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Experimental and FEA of Fracture Toughness on In-Situ Al/TiB_2 MMCs in Different Mould Conditions

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Abstract - ***In the present work, In-situ Al/TiB_2 composites have been successfully synthesized and fabricated through chemical reactions between Aluminium, Titanium and Boron bearing salts and to test in terms of mechanical property (i.e fracture toughness) and numerical simulation by Finite Element Analysis (FEA). The fracture toughness determined the experimental values of the fracture toughness. The experimental results were validated using FEA to simulate fracture toughness also developed. On the basis of obtained simulation results correlate with experimental values. The predicted results were in good agreement with the experimental values. The observation of SEM micrographs and XRD graphs shows homogenous distribution of the reinforcement particles in the cast composite.***

Keywords: *In-situ, Al/TiB_2, Finite Element Analysis, fracture toughness.*

1. INDRODUCTION

Metal matrix composites are produced from metals and ceramics to obtain the unique combination of properties such as high modulus, strength and wear resistance, good ductility and thermal conductivity, low density and thermal expansion [1] [2]. 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. The ex-situ composites are fabricated by directly adding reinforcements in to its matrix [3] [4].

Stir casting is a liquid state method of fabrication of composite materials in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir casting is the simplest and the most cost effective method of liquid state fabrication. The smooth transfer of the dispersions into the melt, impeller design, mixing and casting conditions are the important steps involved for the uniform distribution of the dispersions [5].

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 [6].

Fracture toughness is an indication of the amount of stress required to propagate a pre-existing flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, or service of a material/component. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof. Since engineers can never be totally sure that a material is flaw free, it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the LEFM (Linear Elastic Fracture Mechanics) is considered for a brittle material where only elastic analysis is carried out to determine stress and displacement fields near the crack tip with characterizing parameters like Stress Intensity Factor (SIF). The critical crack length when the stress intensity factor is equal to the fracture toughness is to be determined [7] [8].

Failure analysis are mainly based on experimental analysis recently Finite element analysis has become a novel and supplementary approach to failure analysis. This is applied in many of the mechanical engineering problems and results obtained are found to be agreeable with the experimental results. For i.e. Numerical simulations of tubular shell subjected to combined loading were conducted. The analytical solutions showed excellent agreement with the numerical results predicted by FEM [9] [10].

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

2. EXPERIMENTAL PROCEDURE

2.1. Materials

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 (KBF4) were used to synthesize and to form TiB_2 reinforcement.

2.2. Processing

Aluminium was melted at different conditions i.e. 780˚C, 800˚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. The above In-situ based Al/TiB_2 MMCs were fabricated by sand mould and permanent mould conditions and mechanical behaviours was analyzed.

2.3. Fracture toughness

The fracture toughness specimens were pre cracked in accordance with ASTM E399 to provide a sharpened crack of adequate size and straightness. The applied load ranges were determined from the geometry of the test specimens and material properties, and remained fixed throughout the tests. The tests were continued until the specimens failed ultimately due to unstable crack growth or fracture. Fracture toughness test was carried out in the Instron 8801 testing machine is shown in Fig.1. The fracture toughness test specimens as shown in Fig.2.

Fig-1: Instron Testing Machine

Fig-2: Fracture toughness specimens after testing conditions

3. FINITE ELEMENT ANALYSIS

The ANSYS program has many finite element analysis capabilities, ranging from a simple to transient dynamic analysis. The ANSYS documentation describes specific procedure for performing analysis for different engineering disciplines. A typical ANSYS analysis has three distinct steps
PRE-PROCESSOR

- Apply Material Properties
- Create the model as per the specimen
- Meshing is carried out as per the size control

SOLUTION

- Define the condition specimen
- Define the load

POST PROCESSOR

- Solve and plot results

This section presents a finite element modeling for the size of 3PB specimen, made as per ASTM (E399) standard. Half specimen was modelled using symmetry boundary conditions as shown in Fig.3(a & b). These triangular elements are available in ANSYS.13 in two dimensions by modifying the PLANE (8node183) element using the KSCON command.

The FE models initially formed with elastic material properties, E = 94.2E3 MPa and γ = 0.33, and a load P of 25 Mpa and Mesh the 3PB specimen. The nodes at the quarter points adjacent to the crack tip ensure that the displacements in the near-tip region are proportional to *r* (where r is the distance from the crack tip) the Stress intensity factor K_{IC} is the relevant fracture parameter to characterize the stress and strain fields around the crack tip. ANSYS Parametric Design Language, APDL, is employed for creating the fully automatic program to simulate the problem without any user interaction through this process.

