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Joinability of Particulate Reinforced Alumix 231 Based Composite Materials Produced by Powder Metallurgy Route

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In the present study, weldability of Alumix 231 based composite materials reinforced with Al_2O_3 and B_4C and produced by powder metallurgy route is investigated. Various amounts of (0, 5, 10, and 15% wt.) Al_2O_3 and B_4C powders are added to the pre-alloyed Alumix 231 (Al–2.5% Cu–0.5% Mg–14% Si) powders separately and then mixed in a three-dimensional mixer for 45 min. Powders are compacted and sintered in an argon atmosphere at 640°C for 4 h. Produced blocks are welded by the Tungsten Inert Gas (TIG) welding at 25 V, 197 A and 14 l/min shielded gas flow in commercially pure argon atmosphere. Macro- and microexamination together with some mechanical properties of the welded area are studied. The results show that, although high amount of particles resulted in a decrease in the density, these composite materials can still be welded by the TIG welding method successfully.

Исследуется свариваемость произведённых методом порошковой металлургии композитных материалов на основе Alumix 231, армированных Al_2O_3 и B_4C. Различные количества (0, 5, 10 и 15 масс.%) порошков Al_2O_3 и B_4C по отдельности добавлялись в предварительно сплавленные порошки Alumix 231 (Al–2,5% Cu–0,5% Mg–14% Si), а затем перемешивались в трёхмерном миксере в течение 45 минут. Затем порошки прессовались и спекались в атмосфере аргона при 640°C в течение 4 часов. Полученные блоки сваривались вольфрамовой сваркой в атмосфере инертного газа при 25 В, 197 А и потоке инертного газа в 14 л/мин в атмосфере технически чистого аргона. Были проведены макро- и микроисследования некоторых механических свойств сварной зоны. Их результаты показали, что, хотя оказалось большое количество частиц с пониженной плотностью, эти композитные материалы могут быть успешно сварены методом вольфрамовой сварки в атмосфере инертного газа.

Досліджується зварюваність вироблених методою порошкової металургії композитних матеріялів на основі Alumix 231, армованих Al_2O_3 і B_4C. Різні кількості (0, 5, 10 і 15 мас.%) порошків Al_2O_3 і B_4C окремо додавалися у попередньо стоплені порошки Alumix 231 (Al–2,5% Cu–0,5% Mg–14% Si), а потім перемішувалися в тривимірному міксері впродовж 45 хвилин. Потім порошки пресувалися та спікалися в атмосфері арґону при 640°C впродовж 4 годин. Одержані блоки зварювалися вольфрамовим зваренням в атмосфері інертного газу при 25 В, 197 А та потоці інертного газу у 14 л/хв. в атмосфері технічно чистого арґону. Було виконано макро- та мікродослідження деяких механічних властивостей зварної зони. Їх результати показали, що, хоча виявилася велика кількість частинок зі зниженою густиною, ці композитні матеріяли можуть бути успішно зварені методою вольфрамового зварювання в атмосфері інертного газу.

Key words: microstructure, hardness, Alumix, composites, Al_2O_3, B_4C, powder metallurgy, Tungsten Inert Gas welding.

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1. INTRODUCTION

Powder metallurgy (PM) is a process, in which product is fabricated from metal or ceramic powders, which are mixed, pressed in a mould, and sintered to increase the strength. Although limited in terms of product size and weight, the PM process has capable of producing net-shaped and highly complex parts from a wide variety metal and metal alloy powders economically. Because of excellent improvement features, aluminium based products are in great demand in application such as aerospace, automotive, military, electronic industry and maritime than any other conventional materials [1, 2]. The PM is known as modern manufacturing technique and one of the best suitable processes for advanced materials production. The advantage of modern technologies is that the PM method can change many different materials to further products. The main objective of the powder metallurgy technique is also to become strong strengthened parts by pressing and sintering starting from raw materials. By means of the PM route, it is possible to produce materials with different chemical compositions. Among these materials, aluminium is of special interest. Aluminium is commonly used in aerospace and automotive industry has the characteristics as light, corrosion resistant and having high specific strength material [1, 3, 4]. By making addition of different metal or ceramic particles to Al alloys, not only sintering behaviour but also a lot of engineering properties can be improved. These enhancements are commonly due to the added ceramics particles [2, 5, 6]. Studies in recent years, another class of material, namely the composite materials, are becoming increasingly important [7]. A composite is a structural material that generally consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other [8–11]. Different classification has been made for composite materials.

