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Finite Element Modeling Analysis on In-Situ Al/TiB_2 Metal Matrix Composites

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Abstract

Background/Objective: Hardness of Al/TiB_2 Metal Matrix Composites (MMCs) fabricated through in-situ reaction technique is indirectly dependent on pouring temperature. The objective is to predict Hardness through FEA and compare with experimental results. **Methods/Statistical Analysis:** The Al/TiB_2 (MMCs) ingots are obtained by melting A356 Aluminium alloy and mixing calculated amounts of KBF_4 and K_2TiF_6 to yield a maximum of 6% TiB_2 reinforcements and cast at different pouring temperature, while maintaining the time of stirring and holding time constant. The Brinell hardness of the resulting material is experimentally found and compared with predicated values by FEA in Ansys software package. **Findings:** The Hardness of the resulting Al/TiB_2 MMCs fabricated increases with pouring temperature and also depends on the stirring time as the KBF_4 and K_2TiF_6 salts are mixed and holding time in the mixed condition. In this study the castings were obtained for different pouring temperatures, but the stirring and holding time kept constant. The fundamental concept of this study is that as the pouring temperature increased the formation of % TiB_2 reinforcement increased there by resulting in increased hardness with pouring temperature. The tensile strengths of the samples with different pouring temperature are experimentally found and using this in FEA hardness is predicated. FEA predictions and experimentally found values are found to differ between 7.36% to 10.97% only. The novel finding is that it is possible to predict the hardness theoretically by FEA with a reasonable accuracy of over 90% instead of finding through laborious practical work. **Applications/ Improvements:** Whenever the Hardness of an Al/TiB_2 MMCs is needed it is possible to predict the hardness using FEA-Ansys package if the tensile strength of the material is known. There is no need for laborious practical method to be followed.

Keywords: Al/TiB2, Brinell Hardness, Finite Element Analysis, In-situ

1. Introduction

It is known that the Metal Matrix Composites (MMCs) have been widely used because of their excellent characteristics such as high specific tensile strength, high modulus, high wear resistance as well as high temperature properties. Their unique outstanding performance makes them promising potential candidates for applications in automobile and aerospace industries[1]. Particulate Reinforced Metal Matrix Composites (PRMMCs) have been fabricated normally by conventional ex-situ research work due to their ease of fabrication, lower cost and isotropic properties[2]. The ex-situ composites are fabricated by directly adding reinforcements in to its matrix Aluminium-based reinforced TiB_2 exhibits improved mechanical and corrosion properties which find relevance in automobiles and aerospace materials for structural applications and also in naval vessels[3].

In situ Al- TiB_2 composites were synthesized successfully through the mixing salts reaction among the KBF_4, K_2TiF_6 and Al. In-situ MMCs attracted due to their advantages, such as well distributed fine reinforcement and good bonding between matrix and reinforcement[4]. Ductility to be reduced in Al/TiB_2 MMCs hence it has a higher tensile strength than pure alloy[5]. TiB_2 is particularly attractive because it exhibits high elastic modulus, hardness, high thermal conductivity and mainly TiB_2 particle do not react with molten aluminium[6].

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In indentation testing, while the hardness of the specimen is obtained through analyzing the residual indent, the Young's modulus, E, is normally computed from the load displacement responses. Although pointed indenters such as Brinell, Rockwell, Vickers, and Knoop indenters are very popular methodology of using a spherical indenter for determining the properties of homogeneous materials[7].

At present Finite Analysis is one of the most widely used practical method and it dissolve in to all engineering problems. They are in use engineering in such spheres of science as: solid mechanics, fluid mechanics, biomechanics, material engineering, thermal analysis, magnetically and electrically analysis. Finite elements method permits in considerable time shortening for projecting processes and gives the possibility to research the influence of each factors on the whole mathematical model. Particularly economic point of view it in more suitable method and it permits to avoid, it permits to avoid the expensive laboratory investigations. The simulation results are more reliable and well approximate to real values[8,9]. ANSYS is a complete FEA software package used by engineering like structural, electrical, mechanical and electromagnetic.

