Superficial hardening improvement of nano and micro composite Al TiC

ABDERRAOUF GHERISSI • Department of Mechanical Engineering, Faculty of Engineering, University of Tabuk, KSA - Saudi Arabia ■ gherissi.abderraouf@gmail.com

MALIK ALI • Department of Mechanical Engineering, Faculty of Engineering, University of Tabuk, KSA - Saudi Arabia ■ malikali77@yahoo.com

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Abstract

The present investigation aims to study the improvement of the composite surface hardness by air abrasive jet polishing (AJP) of SiO_2 particles. The experiments were conducted by synthesizing Al-TiC composites through melting the aluminum at 850°C and added TiC gradually for 10 minutes to the liquefied aluminum with different sizes and ratios (300-500 nm and 100-200 μm) and (5, 10, 15, 20 and 25 wt.%) respectively of TiC. The molten Al-TiC was poured to a previously prepared sand mould. The hardness improvement for pure Aluminum, Al- micro-TiC and Al- nano-TiC composites were 7%, 11%, and 15% respectively. The obtained results demonstrate the importance of superficial hardening of composites Al-TiC by impact of the SiO_2 air jet and show that the surface hardness improvement is greatest for the nanocomposites compared with micro-composite and pure matrix material.

Keywords: abrasive jet polishing, nano and micro composites Al-TiC, hardness improvement, SiO_2
Kulcsszavak: csiszolófűvós polírozás, Al-TiC nano és mikro kompozitok, keménység növel, SiO_2

Abderraouf GHERISSI

Assistant Professor of Mechanical Engineering at the Mechanical Engineering Department, College of Engineering, University of Tabuk in Saudi Arabia. Actually involved in several research projects in the field of Composite materials, advanced production process and clean energy.

Malek ALI

Associate Professor, Department of Mechanical Engineering, University of Tabuk, Tabuk, Saudi Arabia. Research experience in the following areas: Synthesis Advanced Nanomaterials, Metallurgy, Nano. Composites (Polymer, Ceramics, Metals), Corrosion and Energy Manufacturing/Fabrication of Metallic.

1. Introduction

The surface finish of Al-TiC components plays an important role in the mechanical response and wear resistance. Therefore, the surface treatment is a primordial process to achieve certain qualities that are not available from the primary manufacturing processes. One of the effective surface treatment processes is the polishing process using abrasive jet of particles. The effect of polishing techniques and penning on surface roughness and hardness are widely studies on composites [1]. Abrasive jet machining (AJM) is a process that does not include a physical contact between the tool and work piece so there are no thermal stresses and shocks developed. AJM can be used for many processes such as cutting, cleaning, polishing, etching, drilling and finishing operations. The effects of polishing techniques on surface roughness and micro hardness of resin composites are desirable in order to reduce the number of clinic sessions and bringing more comfort and satisfaction to the patient in dental application [2-4]. In addition, the air abrasion is commonly used on surface treatment for porcelain veneers [5]. The effect of different air-abrasion particles on metal-ceramic bond strength is widely analyzed in the work of Tolga Kulunk et al. [6]. Other studies using abrasive water jet polishing were conducted to improve the fatigue strength of metals [7, 8]. F. Boud et al. [9] studied the impact of plain water jet machining on the surface integrity of aluminum 7475. Others focused on penning treatment such as Kyun-Taek Cho et al. [10] who worked on surface hardening of aluminum alloy by soft-shot polishing treatment with Zn based ball. In this work, a nano and micro composites of Al-TiC are chosen as testing materials. Several previous works have been done in the synthesis of Al-TiC composites [11, 12]. In an attempt to improve the Al-TiC composites surfaces hardness with different TiC sizes and ratios a high efficient and low-cost AJP machine is designed to conduct the proposed testing.

