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PREDICTION OF MECHANICAL PROPERTIES OF AL/TIB$_2$ MMCS CAST THROUGH SAND MOULDS BY FEA VALIDATED BY EXPERIMENTAL RESULTS

* Rajaravi C [1], Lakshminarayanan P R [2] and Gobalakrishnan B [3]

[1,2,3] Department of Manufacturing Engineering, Annamalai University,Chidambaram – 608 002, Tamil nadu, India.

ABSTRACT

Aluminum alloy A356/TiB$_2$ In-situ MMCS have been fabricated through salt metal reaction route. In this present study the A356 alloy reinforced with TiB$_2$ particle cast in sand mould with different pouring temperatures. This showed that the mechanical properties (i.e. Fracture Toughness, Tensile Strength, and Hardness) increase with pouring temperature up to 820 ˚C. The observation on SEM and XRD study confirmed the formation of TiB$_2$ particulates. The experimental results validated the FEA results obtained through ANSYS 13. The predictions on mechanical properties using these models are in good agreement with experimental data for sand mold with different conditions.

Key words: *Titanium-di-boride, Al/ TiB$_2$ MMC, mechanical property, FEA.*

1. Introduction

Particulate Reinforced Metal Matrix Composites (PRMMC) have received intensive interests due to their outstanding combination of mechanical properties. These properties make them potential candidates in aerospace, automotive and manufacturing field [1, 2]. PRMMCs have been fabricated normally by conventional ex-situ process due to the ease of fabrication, lower cost and isotropic properties. The ex-situ composites are fabricated by directly adding reinforcement in to the matrix [3-4]. In this In-situ method, reinforcements are synthesized inside the metal by chemical reaction during formation of composite. In-situ MMCs attracted due to their advantages, such as well distributed fine reinforcement and good bonding between matrix and reinforcement [5-7].Finite Element Analysis (FEA) is a numerical method of analysis for stress variation due to deformations in structure of any given geometry. FEA permits in considerable time shortening for project process and give the possibility to research the influence of each factors on the whole mathematical model and the simulation results are more reliable and well approximately close to real values. ANSYS is a complete FEA software package used in engineering fields like structure, electric, mechanical and electromagnetic [8].

In this study, the In-situ Al/TiB$_2$ composites were successfully synthesized through salt metal reaction route and the researcher has undertaken to study the mechanical properties cast in sand mould. The mechanical properties (i.e Fracture Toughness, Tensile Strength) were examined through experimentally for In-situ Al/TiB$_2$ composite with different pouring temperatures and validated for FEA.

2. Experimental Study

Cast Aluminium alloy reinforced with approximately 6% TiB$_2$ particles were produced in-situ by adding the pre-weighed salts of Potassium Hexa Fluro Titanate (K_2TiF_6) and potassium Tetra Fluro Borate (KBF_4), mixed by hand stirring with a graphite rod for about 15 minutes. Within 15 minutes the salts were slowly added and stirred for further 10 minutes. Before adding the salts in the aluminium melt they were preheated at 250˚C for 30 minutes. The melt temperature was maintained differently and five different cast ingots with different melt/ pouring temperatures of 780 0 C, 7900 C, 8000 C, 8100 C and 8200 C were obtained then the ingots were machined to get the specimens required for experimentally determining the Fracture toughness, Tensile strength and Hardness. The ingots were cast in Air set sand moulds. The sand mould was prepared by mixing 15 kg of dry sand with 0.562kg Air set resin and filling and ramming the same in a wooden mould box and with the pattern kept in position. The sand in mould box was allowed to Air set for 1 hour and the detachable wooden panels of wooden mould box were removed and the pattern was also removed and thus the air set sand mould was made ready.

**Corresponding Author - E- mail:* rajaravi.mech@gmail.com

2.1 Fracture Toughness

Fracture toughness was experimentally found using Instron 8801 Dynamic testing machine. The test was continued until the Specimens failed ultimately due to unstable crack growth or fracture. Samples were fabricated according to ASTM standard E399 as shown in Fig.1.a. & 1.b.

