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MANUFACTURING OF NANO-SURFACE AA7075 COMPOSITES BY FRICTION STIR PROCESSING

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Abstract

Friction stir processing (FSP) is a novel processing technique that has been used for surface composite development and microstructural modification. The fabrication of Al_2O_3 nanoparticles (~40 nm) reinforced aluminum matrix composite (AMC) using FSP is studied in this paper with the aim of manufacturing high specific strength, hardness, wear and corrosion resistance surface nanocomposites for lightweight transportation applications. The Al_2O_3 nanoparticles were packed into the groove of 1 mm width and 7.5 mm depth that were machined in 15 mm thick plate of Aluminum alloy AA7075-O. Single pass FSP was performed using tool of cylindrical probe tool of 6 mm diameter and 20 mm diameter shoulder, constant rotation rate and traverse speed of 840 rpm and 40 mm/min respectively. A multipass FSP was performed to improve both dispersion and uniformity of the Al_2O_3 nanoparticles. The effect of post processing heat treatment after incorporating Al_2O_3 nanoparticles into different temper conditions of AA7075-T6 and AA7075-O was investigated. The fabricated AMC nanocomposites were analyzed and characterized using optical microscope, scanning electron microscope (SEM) and hardness testing. The hardness of the AMC increased with 89% higher versus that of the matrix alloy.

Introduction

Aluminum matrix composites (AMCs) reinforced with ceramic particles are new promising structural materials used in many lightweight applications such as aerospace, marine and transportation applications, due to their high elastic modulus, strength and resistance to wear, creep and fatigue [1]. However, these composites are known to suffer from both low toughness and ductility due to the addition of non-deformable ceramic reinforcements that restricts their extensive applications to a specific range [1,2]. A combination of both high toughness material and resistance to wear is highly sought desired; this combination of properties cannot be accomplished in homogenous materials. Consequently, it is necessary to reinforce the surface layer by replacing a bulk AMC with a harder surface composite, resulting in a material that has a hard surface and is still tough as the rest of the material is still keeps its original properties [3]. The new material is known as surface metal matrix composites (SMMCs) [1].

By using different techniques such as high-energy electron beam irradiation and plasma spraying, surface composites have been developed [3-5]. The main idea of these techniques is based on using liquid phase processing at high temperature [1]. However, using these techniques it is difficult to control the unwanted interfacial reactions between the metal matrix and the reinforcements, creating some destructive phases [1]. To achieve an ideal solidified microstructure in the surface composite layer, it is necessary to have a significant control of the processing parameters; these restrictions can be overcome only if it is accomplished in a solid state processing technique [1].

Friction stir processing (FSP) is a new solid state processing technique, which was established by Mishra et al. [6-8]. FSP is a promising technique for modification of the microstructure and surface composite development, depending on the main concept of friction stir welding (FSW). The main idea of FSP is very simple, where the rotating tool with pin and shoulder is integrated into a single piece of material. It has been used in the processing of a surface composite on an aluminum substrate [8,9]. FSP is identical to powder metallurgy (PM), cast aluminum alloys and metal matrix composites (MMC) [10-12] in the sense of producing a new composite with enhanced properties to the main matrix alloy. FSP has special advantages compared to other techniques of metalworking due to many reasons [8]. First, FSP is a multipurpose technique with a full function for the synthesis, manufacturing and processing of materials. Second, FSP is a short route with one step processing that accomplishes densification, homogeneity and refinement in microstructure. Third, by adjusting FSP parameters, (tool design and active heating), the mechanical properties and microstructure can be precisely controlled. Finally, by changing the length of the tool pin with the depth being between several hundred micrometers and ten of millimeters, the processed zone depth can be changed, which it is difficult to be obtained using other techniques of metal working.

FSP has been used recently for the development of MMCs in a number of metallic alloys [13-15]; for example, Bozorg et al [13] used FSP to incorporate nano alumina in AA6082. Mahmoud et al [14] used FSP has examined the effects of tool probe shape and size on the formation of surface composite by uniformly distributing SiC particles into a surface layer of an A1050-H24. Azizieh et al [15] have incorporated nano alumina particles in magnesium alloy AZ31 using FSP.