2. Experimental procedures

Aluminum (Al) was used as matrix material whereas TiC particles with different sizes and ratios (300-500 nm and 100-200 μm), (5, 10, 15, 20 and 25wt. %) were used as reinforcement in the Al-TiC composites. Melting of Al was carried out using a resistance furnace operating at 850°C . The reinforcements were then added gradually for 10 minutes to the molten aluminum with different weight ratios (5, 10, 15, 20 and 25) wt.% of TiC. Mixtures were stirred for 10 minutes after the additions of TiC. The stirrer rod was operated at 450 rpm to ensure a good distribution and homogeneity of the nano and micro TiC powder in the molten Al matrix. With 10 $^\circ\text{C}/\text{min}$ heating rate the furnace, the temperature was held at 850°C to ensure high fluidity of Al. After the Al-TiC became homogenous, the liquefied Al-TiC was poured in to previously prepared sand mould. However, at a temperature of 700°C the molten became in a semi-solid state, where the slurry cannot be poured into the mold because at this stage, its viscosity is high and the fluidity is greatly low. Therefore, before pouring the slurry into the mold, it was necessary to re-melt it to a molten condition, and re-stir before pouring [13]. The abrasive jet machine (AJM) is utilized in the unconventional machining process of material removal from a work piece by the application of a high speed stream of abrasive particles carried in the air medium from a nozzle as shown in Fig. 1.

The AJM is used to cut hard and brittle materials where a three-axis CNC machine is utilized for material removal process. The machines are designed and selected through appropriately to the tasks. To design and construct the AJM components several factors have to be considered: compressible flow law, carrier gas, flow rate, vibration level, nozzle size, stand-off effects, material removable rate estimation, etc. The

selection of parts, the assembly process, the fabrication and the test of the machine performance were carried out. The AJM was designed and constructed to perform a CNC engraving, cutting and drilling as shown in Fig. 2.

Fig. 1 Schematic representation of the AJM
1. ábra AJM sematikus ábrázolása

(a)

(b)

Fig. 2 The abrasive jet machine (AJM) (a), the nozzle (b)
2. ábra AJM (a), fúvóka (b)

The AJP was designed with abrasive Silica sand (SiO_2) and used with a 90° impact angle and average gas pressure of around 5 bar with 2 mm nozzle diameter and a standoff height of 10 mm. The mass flow rate of SiO_2 was set to 1.2 gram/s. Total polishing time was 10 seconds. Control of the nozzle position and the blasting time on the top surface were controlled by a CNC table. Hardness test evaluation was carried out through the Brinell test machine WP 300 from GANT Company. Brinell hardness test carried out at 9.8 KN for 30 seconds. The test was used to investigate the influence of sizes and weight fraction of TiC on the matrix hardness. A total of five samples were taken for each ratio of the Al-TiC to obtain the average hardness value

for an accurate result. The concept of hardness improvement by abrasive jet polishing of SiO_2 particles is represented in Fig. 3. The Silica sand SiO_2 particles are characterized by a large number of irregular angular surface features and have a relatively high hardness (Mohs Hardness 6-7).

Fig. 3 The concept of hardness improvement by abrasive jet polishing of SiO_2
3. ábra A keménység növelésének koncepciója SiO_2 csiszolófűvós polírozásával

In order to evaluate the efficiency of the abrasive polishing machine, a primary experiment was carried out on four known specimens delivered from GANT Company under standard references as shown in Table 1. The polishing test was performed using aluminum alloy EN AW-6082 (called in ISO: Al Si1MgMn), copper CW004A (designation for the 99.9% pure copper), Brass CW614N with 37-45% Zinc, steel alloy S235 – IAC-C with maxi C% of 0.22 and Mn % of 1.6.

Based to the experimental results grouped in Table 1, it is observed that the increasing of the hardness of the aluminum alloy is about 51%, for the copper alloy is 73%, for brass is 53% and for steel is 29%. The improvement of surface hardness was significant, which confirm the effectiveness of the present jet polishing process on the material surface finishing.

Material	Brinell Hardness before polishing	Brinell Hardness after polishing $t^*=10\text{s}$ $d^*=10\text{ mm}$ Polishing at $MP=1.2\text{ gram/s}$	Percentage of hardness improvement $MP^*=1.2\text{ gram/s}$
Aluminum Alloy EN AW-6082	67 HB	101 HB	51%
Copper Alloy CW004A	55 HB	95 HB	73%
Brass CW614N	90 HB	138 HB	53%
Steel S235-IAC-C	130 HB	168 HB	29%

* t (s): Time of polishing.