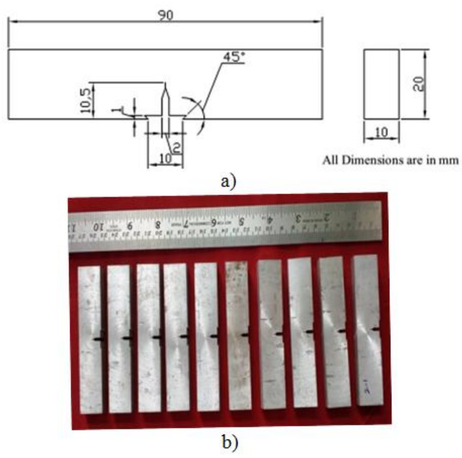


Fig.1 (a) 3 point bend specimen as per ASTM-E399 (b) Fracture toughness test specimens

2.2 Tensile Test

Tensile specimens were prepared according to ASTM standard E8-03. In each casting two samples were tested. Tensile test was carried out in an electro-mechanically controlled universal testing machine. The tensile test specimens are shown in Fig. 2.a & 2.b.

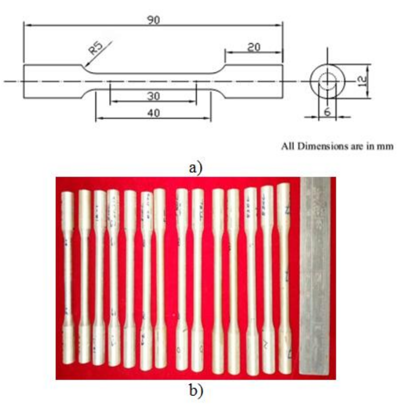
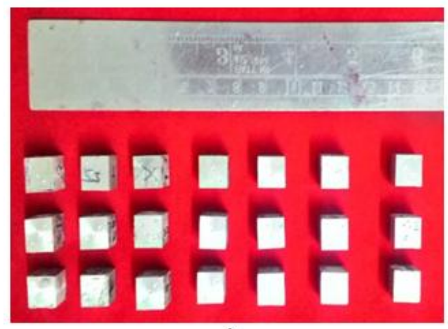


Fig.2 (a) Tensile test specimens as per ASTM- E8-03 (b) Tensile test specimens

2.3 Hardness Test

The hardness tests were carried out by Brinell hardness testing machine and hardness values were tested with three replications. The average results obtained are taken for final values. The hardness test specimens are shown in Fig.3.a.



a)

Fig.3 (c) Hardness test specimens

3. Finite Element Analysis

Finite Element Analysis, a theoretical tool for solving engineering task and making simulation which is cheaper than carrying out laboratory research, reduces time of solving the problem and gives reliable results. FEA simulation of deformations during fracture toughness, tensile and hardness were used in ANSYS program.

ANSYS work methodology

- Apply material properties
- Create the model as the practical experimental
- Meshing is carried out as per the size control
- Define the special conditions
- Define load
- Solve
- Results

3.1 FEA model of 3 point bend specimen

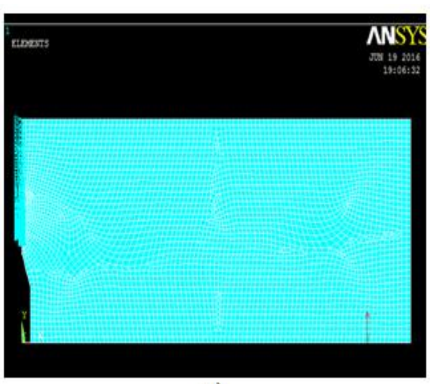
FEA of 3 point bend specimen is idealized by 4 node 182 elements. Only half of the specimen was modeled with appropriate boundary conditions on the plane of symmetry. The FE models initially formed with elastic material properties, E = 94.2E3 MPa and γ = 0.33, and a load P of 13 MPa and Mesh the 3PB specimen. As shown in Fig.4.a

3.2 FEA model of tensile specimen

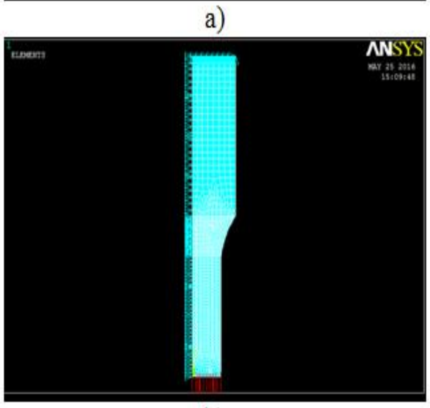
The specimen is meshed with the plane 182 element obtained with 1616 nodes. The geometrical data input to the computer is taken from the tensile test configuration according to ASTM E8M-04 standards. One end of the specimen is fully restrained and the other end is constrained to have translations along the principal material direction. The computer simulations are performed by applying the load 100 kN and boundary conditions are shown in Fig.4.b.