The aim of this work is to incorporate alumina nano particles in AA7075 for military vehicles and automotive applications, where the aim is to enhance the surface hardness and strength properties, while maintaining the bulk toughness and ductility, this development allows the expansion of the use of this novel material in applications where light weight combined with high specific strength and toughness are required.

Experimental Procedure

The material used in this study is AA7075-O plate of 15mm thickness and measured Vickers hardness of 66Hv. AA7075-O was used as a metal matrix and Al_2O_3nanoparticles with average size of 40nm as the reinforcements. Workpieces were prepared with a length of 200 mm and width 150 mm. A groove of 7.5 mm in depth and 1 mm in width was machined through the surface of the AA7075, where Al_2O_3nanoparticles were packed into these grooves. Then a probeless tool of 20 mm shoulder diameter was used for top closing of the grooves after packing of the nanoparticle at the same FSP parameters used. FSP using the conventional FSP tool made of H13 tool steel that heat treated to obtain 55HRC hardness was carried out. The FSP tool dimensions were of 6mm probe diameter, 10mm probe length and 20mm diameter shoulder. FSP was performed at constant rotation rate of 840 rpm and constant traverse speed of 40mm/min and tool tilt angle was set at 3 °.The material was processed for one, three and four passes all in the same direction. After FSP the material of O temper condition was age hardened to T6 temper condition by solution treatment at 515^oC and water quenching followed by age hardening at 120^oC for 24hrs.After the manufacturing of the new nano-surface dispersed material, samples from the different FSP processed materials were cut perpendicular to the processing direction. The samples were initially mounted using hot mounting press and prepared according to the standard preparation technique starting with grinding and then mechanical polishing using 6 µm, 1 µm diamond suspension and using 0.05µm alumina suspension. A number of material characterization tests were carried out; namely: optical microstructure, microhardness, and scanning electron microscopy (SEM Zeiss Leo Supra 55) investigation. The samples for metallographic examination and after final polishing were etched using diluted Keller's reagent of chemical composition (100ml distilled water, 10 ml HNO3, 10 ml HCL and 2ml HF) for 20 sec.

The microhardness was measured using a Vickers Microhardness Tester machine where a number of at least 15 readings were taken inside the processed zone and then averaged and also across the whole section of the FSProcessed zone at 0.5 mm intervals, using load of 4.9N.

Result and Discussion

Optical Microstructure

Figure1 illustrates the optical macrograph for the transverse cross section of FS processed A7075-O. The advancing side (AS) and the retreating side (RS) are indicated. It can be observed that the AS is sharp with clear interface between the base material grain structure and the new fine grain structure in the stirred zone. A tunnel type defect can be observed at the bottom of the AS that can be overcome by adjusting either the tool geometry and/or the processing parameters.

Optical microstructure is investigated after FSP and also applying the post heat treatment (PHT) regime to examine the effect of PHT on the fine grain structure developed after FSP.
Figure 2aillustrates the optical microstructure at the interface between the processed zone and the base material that clearly showing the fine grain structure developed after FSP. The fine grain structure in the processed zone is also varied in terms of geometry and size as can be shown in b and c of the same Figure 2 this can reflect the deformation inhomogeneity in the processed zone.

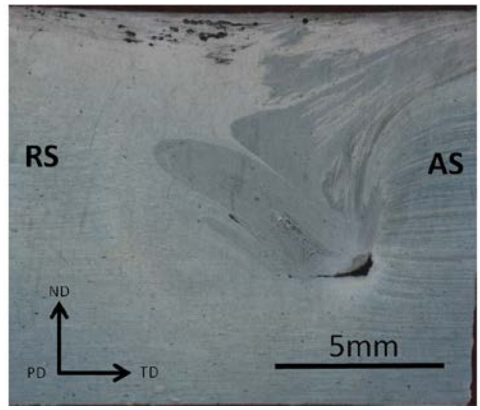

Figure 1, Optical macrograph for the transverse cross section of FS processed AA7075-O.

