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The influence of the sintering conditions on the properties of the stainless steel reinforced with TiB_2 ceramics

I. Sulima [a,*], P. Klimczyk [b], P. Hyjek [a]

[a] Institute of Technology, Pedagogical University, ul. Podchorążych 2, 30-084 Kraków, Poland

[b] Institute of Advanced Manufacturing Technology, ul. Wrocławska 37A, 30-011 Kraków, Poland

* Corresponding author: E-mail address: isulima@ap.krakow.pl

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ABSTRACT

Purpose: The paper analyzes the influence of the temperature and pressure on the properties and structure of the austenitic AISI 316L stainless steel reinforced with 1% vol.TiB_2 ceramics.

Design/methodology/approach: The sintered austenitic AISI 316L stainless steel reinforced with 1% vol. TiB_2 were obtained using the high temperature-high pressure (HT-HP) method at pressure of 5.0 and 7.5 ± 0.2 GPa and temperatures 900°C, 1150°C and 1300°C. The duration of sintering was 60 seconds. Young's modulus measurements were carried out using ultrasonic method. Mechanical properties were determined by Vickers hardness test. For microstructure observation scanning electron microscope JEOL JSM-6460LV was used.

Findings: The decrease of the hardness of the sintered austenitic AISI 316L stainless steel with the increasing temperature of sintering was observed. However, the Young's modulus increases with the growth of the temperature of sintering. The results showed that the hardness increased with increasing pressure. The microstructural investigations indicated that the TiB_2 ceramics were distributed along grain boundaries.

Practical implications: The obtained results show that the temperature and pressure have influence on the mechanical and physical properties of the investigated steel reinforced with 1% vol.TiB_2. These results may be used to design new materials i.e. austenitic stainless steel reinforced with TiB_2 ceramics.

Originality/value: The results from this work can be useful in determining conditions for sintering the austenitic AISI 316L stainless steel reinforced with various volume fractions of TiB_2 ceramics.

Keywords: AISI 316L stainless steel; TiB_2 ceramics; Sintering; HT–HP technique

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MATERIALS

1. Introduction

The AISI 316L stainless steel possesses the unique combinations of superior mechanical properties: tensile strength (500-750 MPa), hardness (160-190 HB), elongation (40%), high crack resistance and aqueous corrosion resistance. Such unique properties give AISI 314L stainless steel a wide application in the chemical, petrochemical and power industry [1].

The most commonly used ceramic particles for reinforcement of various types of steel matrices include various oxides (e.g., Al_2O_3 and ZrO_2), nitrides (e.g., TiN and Si_3N_4), and carbides (e.g., TiC, Cr_3C_2, VC, and B_4C) [2]. Among various ceramic particulates, titanium diboride is recently expected to be one of the best reinforcements for steel matrix due to its high hardness (3400 HV), high melting temperature (3225°C), high modulus of elasticity, high thermal stability at higher temperature, good wettability and outstanding tribological properties [3-5]. The TiB_2 is thermodynamically stable in liquid iron or aluminium. Thus, the addition of TiB_2 to a metal matrix can greatly improve strength, hardness, and wear resistance without apparent loss of thermal expansion coefficient and electrical and thermal conductivities as compared to other ceramic reinforcements [6-8].

Few studies have reported the use of TiB_2 reinforcements in stainless steel matrix. Tjong and Lau [9,10] reported on the enhancement of sliding wear and abrasion resistance of AISI 304 stainless steel reinforced with various volume fraction of TiB_2 ceramics by hot isostatic pressing. The improved wear resistance was attributed to the presence of hard ceramic particles within stainless steel matrix. In a recent study [11] authors introduced the novel in situ (TiC and TiB_2) reinforcements in 465 stainless steel matrix through the following reaction: $2Ti + C + 2FeB = TiC + TiB_2 + 2Fe$. The TiC and TiB_2 steel matrix composites were synthesized successfully and no other reaction product was detected in the composite. Metal matrix composites reinforced with hard particulates are candidates for wear resistance application. Also, Akhtar [12] studied the steel matrix composite reinforced with TiB_2 and TiC (30 to 70 wt.%) that had been produced through the synthesis reaction from Ti, C and FeB. The composites with higher TiC and TiB_2 content provide better wear protection or resistance.