According to the type of the matrix material used in, composite materials are divided into three main classes. These are polymer matrix, ceramic matrix and metal matrix composite materials [10, 12]. Among them, aluminium alloy matrix composites attract much attention due to their lightness, high thermal conductivity, moderate casting temperature, *etc.* [13]. Due to the ease of formability and lightweight, aluminium has found many applications in industrial areas [1, 3]. Because of poor wear resistance of aluminium and its alloys, much research work had been carried out to strengthen them by producing aluminium matrix composites [14, 15]. The ceramics particles such as SiC, Al_2O_3, or B_4C are commonly used as reinforcements to reinforce the aluminium matrix.

Metal matrix composites, especially for specific application, are produced by different techniques. Produced powder metal composite parts should be joined with each other or different materials. Production of parts with large surface areas as well as the complex shaped ones by the PM method is difficult, since the production of the parts with large surface areas causes the increase of mould and press power cost. Therefore, determination of the welding parameters for the powder metal parts and the weldabilities of those materials will assist production of large surface and complex shaped parts.

However, welding of powder metal materials is different from the welding of conventional materials manufactured by rolling or other manufacturing methods. The most important factor is the porosity. Porosity volume and relative density affect the quality of welding and its character. Porosity changes the properties of thermal conductivity and hardenability of the material and affects the welding process because of the oxides and impurities within the structure. Thermal expansion between mating materials of different composition results in dissimilar volume changes when metals are heated and subsequently cooled. Extreme differences in expansion or contractions rates increase the potential for cracking at the weld interface [16]. Their industrial application is much limited owing to the high viscosity of the molten pool, the segregation and agglomeration of reinforcing particles, and especially the serious interface reaction between particle and aluminium matrix, leading to less acceptable mechanical properties [17].

In the present study, Alumix 231 reinforced with Al_2O_3 and B_4C composite materials have been produced by PM route. Produced parts were welded by the TIG welding at various welding parameters in Ar atmosphere. Macro- and microexamination together with some mechanical properties of the weld area have been performed.

2. MATERIALS AND EXPERIMENTAL METHOD

For the experimental work, two different groups of composite parts were prepared. First group of parts included 5%, 10% and 15% Al_2O_3 (weight % and with 99% purity) were added to Alumix 231 powders (Al–2.5% Cu–0.5% Mg–14% Si) and second group of parts included 5%, 10% and 15% B_4C (weight % and with 99.9% purity) particles were added to Alumix 231 powders (Al–2.5% Cu–0.5% Mg–14% Si). Both groups of powders are mixed in a three-dimensional mixer for 45 minutes. Mixed powders are compacted in a uniaxial press under 600 MPa in order to produce samples with $10\times40\times70$ mm^3 in size. Compacted parts are heated up to 640°C, with 5°C /min heating speed and sintered for 4 h in commercially pure argon atmosphere. Sintered samples are cooled to room temperature with the cooling rate of 10°C/min in argon atmosphere. The densities of samples are measured using Archimedes principle.

The surfaces of the 10 mm thick composite specimens are brushed in order to remove the surface oxide film and prepared as X-shape weld groove before welding process. Samples were welded using the TIG welding method under argon atmosphere as shielding gas and then cooled to room temperature. Welding parameters are given in Table 1, and Fig. 1 shows the macrograph of welded powder metal parts.