Figure 3 (a-c) shows the grain structure after T6 heat treatment of FSProcessed AA7075-O. Figure 3(a) shows the microstructure at the interface between the processed zone and the base material with no clear effect for the heat treatment can be seen at that level of magnification. However in Figure 3(b) only slight coarsening can be observed. It should be noted here that the grain growth is just of a normal type with no abnormal grain growth (AGG) occurring. It has been reported in many studies [16] that the post weld heat treatment of FSprocessed or FSwelded aluminum is accompanied with abnormal grain growth. The non-existence of AGG in this case can be attributed to the dispersion of the material with nano alumina particles. In Figure 3(c) another micrograph inside the processed zone is shows the some band structure with only slight grain coarsening also can be observed.

Hardness Investigation

Vickers microhardness is measured for all the FS processed 1, 3 and 4 passes samples either inside the FS processed zone and also across the transverse cross section to investigate the effect of incorporating Al_2O_3 nanoparticles on the hardness values and the result is illustrated in Figure 4. This figure clearly shows the increase of hardness values after FSP and also the increase of hardness values after increasing the number of FSP passes. This implies that increasing the number of passes enhances the uniform distribution of the nanoparticles inside the FSP zone. Figure 5 shows the microhardness values across the transverse cross section of the processed zone, which confirms the results shown in Figure 4. Also it should be noted here that after 4 passes of FSP, the hardness increase is not only in the processed zone but also extends to the heat affected zones which can be due to the effect of precipitation that occurs during the prolonged thermal cycles after 4 passes of FSP.

The Vickers microhardness is also measured after PHT of the processed material and Figure 6 illustrates the comparison between the hardness profiles before and after PHT of the FS processed material.

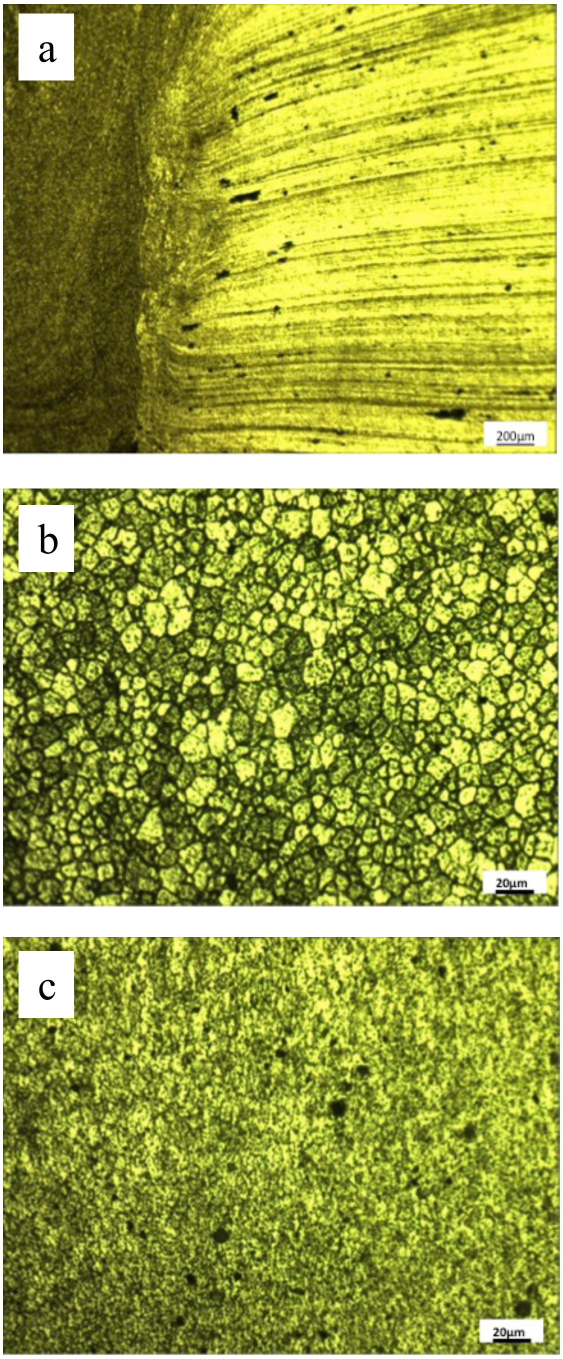

Figure 2, Optical microstructure at the AS in a) and inside the processed zone in b and c.