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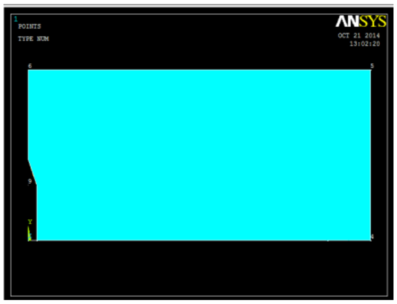

Fig-3.a: FEA 1/2 of real model the 3PB specimen

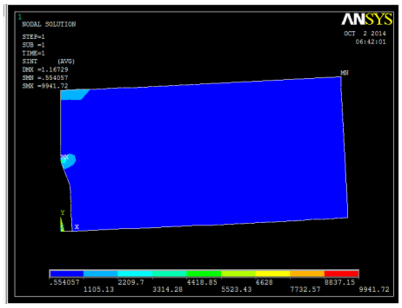

Fig- 3.b: Image of the FE model simulating the 3PB test

4. RESULTS AND DISCUSSION

4.1 Materials Characterization

Fig.4 (a&b) shows SEM Micrographs in different magnification of Al- 6 wt % TiB_2 permanent mould metal matrix composites. The SEM images confirmed TiB2 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, 800°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.

Fig.5 (a&b) shows the presence of TiB_2 and Al_3Ti formation in sand mould and permanent mould with XRD result at different pouring temperatures

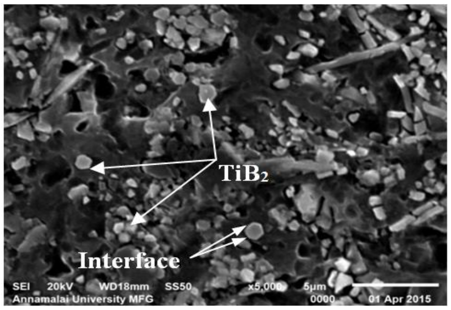

Fig.4.a

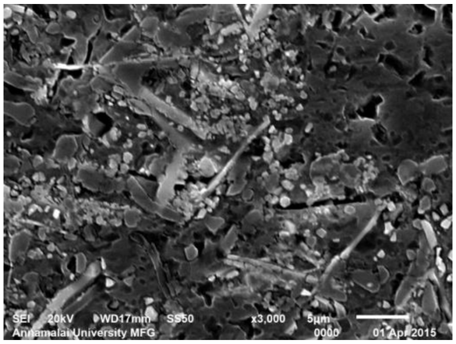

Fig.4.b

Fig-4 (a & b): SEM Micrographs of Al- 6 wt % TiB_2 composites (permanent mould and sand mould) with different temperature

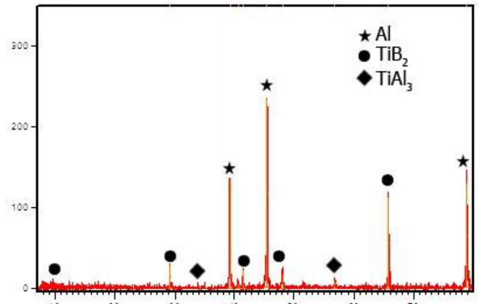

Fig-5.a: XRD graphs show the sand mould of Al/TiB_2 MMC

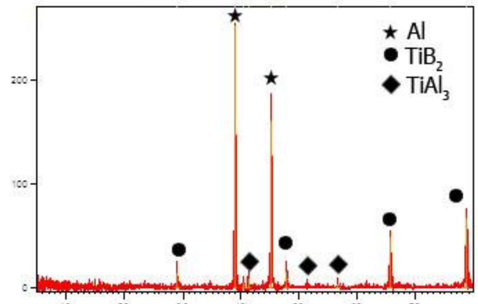

Fig-5.a: XRD graphs show the sand mould of Al/TiB_2 MMC

4.2. Fracture toughness

Chart-1 shows the UTS bar graph the fracture toughness was compared in sand and permanent mould conditions. Show significant improvements of fracture toughness in permanent mould condition. In permanent mould condition as the temperature increases fracture toughness K_{IC} also increases in range tested. In sand mould condition fissure cracks were formed due to Al_3Ti formation and it affect the hardness of Al/TiB_2 composites at temperature above 800˚C.