TABLE 1. Welding parameters.

Current type	Alternative
Filling wire thickness	4 mm
Welding current	197 A
Electrode diameter and type	2.4 mm, Tungsten
Gas flow rate	14 l/min

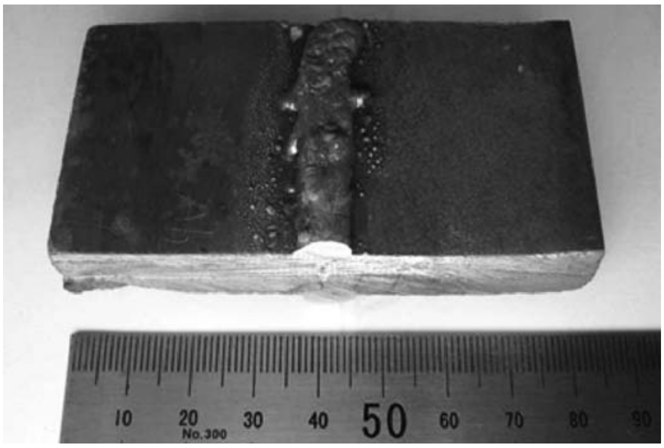

Fig. 1. Macrograph of welded powder metal parts.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Change of Density

Green and sintered densities of both composite parts are given in Table 2 and Table 3. The sintered density of the sample increased as shown in the Tables. Figure 2 shows the density change of the samples

TABLE 2. Density values of raw and sintered metal matrix composite samples (group 1).

Test samples	Compression pressure, MPa	Green density, %	Sintered density, %
Pure Alumix 231	600	95.9	97.7
Alumix 231 + % 5 Al_2O_3	600	93.7	94.8
Alumix 231 + % 10 Al_2O_3	600	93.3	94.1
Alumix 231 + % 15 Al_2O_3	600	92.2	92.9

TABLE 3. Density values of raw and sintered metal matrix composite samples (group 2).

Test samples	Compression pressure, MPa	Green density, %	Sintered density, %
Pure Alumix 231	600	95.9	97.7
Alumix 231 + % 5 B_4C	600	91.9	95.6
Alumix 231 + % 10 B_4C	600	90.3	95.2
Alumix 231 + % 15 B_4C	600	88.2	90.1

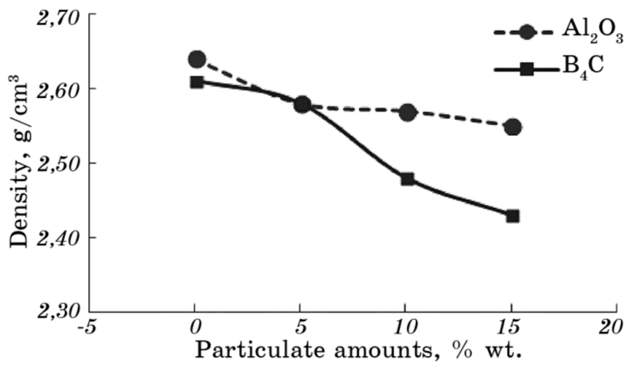

Fig. 2. Effect of particulate (Al_2O_3 and B_4C) amount on the density of Al based composite.

depending on the Al_2O_3 and B_4C amounts. The curves show that increasing of the reinforcing element results in a decrease in density at a constant sintering temperature. The figure also shows that increasing particle amount in B_4C reinforced composite decreases density more than Al_2O_3 reinforced composite.