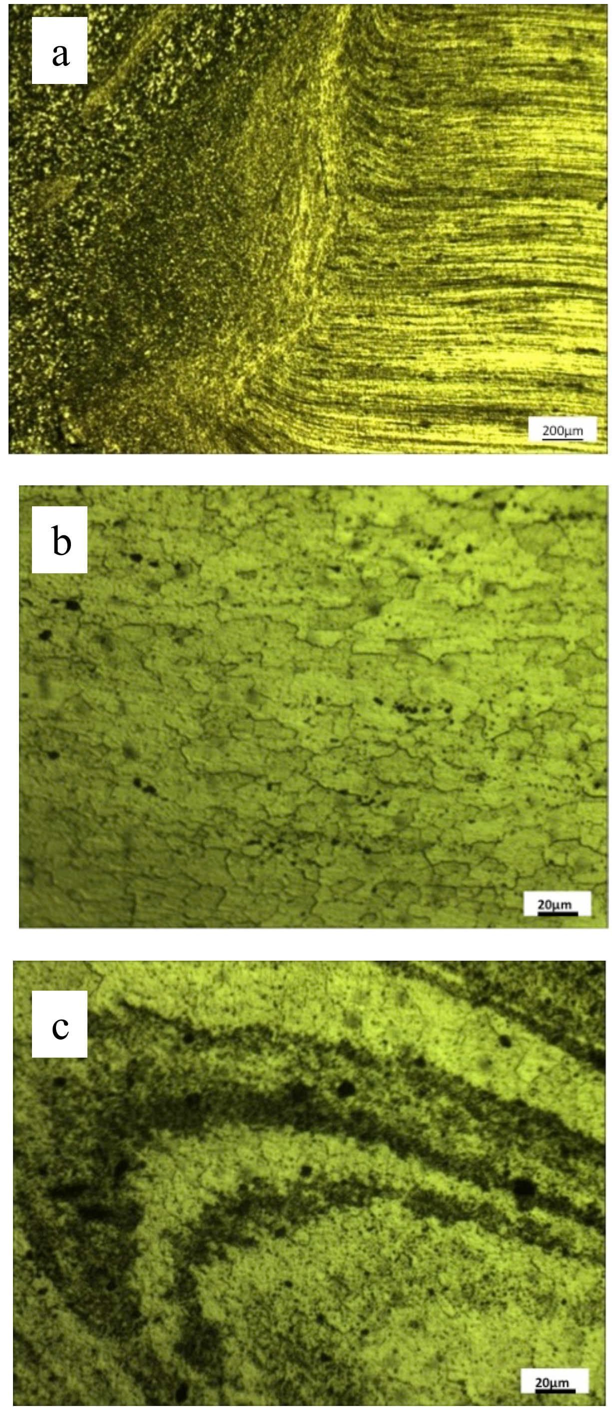

Figure 3 (a-c), Optical microstructure inside the processed zone of the FSProcessed AA7075-O after T6 heat treatment. a) at AS interface, b) inside the processed zone and c) at the banding structure.

The hardness increase after PHT is obvious while the effect of incorporating the Al_2O_3 nano particles on the hardness values seems quite complicated. PHT after 1 pass gives the highest hardness values however increasing the number FS passes has a diverse effect on hardness after PHT as it can be observed after 3 and 4 passes. This can be due to the existence of the nano particles as well as the precipitation that occurred during FSP.

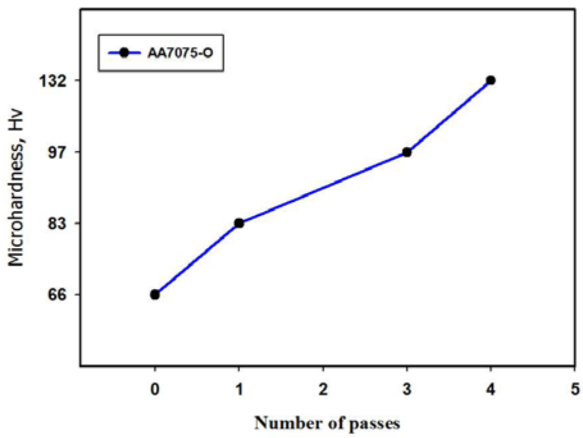

Figure 4, Effect of FSP number of passes on the Vickers microhardnessof surface nano AA7075-O composite.