* d (mm): Standoff distance between nozzle and top surface of the workpiece.

* MP (gram/s): Mass flow rate of abrasive particle of SiO_2

Table 1 Hardness improvement of standard specimens by polishing test
1. táblázat A minták keménységének növekedése polírozási teszt alapján

3. Results and discussion

3.1 Hardness results before polishing

In this part, hardness test was conducted to investigate the influence of sizes and weight fraction of TiC on the matrix

hardness. A total of five samples were taken for each ratio of Al-TiC to obtain the average hardness value for an accurate result. The hardness values of the micro and nano composites depend on the amount of particles, sizes, and uniformity distribution of TiC particles in the Al matrix as shown in Fig. 4.

Fig. 4 Comparison between average HB for nano and micro
4. ábra Átlagos Brinell-keménység összehasonlítása nano- és mikro kompozitokon

It is observed from the results of hardness in Fig. 4 that all reinforced specimens have a higher hardness than that of the matrix material. In general, the hardness increases with increasing the hard particles (TiC). The hardness for specimens with 20 wt% and 25 wt% TiC decreases due to the agglomeration of TiC particles. For these samples, the highest hardness measured is at 15 wt% Nano TiC at 28 HB while the minimum hardness is at 0 wt%, and that proves that the aluminum reinforced with TiC improves the hardness. Moreover, it was observed based on Fig. 4 that the nano-particles of TiC gives a little higher hardness for the composite Al-TiC compared with micro particles. The decrease of hardness at 20 wt% and 25 wt% of TiC is due to the effects of grain boundary.

The presented results had been observed in several investigations, which indicated the decrease of hardness below a critical grain size [17], [18] and [19]. Both experiments and simulations in [20], [21] and [22] have also shown that the strength/hardness decreases with further grain refinement below the critical value. This indicates the occurrence of a shift in the dominated deformation mechanisms from dislocation-mediated plasticity to grain-boundary-associated plasticity such as grain-boundary sliding, grain-boundary diffusion and grain rotation. Due to the small size of powder (especially in nano powder) a change is evident in hardness value for each specimen. If a particle is dispersed in the composite, a better value for hardness would be obtained. The agglomeration that occurs affects the mechanical behavior of the specimen. This is due to the powder collected at one portion of the specimen that causes a soft and porous surface.

3.2 Hardness improvement after polishing of the composite Al-TiC

All specimens were tested for Brinell hardness before the polishing. The outer surfaces of the workpieces were machined using an abrasive jet at a standoff of 10 mm and mass flow rate of abrasive particles of 1.2 gram/s. Then, the Brinell hardness test was repeated again on the same specimens. The degree of surface roughness was changed and the hardness as well. The amelioration of the hardness of the nano and micro composite Al-TiC samples at different ratios of TiC are regrouned in Table 2.

The percentage rates of hardness improvement in specimens were calculated through five experimental tests on each specimen. The average is presented in Table 2 for micro-composite and nano-composite with different ratios of TiC. By comparing the hardness before and after polishing it is clearly noticed that the increasing of hardness is about 7% to 15% for nanocomposites and about 6% to 11% for micro-composites due to the impact

of SiO₂ particles by abrasive jet polishing. This process produces tensile stresses in the surface because the surface is trying to become plastically larger.

As a reaction to the polishing or peening treatment a compressive unused stress is formed in the surface layer. These compressive unused stresses have to be balanced by unused tensile stresses in the entirely elastically deformed component interior.

Material specimen micro composites	Before polishing (HB)	After polishing (HB)	Percentage of hardness improvement
Pure Al	26.2	28	7%
Al- 5wt% TiC	26.7	28.7	7%
Al- 10wt% TiC	27.3	29	6%
Al- 15wt% TiC	27.7	30.7	11%
Al-20wt% TiC	26.9	29	8%
Al- 25wt% TiC	26.3	28.5	8%
Material specimen nano composites	Before polishing (HB)	After polishing (HB)	Percentage of hardness improvement
Pure Al	26.2	28.4	8%
Al- 5wt% TiC	26.9	28.8	7%
Al- 10wt% TiC	27.6	30.5	11%
Al- 15wt% TiC	28	32.3	15%
Al-20wt% TiC	27.4	31	13%
Al- 25wt% TiC	26.7	29	9%