In the PM method, some porosity remains in the matrix after pressing and some of it disappears during sintering [18]. In the present study, some pores occurred at the interface of the matrix-reinforcement particles that is believed to reduce the density of the samples. The photograph in Fig. 3 shows both pore and alumina particle distribution in the matrix. Similarly, both pores and B_4C particles are seen in Fig. 4. Guldur *et al.* and Rahimian *et al.* studied the effect of

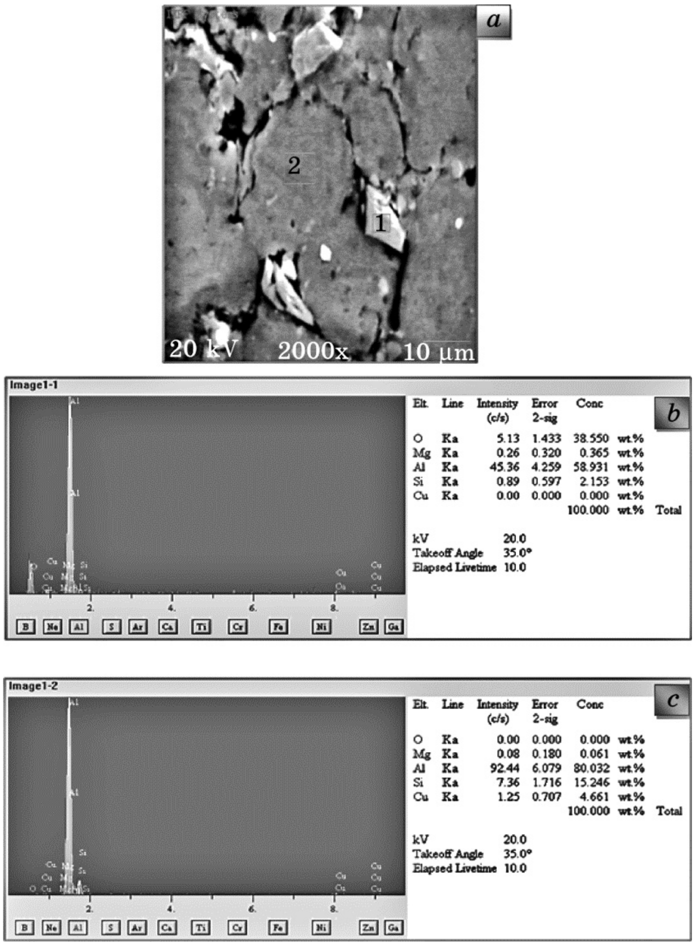

Fig. 3. SEM microstructures and EDX analysis of the produced composite material (group 1).