The aim of this study is to conduct hardness test by Brinell hardness tester and determined the experimental values of the hardness. The experimental results are compared and by validated using FEA analysis.

2. Experimental Work

Aluminium (A356) was used as the base metal. Two types of salts, namely potassium Hexa Fluro Titanate (K_2TiF_6) and Potassium Tetra Fluro Borate (KBF_4) were used to synthesize and to form TiB_2 reinforcement. Aluminium was melted at different conditions i.e. 780˚C, 790˚C, 800˚C, 810˚C, 820˚C, after which the two types of salts K_2TiF_6 and KBF_4 are preheated and maintained at 250˚C for about 30 min. After that the salts were added into the molten Aluminium by using the stir casting method. The stirring of molten metal was continuously up to 30 min. K_2TiF_6 and KBF_4 salts were added into molten Al resulting in exothermic reaction to form In-situ TiB_2 particulates in Al. Unwanted compounds such as Al_3Ti and AlB_2 also form. Al_3Ti is a brittle compound and it degrades the mechanical properties of composites. Moreover, Al_3Ti was reduced by maintaining longer reaction time and holding time at temperatures between 700˚C to 800˚C. The above in-situ based Al/TiB_2 MMCs were fabricated by sand mould and permanent mould conditions and mechanical behaviors was analyzed.

2.1 Hardness Test

The composite materials containing a soft matrix and hard reinforcement phase, like TiB_2 reinforced composites, the selection of region in the sample were evaluating the hardness data is very important. The hardness tests were carried out with three replications by Brinell hardness testing machine and hardness values of the samples were measured on the (10x10) mm square samples using a steel ball with 1.58 diameters at a load of 100 kgf. The Brinell hardness measures the overall respond of the material and it is relatively insensitive to localized effect. The hardness test specimens are in Figure 1.

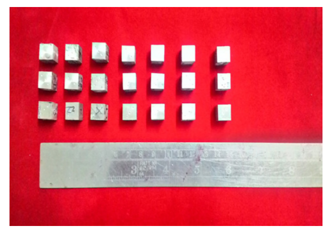

Figure 1. Hardness specimens before and after testing.

3. Simulation Modeling

FEA simulations of deformation during hardness test by Brinell method was used in ANSYS program. Taking into consideration that real model is symmetric and model made in Ansys is ¼ of real model. The advantage of simulation, axis-symmetric problems is that the spherical ball is considered as a quarter circles. The contact pair is created between indenter and sample as shown in Figure 2(a).

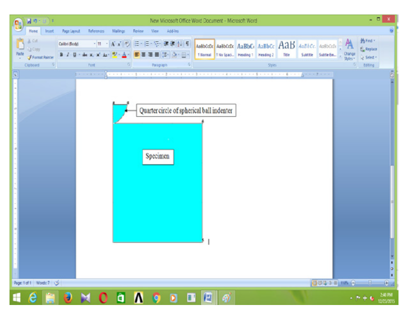

Figure 2 (a). FEA the indenter and specimen.

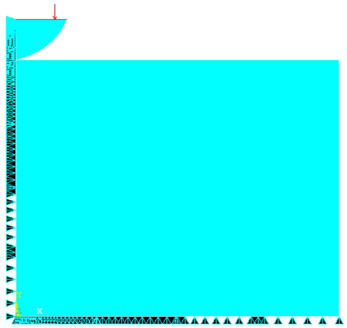

Figure 2 (b). FEA the indenter and specimen is meshed and this model.

This investigation is carried out by ANSYS, the indenter and specimen is meshed and this model is shown in Figure 2(b). Along the nodes at bottom line are constrained to move in x and y directions. Axisymmetry conditions are applied along the center line. The interaction of indenter and the specimen is modeled as contact pair with no friction. In simulation program the contact element was used in order to TARGET 169 for ball tip and CONTACT circle 175 for specimen. Mutli-linear isotropic hardening plasticity model is used to extract the plastic properties of the materials. Ansys work methodology flow chart indicates the above process is shown in Figure 3.