Several studies were reported on the use of various techniques for the fabrication of composites with TiB_2 particulate reinforcements such as the conventional powder metallurgy [13], hot isostatic pressing (HIP) [9], high temperature–high pressure method (HT–HP) [7,16] and in situ processes [14,15].

In this study, the high temperature–high pressure (HT-HP) method was used to produce the austenitic AISI 316L stainless steel reinforced with 1 % vol. of TiB_2.

2. Experimental procedure

The starting powders used in the present work are AISI 316L steel (Goodfellow, about 45 μm average grain size) and diboride ceramics (Atlantic Equipment Engineers, below 10 μm average grain size, purity 99.9%). Chemical composition of AISI 316L steel powder was shown in Table 1. Figure 1a presents morphology of AISI 316L steel powder, Figure 1b – TiB_2 powder. The raw powders were prepared by milling in a planetary mill Pulverisette 6 Mono for 3.5 h. Figure 2 showed morphology of mixture of AISI 316L steel powder and TiB_2 powder (SEM).

Table 1.
Chemical composition of AISI 316L steel powder

Chemical composition, wt.%						
C	Cr	Ni	Mo	Mn	Si	Fe
0.03	16.9	12.15	2.1	0.7	0.9	balance

The 316 L stainless alloy contained 1 vol.% TiB_2 were fabricated by HT-HP process. The powder mixtures were formed into discs (15 mm in diameter, 5 mm high) by pressing in a steel matrix under pressure of 200 MPa. Samples were heated using a ceramics gasket provided with an internal graphite heater. For the densification of materials the high temperature–high pressure (HT–HP) Bridgman type apparatus was used. Compacts were obtained at pressure of 5 and 7.5 ± 0.2 GPa and at temperatures of 900°C, 1150°C and 1300°C. Samples were the HT-HP sintered for 60 seconds.

Young's modulus of the samples obtained by the HP-HT sintering were measured basing on the velocity of the ultrasonic waves transition through the sample using ultrasonic flaw detector Panametrics Epoch III. The accuracy of calculated Young's modulus estimated at 2 %.

a)
b)
c)

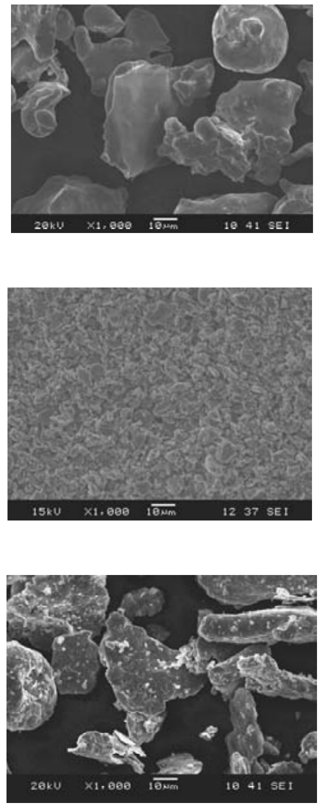

Fig. 1. Morphology of powder particles at magnification 1000x (SEM): a) 316 L steel powder, b) TiB_2 powder and c) mixture of AISI 316L steel powder and TiB_2 powder

Samples for Vickers hardness measurements and microstructure analysis were prepared through lapping on a cast iron plate with diamond paste. The Vickers indentation tests were performed on compacts using FM-7 microhardness tester. The applied load for non-graded materials was 0.98 N.

The microstructures and chemical composition were observed using JEOL JSM 6460 LV scanning electron microscope (SEM) with Energy Dispersive Spectrometer (EDS) (Figs. 3,4).

3. Results and discussion

The results from examination of the selected physical and mechanical properties of austenitic AISI 316L stainless steel reinforced with 1% vol. TiB_2 ceramics are given in Tables 2 and 3.