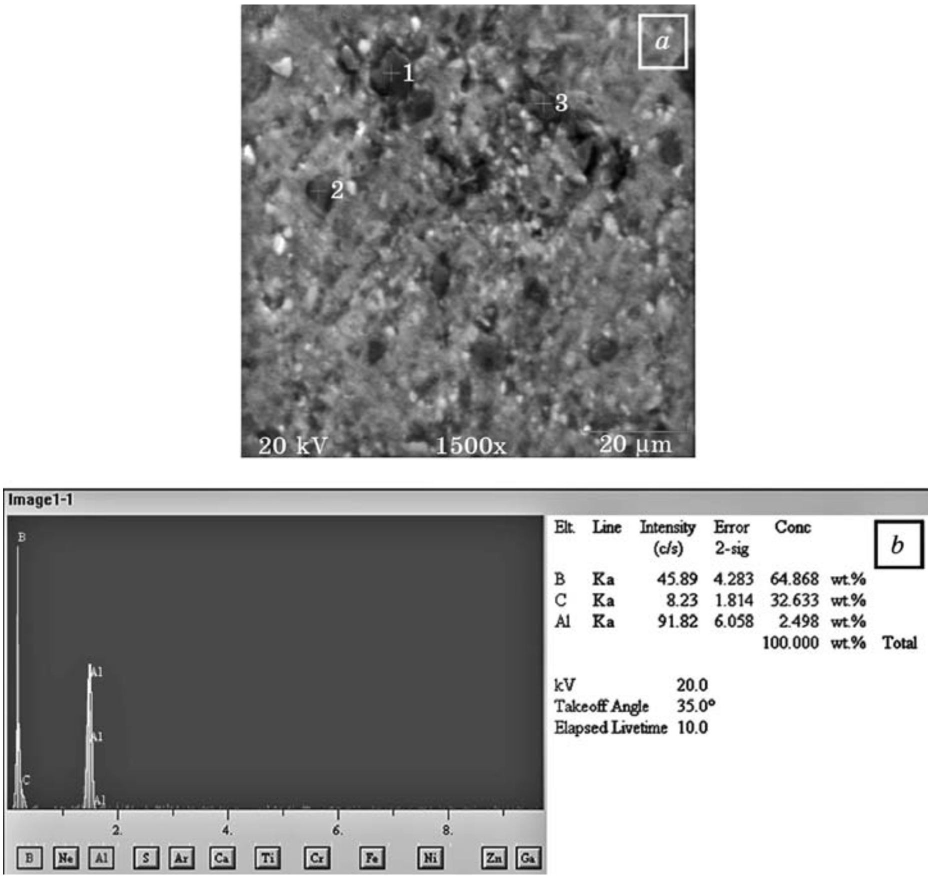

Fig. 4. SEM microstructures and EDX analysis of the produced composite material (group 2).

particle size and volume fraction on composite density, and both reported similar decreases in density [19, 20].

Figure 3, *a* shows the microstructure of Al_2O_3 reinforced composite materials. In order to evaluate the particles and element distributions in the matrix, EDX analyses have also been conducted from the different areas of materials. According to the analysis, the particles seen in the matrix are Al_2O_3 ones, which were surrounded by pores and consequently result in a decrease in density.

The EDX analyses and SEM images taken from weld metal and transition zone are given in Fig. 4. B_4C particles in transition zone are detected as shown in Fig. 4, *a*. It can be stated that the B_4C particles on the weld metal transition zone are distributed homogenously. The EDX analyses and images from the zone in Fig. 4, *a*, *b* confirm the existence of B_4C particles. Micropores are detected around B_4C particles and matrix interface.

3.2. Examination of Microstructure

Figure 5 and Figure 6 show the microstructures of base material, weld metal, and heat affected zone (HAZ) of the Al_2O_3 and B_4C reinforced composites respectively. Figure 5, *a* shows microstructures of weld joints of Al_2O_3 reinforced composite materials including heat affected zone, fusion area and weld zone. From this Figure, it can be seen that dendrites are formed in the weld zone and some porosity are in the vicinity of weld junction. Similar to the aluminium microstructure, typical dendrite microstructures have grown in these compositions. It is clearly seen from the microstructures in Fig. 5, *a* that solidification and growth occur from grains of base metal as epitaxial growing mechanism. Agglomeration of reinforcing element particularly at transi-

