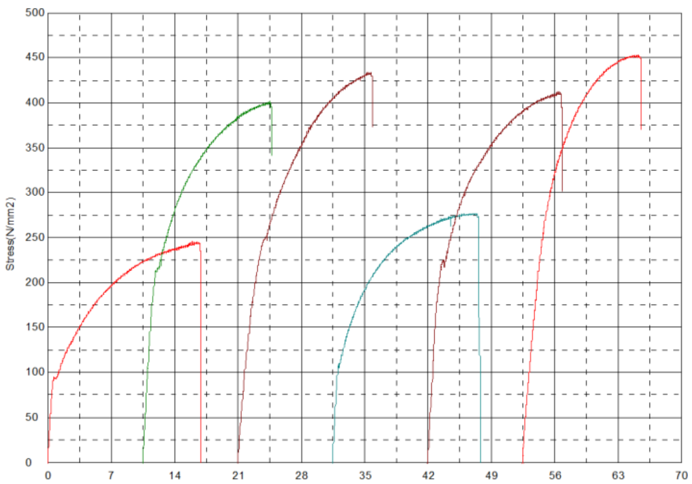

Figure 2. *Variation of stress–strain curves of the PM steel and microalloyed PM steels at different percentages of TiCN content (a) Alloy 1, (b) Alloy 2, (c) Alloy 3, (b) Alloy 4, (c) Alloy 5 and (d) Alloy 6.*

Table 3. *Mechanical properties of sintered PM steel and microalloyed PM steels*

Alloy	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
Alloy 1	94	247	16
Alloy 2	217	403	15
Alloy 3	250	434	14
Alloy 4	110	278	15
Alloy 5	226	412	14
Alloy 6	259	454	13

As can be seen from the Figure 2 and the table 3, an increase is usually observed in the yield strength, tensile strength and toughness values as the proportion of (Nb-V) increases from % 0.1 to %0.15 as weight. This case is a result of the development of the sediments like VC(N) and NbC(N) during the sintering process and during the after-sintering cooling process. It is thought that NbC(N) and VC(N)-like sediments lead to the development of small austenite grains by way of restricting the grain size during the sintering process, thereby improving the resistance of the materials. Hence, Erden et al., produced Ti and V microalloyed steel with PM method. They conducted the sintering process at 1150 °C waiting 60 minutes and determined an increase in the yield and tensile strength as the proportion of Ti and V (% 0.1-% 0.2) rises. The writers demonstrate in their survey that NbC(N) and VC(N)-like sediments lead to the development of small austenite grains by restricting the grain size during sintering and as a result of this, the resistance of the materials improves. In the other surveys that have been conducted (Erden et al., 2016a,b; Erden et al., 2014; Scade et al., 2012a,b; Xiang-done et. al., 2013). it is stated that the carbide and nitrite which develop in the microalloy steels lead to an increase in the toughness and resistance. In the same survey, it is pointed out that solid solution hardening stays at low percentage because of the sedimentation of carbide and nitrite (Erden et al., 2016a,b; Erden et al., 2014).

4. Conclusion

The N-V alloyed PM steel which has different volume ratios (%0.1 and 0.2) and different volume ratios carbon content (%0.25 and %0.35) is produced by cool press and sintering at the argon setting and the following results listed below are obtained from this study.

- Microalloyed steels which contain C, Nb and V and Fe matrix can be produced with powder metallurgy. Solid solution hardening and precipitation hardening which arise during the sintering process or after-sintering cooling process increase the resistance of the steel.
- Microalloyed steels that are added % 0.1 and 0.15 (Nb-V) as weight compared to non-alloy steels showed smaller grain structure. This situation stems from the restriction of grain size by the carbide and nitrite which alloy elements has created.
- Usually, there has been an increase in the yield strength, tensile strength, percentage (%) elongation and toughness values of the compounds which have Nb and V ratio by %0.15 as the alloy ratio rises. This situation is a result of the development of the sediments like NbCN during sintering process and after-sintering cooling process. These sediments lead to the creation of small austenite pieces by preventing grain size and thus improving the resistance of the materials.
- After-sintering density of the non-alloy and Nb and V added microalloyed steels is observed to be generally at about %93. After-sintering condensation showed a little bit increase.

Acknowledgements

The author gratefully acknowledges financial support from Karabuk University Coordinatorship of Resarch Projects with the No: KBÜ-BAP-15/2-KP-058.

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