3.3 FEA model of hardness specimen

FEA simulations of deformation during hardness test by Brinell method were made taking into consideration that real model is symmetric and model made in Ansys is ¼ of real model. The advantage of simulation with axis-symmetric condition is that the spherical ball is considered as a quarter circle only. The contact pair is created between indenter and sample is shown in Fig. 4.c. This investigation is carried out by ANSYS and the indenter and specimen both are meshed in this model. It is constrained to move in x and y directions along the nodes at bottom. 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.



a)



b)

c)

Fig.4 (a) Fracture toughness specimen with loading and boundary condition, (b) Tensile test specimen with loading and boundary condition, (c) Hardness test specimen with loading and boundary condition.

4. Results and Discussion

4.1 Characterization of in-situ Al/TiB_2 composites

Fig. 6 (a, b) shows SEM Micrographs of Al- 6 wt % TiB2 composites cast with different pouring temperature. The TiB2 particles can be found to be homogenously dispersed with uniform distribution of reinforcement particles in the matrix phase is observed from SEM micrographs shown at magnifications of 1500x & 3000x. Castings fabricated with different pouring temperatures and particularly the casting were produced at 820˚C temperature have more number of TiB2 particles dispersed, with reduced common defects such as porosity.

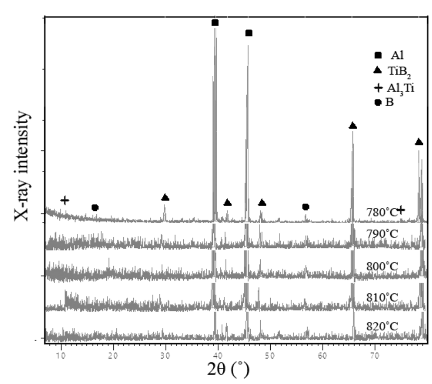


Fig.5 XRD spectra of in-situ Al/ TiB_2 composites show the different pouring temperature.

The presence of TiB_2 particles are evidenced by XRD study with different conditions as shown in Fig 5. After pouring as the cooling rate is low the TiB_2

particles grow in size affecting the mechanical properties [11-13].

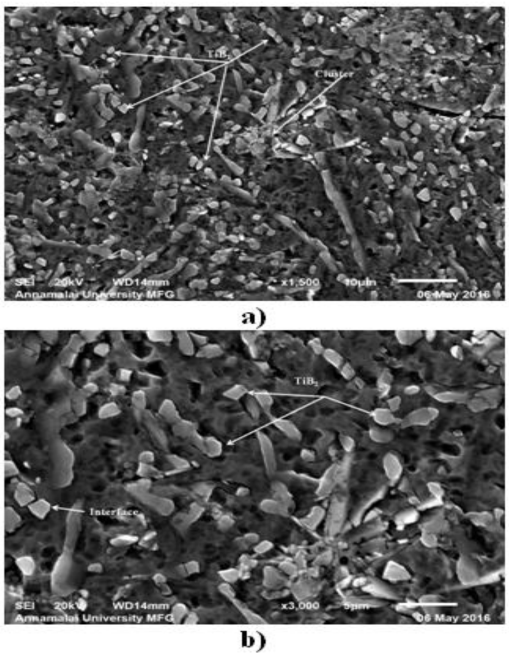


Fig.6 (a) SEM micrograph shows Al/TiB$_2$ prepared 820˚C (X 1500) (d) SEM micrograph shows Al/TiB$_2$ prepared 820˚C (X 3000)

4.2 Mechanical Properties of Composites

4.2.1 Fracture toughness of In-situ A356/TiB$_2$ composites

Table.1 shows that the fracture toughness compared with respect to different pouring temperatures. It shows significant improvements of fracture toughness in 820˚C than 780˚C.

At 820˚C the formations of the particles are more than that with lower pouring temperatures and hence the facture toughness is maximum at 820˚C.