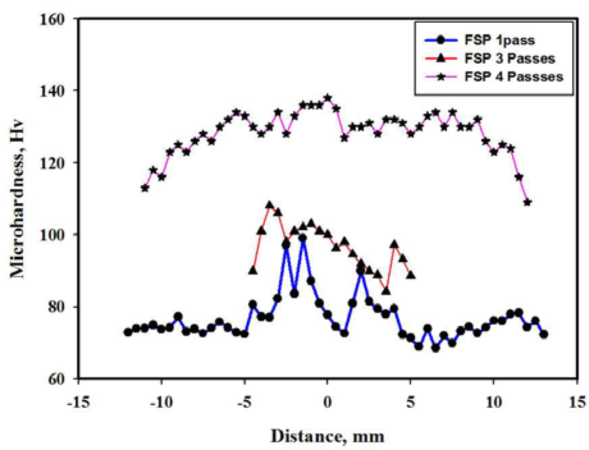

Figure 5, Vickers microhardness profile across the transverse cross section of FSProcessed AA7075-O.

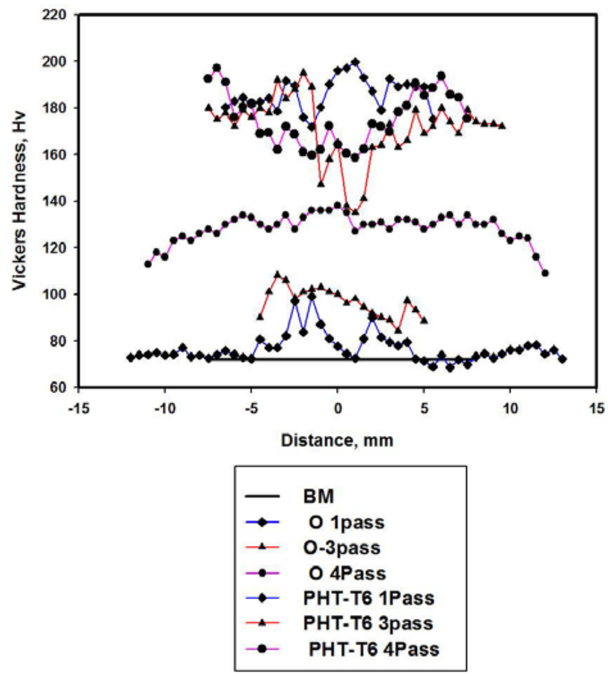

Figure 6, Comparison between Vickers microhardness profile of FSProcessed AA7075-O before and after PHT for T6.

<u>SEM Microstructure</u>

Figures 7 and 8 show the SEM images of FSP AA7075-O, where the dispersion of the Al_2O_3 particles is evident both uniformly inside the matrix as well as agglomerating into larger particles in some areas as shown in Figs. (7 and 8). The uniform overall distribution of the nanoparticles in the FSProcessed matrix interprets the enhancement in the hardness after the FSP(Figures 4-6).

The SEM examination proves the success of friction stir processing technique in incorporating the nanoparticles into the matrix during the friction stir processing which provides a continuous deformation and dynamic recrystallization to the processed matrix.

Though many researchers have attributed the enhancement in hardness and other mechanical properties of the FSProcessed alloys has been attributed to the significant refining of the grains resulting from the continuous dynamic recrystallization encountered during the process, the significant role of adding the nano particles cannot be overruled by comparing the hardness levels in the retreating and advancing sides. The denser concentrations of the Al_2O_3 particles is expected to occur in the advancing side since the particles will be carried by the tool and allowed to embed in the matrix.