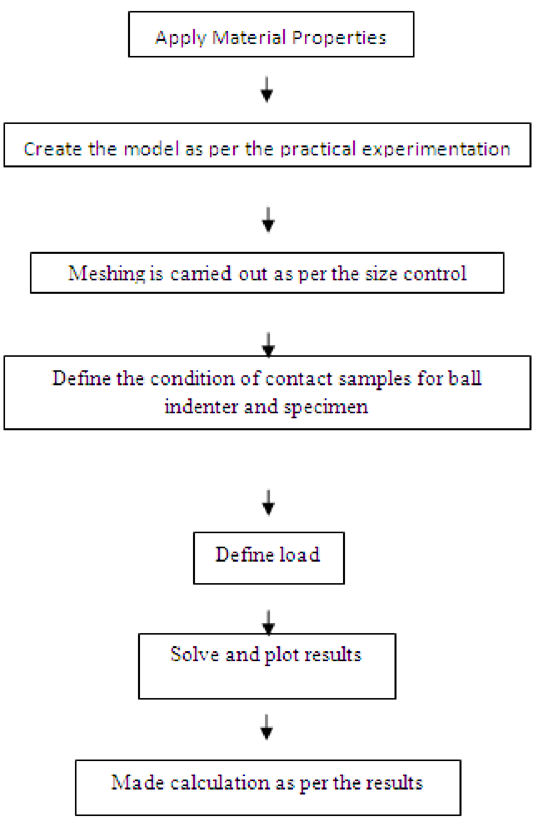

Figure 3. Ansys work plan.

4. Results and Discussion

Figure 4 (a-b) shows SEM Micrographs in different magnification of Al-6 wt% TiB_2 permanent mould metal matrix composites. The SEM images confirmed TiB_2 particles were homogenously dispersed and uniformly distributed in matrix phase. There is good bonding between the matrix and reinforcement phases present in white and dark colure of TiB_2 and aluminium respectively. In compared with different levels of temperature conditions (i.e. 780˚C, 790˚C, 800˚C, 810˚C, 820˚C) particularly in 820˚C temperature the casting have more number of TiB_2 particles were dispersed, with the reduced common defects such as porosity, fluidity and agglomeration.

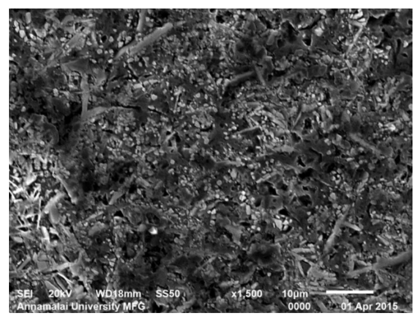

Figure 4 (a). SEM micrograph shows TiB2 presented at permanent mould.

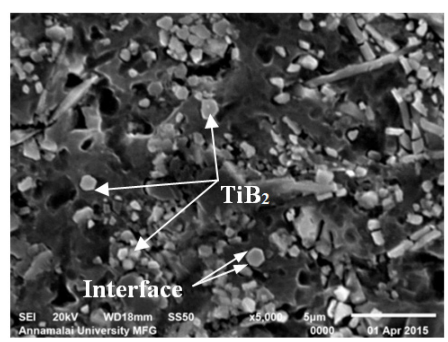

Figure 4 (b). SEM micrograph shows Al/TiB2 prepared at permanent mould.

The Brinell hardness test results are shown in Table 1. In permanent mould condition as the temperature increases hardness also increases in range tested and Al_3Ti formation and it affect the hardness of Al/TiB_2 composites at temperature above 800˚C.

Table 1. Simulation and experimental values are correlated for hardness of Al/TiB_2 MMCs

	Temperature °C				
	780°C	790°C	800°C	810°C	820°C
Brinell Hardness Tests	58.78	64.45	69.44	70.67	76.33
Computer simulations	69.75	74.40	76.80	79.40	86.10
Percentage of error	10.97	9.95	7.36	8.73	10.77

4.1 Hardness Simulation

Mainly finite elements were used and to avoid mistakes in calculations. On the basis of obtained simulation results, i.e., SMX, SMI, DMX, it was possible to compute the calculate hardness and its correlate with experimental values. The simulation hardness values compute forms the Equation (1).

$$H_{Brinell} = N \times SMX \qquad (1)$$

Where,

SMX - In ANSYS program the SMX signature is used in printouts and on maps of tensions.