Table 1. Tensile Strength, Hardness and Fracture toughness of Composite

S.No	Temperature ˚C	Tensile Strength (MPa)	Hardness (BHN)	Fracture toughness Mpa√m
1	780˚C	118	53.37	14.75
2	790˚C	122	55.33	15.22
3	800˚C	129	58.67	15.87
4	810˚C	130	61.56	16.05
5	820˚C	152	66.45	17.54

Table 2. Simulation and experimental values for Fracture Toughness of Al/TiB$_2$ MMCs

Temperature ˚C	Fracture Toughness MPa√m		
	EXP	FEA	Percentage of error
780˚C	14.75	15.86	6.9
790˚C	15.11	16.65	9.2
800˚C	15.87	17.87	11
810˚C	16.75	18.86	9.7
820˚C	17.54	19.89	11.81

As shown in Table.2 the results arrived at experimentally are almost matching the theoretically predicated fracture toughness value of 3 point bent specimens(Fig.5). 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 [14]. The fracture toughness was observed for different pouring conditions and at pouring temperature 820˚C the highest toughness value was predicted theoretically and is 19.89 Mpa√m and the corresponding experimentally found value is 17.54 Mpa√m as shown in Fig.7. Stress intensity factor error in the simulated model doesn't exceed 12 % as shown Table.2 and the experimentally found values are lower because of the probable defects in the materials during fabrications.

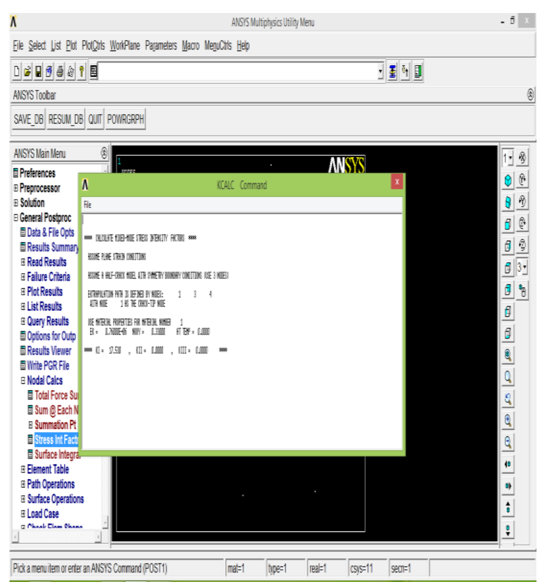


Fig.6 Image of the FE model simulating results of 3PB test

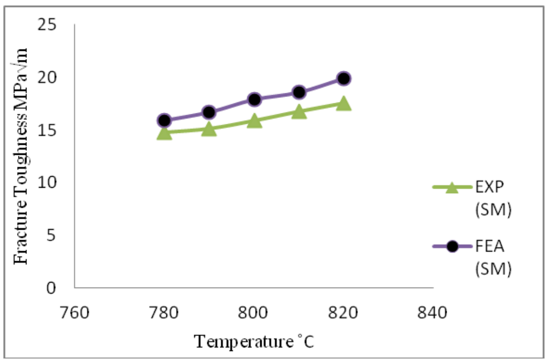


Fig.7 Effect of processing temperature on fracture toughness of composite on FEA and Experimental results.

4.2.2 Tensile strength of In-situ A356/TiB_2 composites

The tensile strength distribution for the specimens is shown in Table.1. UTS of the castings can be observed to be more for higher pouring temperature. At higher pouring temperature TiB_2 formation is more which result in higher tensile strength. The tensile strength of the MMCs increases from 118 MPa to 152 MPa as the pouring temperature increases from 780˚C to 820˚C. The experimental and FEA results are noticed to vary within 6.5 % as shown in Table.3 [15, 16]. The FEA model for tensile strength is shown in Fig.8. The experimentally determined values of tensile strength are almost matching with theoretical predictions as shown in Fig.9.

Table 3. Simulation and experimental values for Tensile Strength of Al/TiB_2 MMCs

Temperature ˚C	Tensile Strength (MPa)		
	EXP	FEA	Percentage of error
780˚C	118	126	6.3
790˚C	122	129	5.4
800˚C	129	143	9.7
810˚C	130	136	4.4
820˚C	152	142	6.5

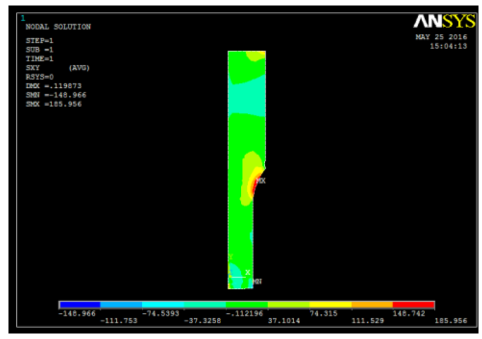


Fig.8 FE model of simulating the tensile test.