Table 2 Hardness improvement for micro, and nano polishing Al- TiC composites
2. táblázat Az nano- és mikro polírozott Al-TiC kompozitok keménységének növekedése

The position of the maximum of compressive residual stresses depends on several parameters such as: the compressible flow law, carrier gas, flow rate, vibration level, nozzle size, stand-off effects, material removable rate estimation, etc. With increasing the shot peening time, deeper surface layers are plastically deformed, until a saturation is reached, which depends on the energy of the impact shot. The surface shows an increased dislocation density and roughness after shot polishing as in Figs. 5(b) and 6(b). This increase in the dislocation density leads to an increase in the material strength of the surface. This hardening of the polishing Al-TiC composite surfaces have been easily proven by Brinell hardness as shown in Table 2. In addition, it is noticed that the hardness decreases after

reaching 15 wt% of TiC in the aluminum matrix due to the high content of TiC in the Al matrix, which is very sensitive to the agglomeration of TiC.

3.3. Microstructure Image Analyses

The micrographs shown in Figs. 5(a) and 6(a) clearly display the distribution of the TiC particles (dark areas) in the Al matrix (bright areas). As shown in Figs. 5(a) and 6(a), the small particles are distributed homogeneously among the big particles (agglomeration of many small particles together). It should be noted that the particle sizes of the small particles are uniformly distributed. However, some pores can be observed. The formation of pores is mainly due to the non-uniformity of the initial TiC particles. Moreover, it is clear from Figs. 5(a) and 6(a) that the reinforcement particles of the composites are embedded in the aluminum matrix. A small agglomeration of TiC particles in the aluminum matrix has been noticed, and this is mainly due to the non-homogeneity involved in the mixing process carried out before casting. The size of the TiC particles in the composites increases as the TiC content increases.

Fig. 5 Microscopic observation of the nanocomposite Al TiC at Wt 10% (a) before polishing and (b) after polishing

5. ábra Al TiC nanokompozitok mikroszkópos vizsgálata (a) polírozás előtt és (b) polírozás után

Fig. 6 Microscopic observation of the microcomposite Al TiC at Wt 10% before polishing and (b) after polishing

6. ábra Al TiC mikrokompozitok mikroszkópos vizsgálata (a) polírozás előtt és (b) polírozás után

The surface shows an increased dislocation density and roughness after shot polishing as in Figs. 5(b) and 6(b). This increase in dislocation density leads to an increase in the porosity and material strength in the surface. The increase in roughness inherited during shot peening must always be considered as negative. At higher magnification overlaps, micro-cracks and areas with an obvious turbulent flow can be found. With the increase in peening time the surface roughness increases as well. A compressive residual stresses can be done to drastically reduce the faster crack propagation rate of the homogeneously deforming surface zone.

4. Conclusion

The presented study exposes the improvement of hardness for composites surfaces by Abrasive Jet Polishing (AJP). Composites of Al-TiC have been synthesized successfully by stir casting process with different sizes and ratios of TiC (300-500 nm, and 100-200 μm) and (5, 10, 15, 20 and 25 wt.%) respectively. An AJP by abrasive silica sand (SiO_2) was used to conduct the experiments. The increases in surface hardness for aluminum alloy, copper alloy, brass, steel were about 51%, 73%, 53%, and 29%, respectively. Hardness improvement for pure aluminum, Al-microTiC, Al-nanoTiC composites were 7%, 11%, and 15%, respectively. From the introduced results, improvements in polished surface workpiece are limited by the SiO_2 grain-impact phenomenon and the embedment of SiO_2 fragments in the workpiece surface. The surface shows an increased dislocation density and roughness after shot polishing. This increase in dislocation density leads to an increased porosity, material strength in the surface, and reduction the faster crack propagation rate of the homogeneously deforming surface zone. The obtained results on Al-TiC composite demonstrate the importance of superficial hardening of composites by impact of the SiO_2 air jet and show that the surface hardness improvement is greatest for the nanocomposites compared with micro-composite and pure matrix material.

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