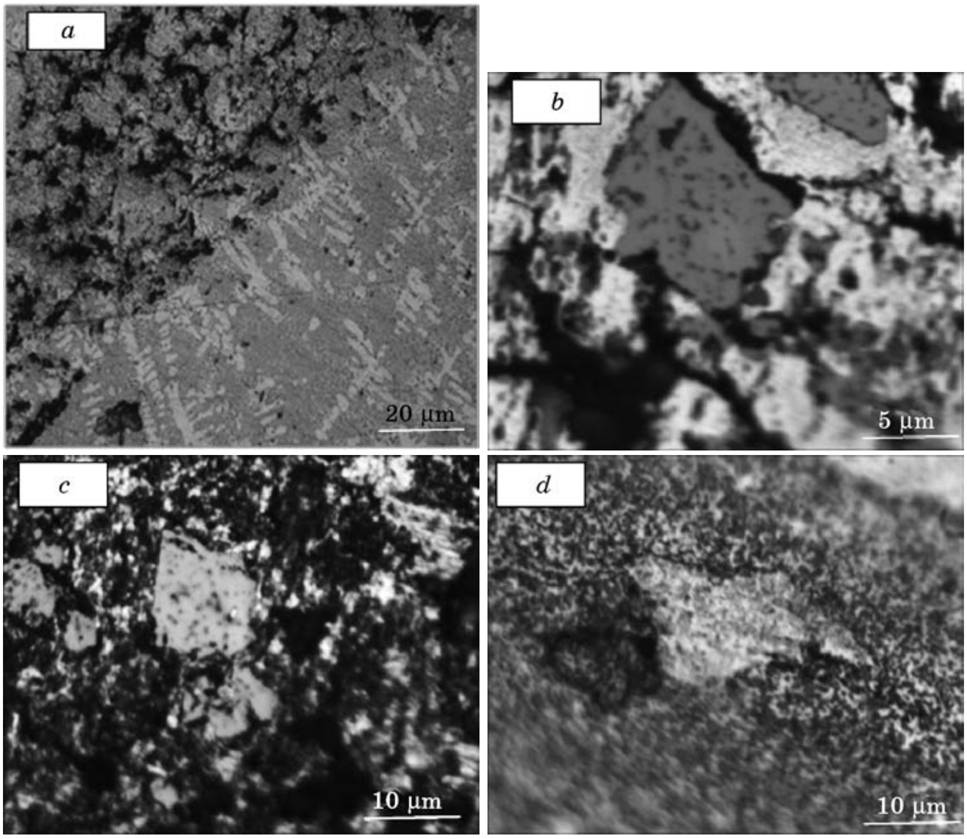

Fig. 5. The microstructure of weld metal and transition zones Al_2O_3.

tion zone can be attributed to the fusion welding process. It can be seen from the microstructure (Fig. 5, *a*) that transition zone is a distinct layer between the weld metal and HAZ. Detailed inspection has shown the absence of both cracks and pore in the weld metal. These results show that Al_2O_3 reinforced Alumix 231 can be welded by the TIG welding method without any problem [21].

The microstructures in the weld centre have few Al_2O_3 particles and mainly are located compatible to matrix, as shown in the Fig. 5, *d*. Similarly, numerous Al_2O_3 particles are found in the HAZ and base metal Fig. 5, *b*, *c*. The above results demonstrate that the distribution and compatibility of the reinforcement element in the different parts of the weld is homogeneous, resulting from the uniform composition in the composite and optimum welding parameters [22, 23].

Figure 6 gives the appearance of weld joint of the composite reinforced by B_4C. Similar results with the composite reinforced by Al_2O_3