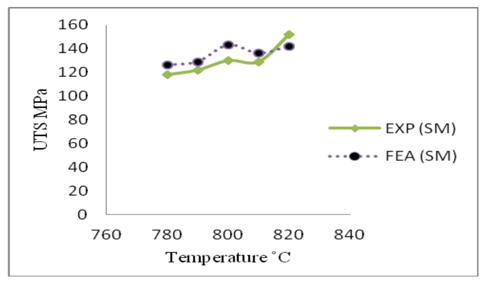


Fig.9 Effect of processing temperature on tensile strength of composite on FEA and Experimental results.

4.2.3 Hardness of In-situ A356/TiB_2 composites

The Brinell hardness test results are shown in Table.1. As the pouring temperature increases hardness also increases in range tested. On the basis of obtained simulation results, i.e., SMX, it was possible to compute hardness. The simulation hardness values were computed using Eqn. (1).

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

Where,

SMX - Max stress value obtained from ANSYS, N-Constant hitch value, depending on Ball indenter moving on block surface and is defined across different hitches.

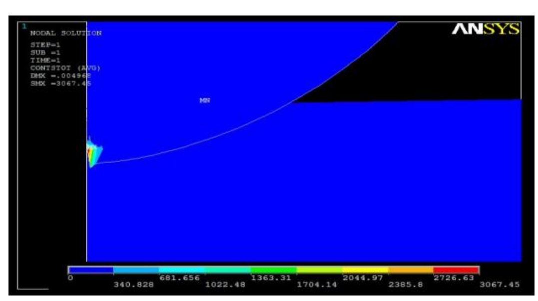


Fig. 10 Image of the FE model simulating the Hardness test

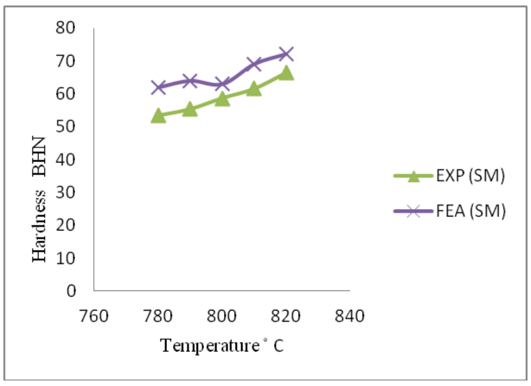


Fig.11 Effect of processing temperature on Hardness of composite on FEA and Experimental

Table 4. Simulation and experimental value for hardness of Al/TiB_2 MMCs

Temperature ˚C	Hardness (BHN) Sand Mould		
	EXP	FEA	Percentage of error
780˚C	53.37	62	13.9
790˚C	55.33	64	13.5
800˚C	58.67	63	6.8
810˚C	61.56	69	10.78
820˚C	66.45	72	7.7

Hardness results obtained with the help of max stress computer simulations is shown in Fig. 10. Error between predicted hardness and experimented values are less than 14% as shown Table.4 [17, 18]. The hardness values obtained for pouring temperature of 820˚C are more than that with other pouring temperatures because the formation of TiB_2 at higher temperature is more. The experimentally determined values of hardness are almost matching with theoretical predictions as shown in Fig.10.

3. Conclusions

Aluminium A356/TiB_2 was synthesized In-situ through the salt-metal reaction route and were analyzed for ingots cast through sand mould. The main conclusions drawn are given below:

- TiB_2 particles have formed as evidenced by XRD and SEM sand mould with different conditions.
- Compared to 780˚C, 790˚C, 800˚C, 810˚C and 820˚C the mechanical properties (i.e., fracture toughness, tensile strength and hardness) are found to be higher at the pouring temperature of 820˚C as formation of TiB_2 particles is maximum at this pouring temperature.
- The errors between the experimental and predicted of values are found to be less as follows: Fracture Toughness-12 %, Tensile Strength-7 %, Hardness-14%. As the error in FEA predictions are less we can use FEA results and avoid costly and time consuming experimental work.

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