The specimens which were the HT-HP sintered at temperature of 850°C, 1150°C and 1300°C at pressure of 5 GPa show densities between 98-100% of the theoretical density (7.95 g/cm^3). In the case of the materials which were sintered at higher pressure of 7.5 GPa at temperature of 850°C, 1150°C and 1300°C, the density received values 99% of the theoretical density (7.95 g/cm^3).

The results of the examinations indicated that the Young's modulus and the hardness of the AISI 316L stainless steel reinforced with 1%vol. TiB_2 depended on the temperature and pressure of the sintering. The increase of Young's modulus with the increase of the temperature was observed. The highest value of Young's modulus of the compacts obtained at temperature 1300°C i.e. at pressure of 5 GPa and 7.5 GPa are 208 GPa and 203 GPa, respectively.

Table 2.
Selected physical and mechanical properties of AISI 316L stainless steel reinforced with 1% vol. TiB_2 obtained by HP-HT methods

Samples number	Temper. [°C]	Pressure (GPa)	Density (ρ_o) [g/cm^3]	ρ_o/ρ_{Teor}	Poisson's ratio ν
(1)	900	5	7.95	100	0.30
(2)	1150	5	7.81	98	0.29
(3)	1300	5	7.83	99	0.28
(4)	900	7.5	7.82	99	0.30
(5)	1150	7.5	7.86	99	0.29
(6)	1300	7.5	7.81	99	0.29

Table 3.
Selected physical and mechanical properties of AISI 316L stainless steel reinforced with 1% vol. TiB_2 obtained by HP-HT methods

Samples number	Temper. [°C]	Pressure (GPa)	Young's modulus E [GPa]	$\frac{E}{E_0}$ [%]	HV1 average
(1)	900	5	196	92	474
(2)	1150	5	201	94	339
(3)	1300	5	208	98	314
(4)	900	7.5	192	90	489
(5)	1150	7.5	200	94	382
(6)	1300	7.5	203	95	372

The decreasing of the hardness with increasing temperature of sintering was observed. In this case, the hardness at pressure of 5 GPa and temperature of 850°C, 1150°C and 1300°C are 474, 339 and 314 HV1, respectively. However, the higher values of the hardness were achieved at higher pressure of 7.5 GPa. Table 3 shows that the hardness at pressure of 7.5 GPa and temperature of 850°C, 1150°C and 1300°C are 489 HV1, 382 HV1 and 372 HV1, respectively.

a)
b)

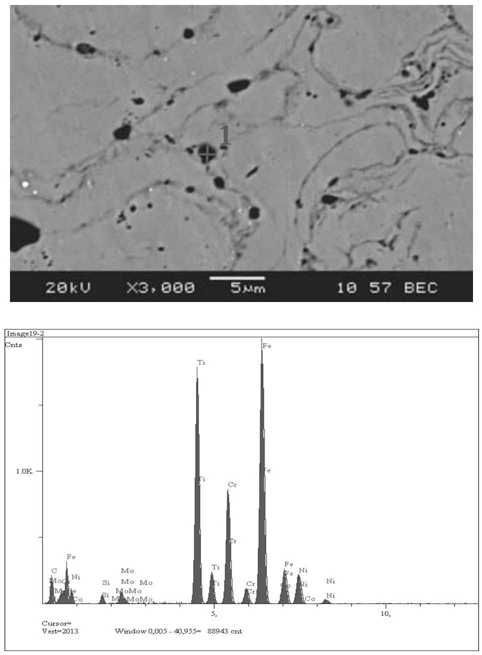

Fig. 2. a) Microstructure of the AISI 316L stainless steel reinforced with 1%vol. TiB_2 (SEM) after sintering at temperature of 900°C, at pressure 7.5 GPa and b) EDS analysis obtained from point 1

a)
b)