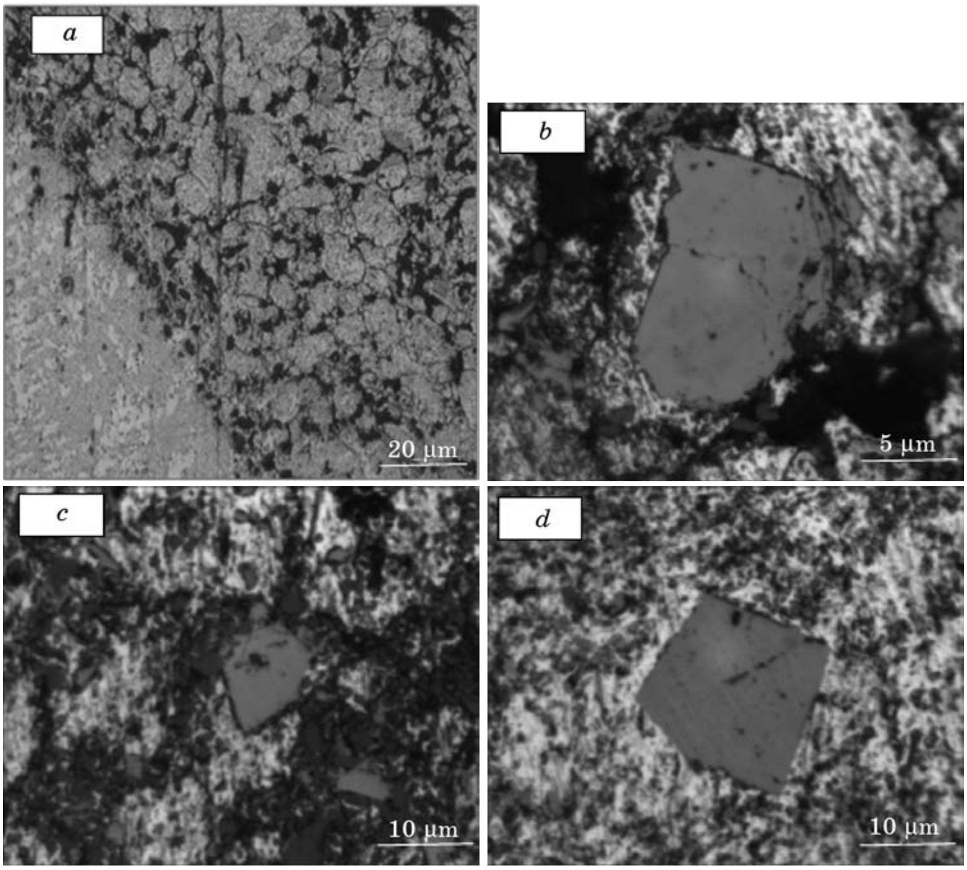

Fig. 6. The microstructure of weld metal and transition zones B_4C.

have been observed. We can see that the weld formation with these optimum welding parameters is the same as for aluminium microstructure with typical dendrites grown in these compositions.

It is also evidently seen from the microstructures in Fig. 6, *a* that solidification and growth occurs from grains of base metal known as epitaxial growing mechanism. In the structures of these samples, agglomeration of particles at transition zone can also be seen and attributed to the fusion welding process [24]. After inspection studies, the absence of both cracks and pore in the weld metal can be reported. These results show that B_4C reinforced with Alumix 231 can be welded by the TIG welding method without any problem [21].

It can be observed in Figure 7 that B_4C particle in weld metal is embedded in the structure. As seen in this Figure, pore formation occurs between the particle and weld metal interface. It is thought that the reason for B_4C particles embedding in weld metal is the high temperature occurring during fusion welding.

3.3. Change of Hardness

The points of obtained hardness values and the hardness distribution of the composites reinforced using by Al_2O_3 and B_4C particles have been shown in Fig. 8 and Fig. 9. The hardness values taken from the base metal has shown the increase with increasing of Al_2O_3 and B_4C amount. It can be said that the hardness values are similar to those seen in Al based powder metal parts. Generally, the hardness distribution of the

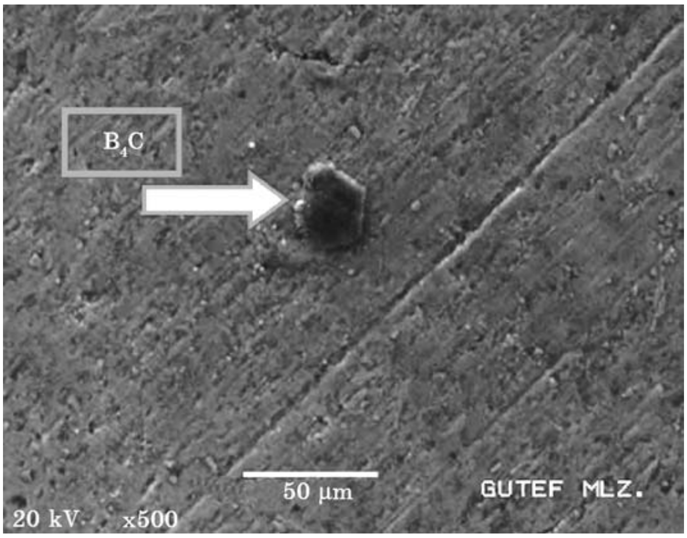

Fig. 7. The appearance of B_4C particles in weld metal.