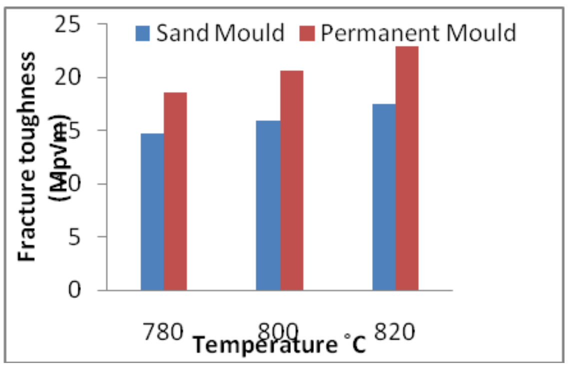

Chart -1: Comparison of Fracture Toughness in different mould condition with different temperature of Al/TiB_2 MMCs.

The fracture toughness results were arrived at with Instron Dynamic Testing Machine and Analysis by FEA of the 3PB. Hence the results arrived at experimentally are almost matching the theoretically predicated fracture toughness value for CT specimen as shown in fig.6. Under mode I (crack-opening) loading K_I may be compared with a material's fracture toughness K_{IC} in order to predict the stability of a crack. The fracture toughness was observed different poring conditions 820˚C conditions composites has higher toughness value predicted theoretically is 22.89 Mpa√m and that of corresponding experimentally found value is 17.54 Mpa√m.

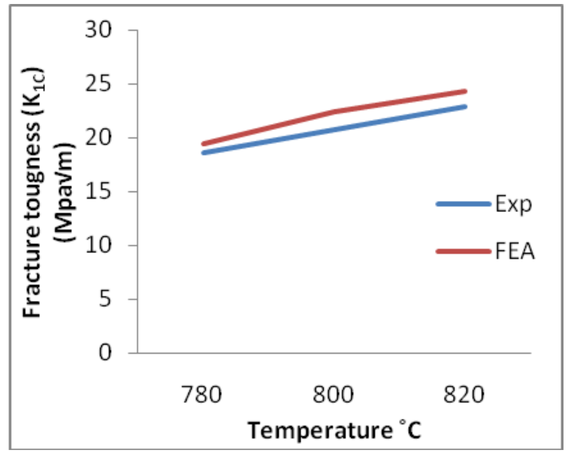

Fig-6.a: Effect of processing temperature on fracture toughness of Al/TiB_2 MMC on FEA and Experimental results in permanent mould.

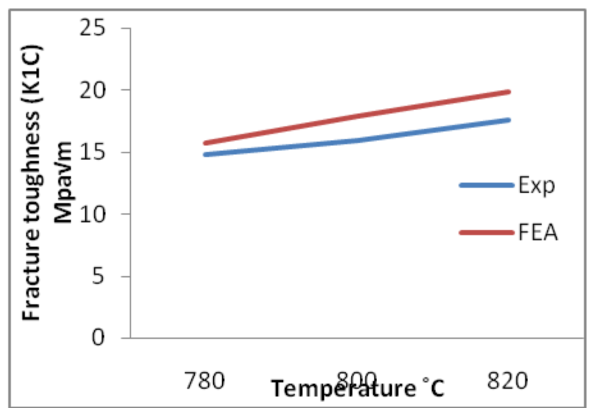

Fig-6.b: Effect of processing temperature on fracture toughness of Al/TiB_2 MMC on FEA and Experimental results in sand mould.

Table.1

Experimental and FEA Comparison of fracture toughness of different mould condition with different temperature of Al/TiB_2 MMCs.

Fracture toughness Mpa √m	Temperature ˚C					
	Permanent mould			Sand mould		
	780˚C	800˚C	820˚C	780˚C	800˚C	820˚C
Exp	18.56	20.68	22.89	14.75	15.87	17.54
FEA	19.45	22.47	24.35	15.68	17.87	19.89

5. CONCLUSIONS

Aluminium (A356) TiB_2 were successfully fabricated different temperature. The TiB_2 was made to achieve a uniform distribution of particles and good bonding with matrix alloy. XRD patterns and SEM images confirmed the presence TiB_2 phase with uniform distribution.

TiB2 particulates were made clean interface with aluminum A356, because of in-situ synthesis method. Variation in the weight percentage of TiB_2 will take place because of change in the volume of cryolite slag.

To compute K_{IC} by the finite element method (FE), quarter-point crack-tip elements is used. The results obtained in ANSYS exhibit a good agreement with the experimental finding. The fracture toughness value found experimentally is less as compared to ANSYS results. This may be attributed to the porosity and clustering of TiB_2 particles in the specimen.

The fracture toughness was compared in sand and permanent mould conditions. Show in table I significant improvements of fracture toughness in permanent mould condition.

It is concluded finally that the permanent mould casting are more suitable for Al/TiB_2 composite fabrication as compared with sand mould.

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