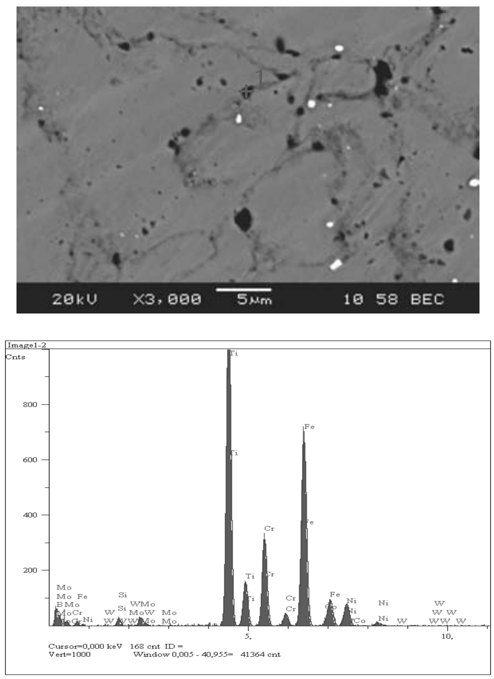

Fig. 3. a) Microstructure of the AISI 316L stainless steel reinforced with 1%vol. TiB_2 (SEM) after sintering at temperature of 1300°C, at pressure 7.5 GPa and b) EDS analysis obtained from point 1

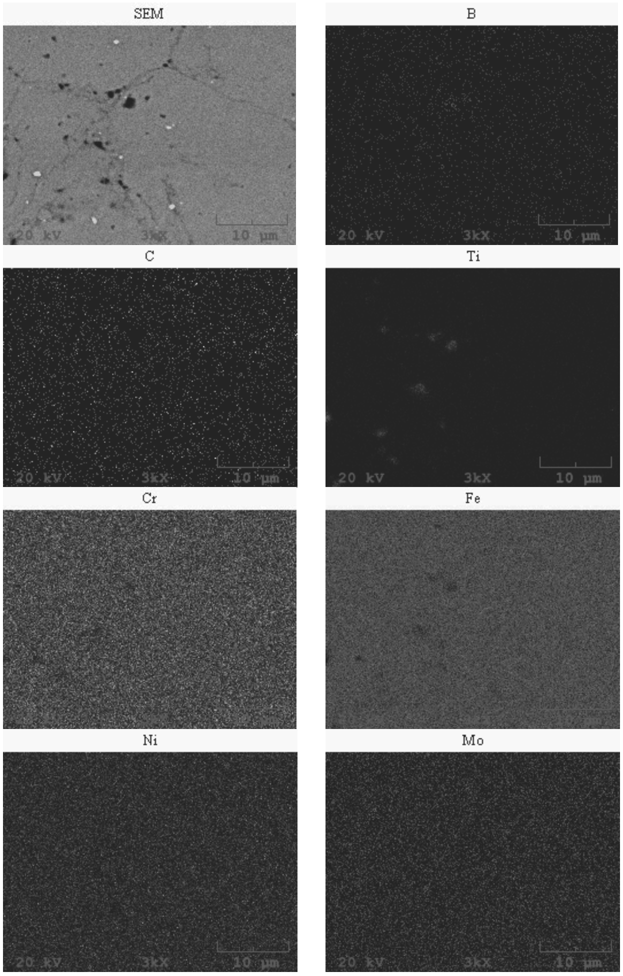

Fig. 4. The SEM microstructure and EDS surface analysis of the AISI 316L stainless steel reinforced with 1%vol. TiB_2 after sintering at temperature of 1300°C, at pressure 7.5 GPa

4. Conclusions

In present study, the austenitic AISI 316 L stainless steel reinforced with 1% vol. of TiB_2 were sintered at different temperature and pressure using the high temperature-high pressure (HT-HP) method.

The density and Poisson's ratio of the resulting materials are very similar. The increase of Young's modulus with the increase of the temperature was observed. However, the hardness reduces along with increasing temperature. The application of the higher pressure of 7.5 ± 0.2 GPa permits to obtain the higher Vickers hardness of these materials in comparison with the sinters which were obtained at pressure of 5 ± 0.2 GPa.

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