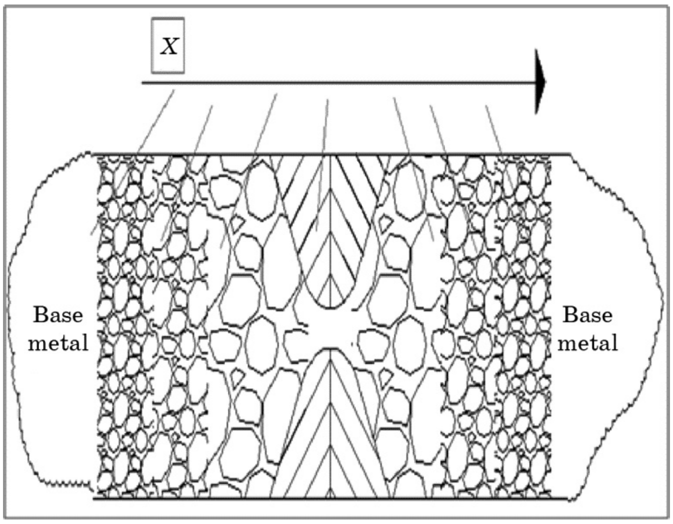

Fig. 8. The points of obtained hardness values (grey lines near the X-axis).

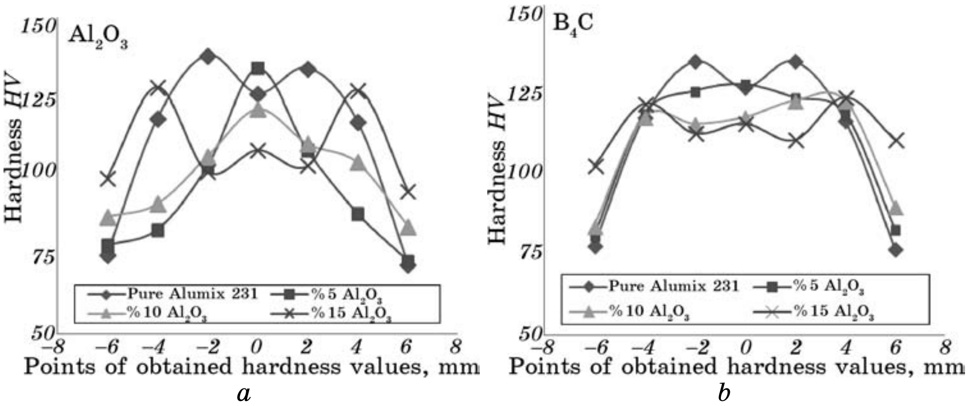

Fig. 9. The distribution of the hardness values of the composites (5% Al_2O_3 and 5% B_4C).

composites is increased from based metal to the weld metal. However, it shows decrease of hardness in the centreline of the weld metal compared to the transition zone.

4. CONCLUSION

Joinability of Al_2O_3 and B_4C reinforced Alumix 231 matrix composites produced by powder metallurgy route has been investigated, and on the basis of obtained test results, the following conclusions can be drawn.

A decrease in density is observed depending upon the increase in the amount of Al_2O_3 and B_4C in the composites produced under constant sintering temperature and sintering time. The reason for the decrease in density is the small pores formed between the matrix material and reinforced element interface. The more increase in the amount of particles the more increase in the micropores in the structure, but density decrease is monotonous.

It can be clearly seen that Alumix 231 matrix Al_2O_3 and B_4C reinforced composites are joined using by the TIG welding technique successfully. The penetration can be obtained to be relevant in terms of weldability of PM parts.

The high temperature occurring during welding process causes the particles embedding in weld metal.

The reason for the increase of hardness values of the base metal is the increasing amount of the reinforcing particles. However, the hardness values taken from weld metal do not display a linear way.

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