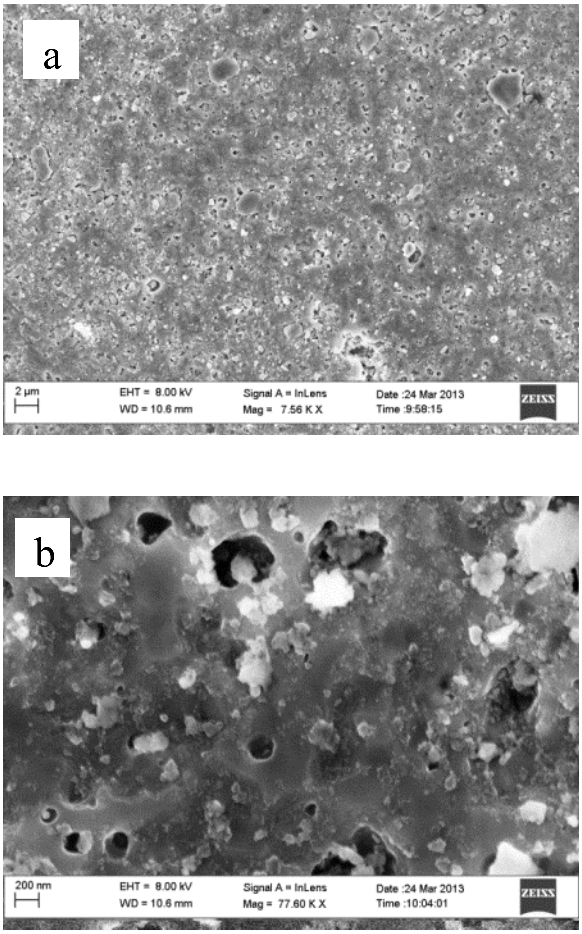

Figure 7, SEM microstructure inside the processed zone AA7075-O. Low magnification in a) and high magnification in b).

Also, one significant observation in this work is the presence of the T6 precipitation phases of (AlZn compounds) in the base metal (BM) after T6 heat treatment, whereas the nugget heat affected zones (HAZ) seem to be free of these phases (gray phases in Fig. 8). These observations suggest that the nanodispersions impede the well known precipitation process during the aging process as has been suggested by one of the authors before [17].

Conclusions

Friction stir processing can be successfully utilized to develop surface-nanocomposites with Al_2O_3nanodispersions homogeneously embedded in the matrix. The new surface nanocomposites showed enhancement in the hardness of the surface of A7075-O to almost double of the starting material after 4 passes FSP with incorporating nano-alumina particles. No obvious AGG is observed after PHT of the FSProcessed material; however the hardness behavior does not follow the conventional heat treatment regime in the processed zone.

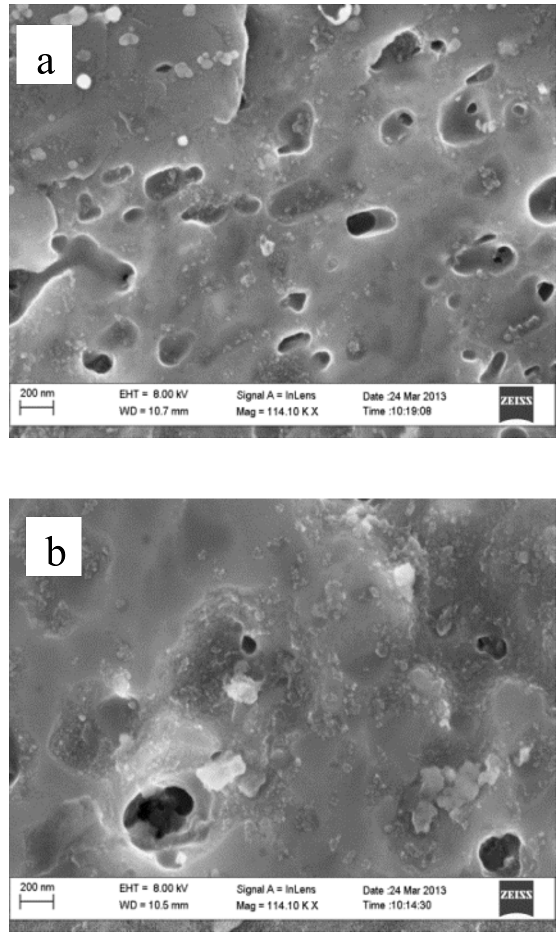

Figure 8 SEM micrograph of BM in a) and HAZ in b) of the FS processed AA7075-O.

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