N- Constant hitch value, Ball indenter move on block surface and is defined across different hitches.

Hardness results obtained with the use of computer simulation was compared with results appointed by experiment what was presented in Figures 5(a-c) present obtained results of numerical analysis with the help of the finite element method gathered as distribution maps of stresses in Al/TiB_2 different conditions. Stresses' error in the simulated model doesn't exceed 10% as shown Table 1. The comparative analysis of the results of computer simulation of stresses with the experimental results was carried out.

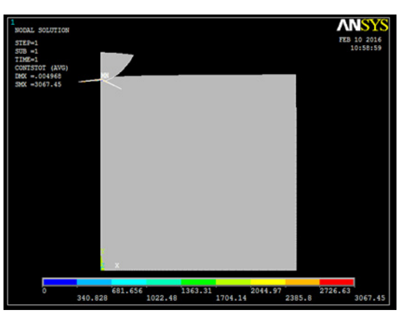

Figure 5 (a). Image of the FE model simulating the hardness test in Ansys.

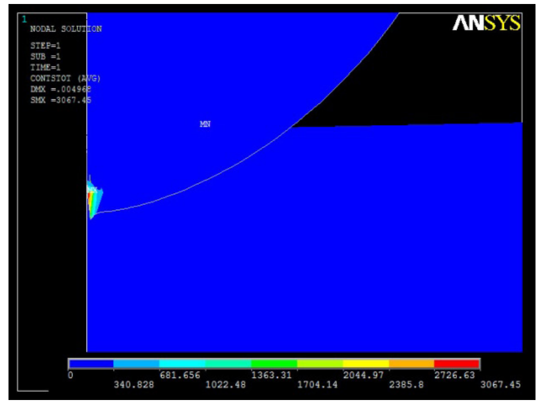

Figure 5 (b). Image of the FE model simulating the contact stress results in Ansys.

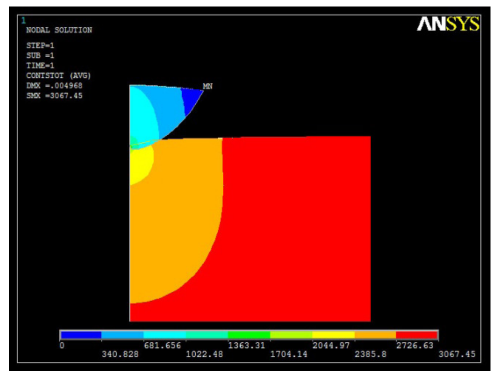

Figure 5 (c). Image of the displacement in y direction in Ansys.

5. Conclusions

By exothermic reaction between K_2TiF_6 and KBF_4 salts in aluminum alloy A356, in-situ aluminum alloy-TiB_2 composites were synthesized successfully. XRD studies confirm the formation of TiB_2 particulates.

In situ processed aluminum/TiB_2 composites are measured hardness and compared in different temperature conditions. It shows significant improvements of hardness 820°C condition. Because it may be attributed to the porosity and clustering of TiB_2 formation is very less and compare to other conditions.

The ANSYS model programmed with use of finite elements method permits to analyze the mechanical (hardness) properties, what makes plausible its application for computation of the hardness.

Hence the results arrived at experimentally are almost matching the theoretically predicated hardness value. The results obtained in ANSYS exhibit a good agreement with the experimental finding as shown in Figure 6.

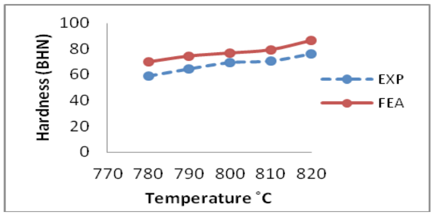

Figure 6. Effect of processing temperature on hardness of composite on FEA and experimental results.

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