Analysis of Factors Influencing Hardness of Al-TiB_2 Composites Using Response Surface Methodology

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***Abstract* - Metal Matrix Composite (MMC) focuses primarily on improved strength, hardness and tensile properties. The AMMCs are widely used in large range of aerospace and automotive application as it has superior properties than other MMC. Properties of this material depend upon the manufacturing techniques and its processing parameters, selection of matrix and reinforcements. Aluminium matrix reinforced with titanium diboride (TiB_2) yield superior properties than the aluminium alloy reinforced with other particulates such as Al_2O_3, Sic, and Tic. The main objective is to produce the composite cost effective way to meet the above requirement. The purpose of this paper is to develop a mathematical model for hardness through Response Surface Methodology (RSM) and analyze the influences of the entire Stir casting parameters (composition of TiB_2, stirrer speed, composition of magnesium (Mg)) on the responses in stir casting with Aluminium Metal Matrix Composites (AMMC) reinforced with titanium diboride. Three factors, three levels Box Behnken design matrix in RSM is employed to carry out the experimental investigation.**

Keywords: Aluminium Metal Matrix Composites (AMMC), Stir Casting, Response Surface Methodology (RSM), Hardness, SEM, XRD.

1. INTRODUCTION

Conventional monolithic materials have limitation in achieving good combination of hardness. Aluminium and its alloys play an important role in the production of MMC. AMMC materials have greater advantages in a wide number of specific fields due to their high specific strength, stiffness, yield strength and dimensional stability. It is basically due to its better formability properties and option of changing strength of the composite through optimal heat treatment. Al–TiB_{2p} composite is not readily available in the market and it is costly. This is due to the difficulty in producing this composite. Few attempts were made to produce it by in-situ process.

The manufacturing of microstructure-mechanical properties of aluminium composites materials fabricated by using stir casting route was investigated by Vivekanandan et al. [2] They had used fly ash reinforced in aluminium matrix and reported the improvements in mechanical properties upto 20% of fly ash. A similar effect titanium carbide particle reinforced with aluminium 6061 matrix composites was observed by S.Gopalakrishnan et al. [1] they had investigate specific strength and hardness of the material improved appreciably with more addition of Tic. Muhammad Hayat Jokhio et al. [7] have reported information regarding Al_2O_3 particles up to 10% increase in tensile strength and hardness. N.B.Dhokey et al. told that AL-TiB2 composite (2.5% TiB_{2p}) shows good improvement in harness as compared to pure Aluminium. It is observed that excess amount to the tune of 120% KBF_4, is required to get optimum level of TiB_2. Any additional increases to 140%KBF_4, increases hardness but increases wear rate due to weakening of matrix as a result of segregation of TiB_2 particles. TiB_2 particle are moderately distributed in Aluminium matrix and are clearly visible in SEM Micrograph.

S.Dhanalakshmi et al. suggested that AL-Si alloy/10 wt% Sic composites would be fabricated using stir- casting technique by varying the stirrer speed and melting temperature.

Stir casting technique is the conventional and economical way of producing AMMC. But, with the conventional stir casting technique, it is difficult to produce a particulate reinforced composite. In this present method suitable modifications were carried out on conventional stir casting method to take care of the reaction of molten aluminium with atmosphere, segregation of reinforcing particles and wettability. Controlled bottom pouring arrangement helps to regulate the molten metal flow. But, when compared to the present method, particle infiltration is relatively a difficult process [2].

Pardeep Sharma et al. [3] has resulted processing variables such as holding temperature , stirring speed, size of the impeller and the position of the impeller in the melt are among important factors to be observed in the manufacturing of cast metal matrix composites as these have an huge change on mechanical properties.

Jenarthanan mugunthu et al. (2012) investigated mathematical model successfully predicted the delamination during milling of GFRP composites. The developed second-order response surface model was validated using confirmation test and the error was found to be within ±0.3 percent. This process is easy to predict the main effects of different influential combinations of machining parameters.

P.Shanmughasundaram et al. suggested that the optimum value would be obtained in radial flow model impeller. The verification experiment was conducted for the optimum parameter. The best results have been obtained. The closeness of the results of prediction based on calculated S/N ratios and experimental values show that the Taguchi experimental technique can be used successfully for both optimization and prediction.

In the present work, a mathematical model has been developed to predict the hardness of fabricated composites using RSM. The design “Expert 8.0” software was used for regression and graphical analysis of the data collected. The study of effect of stir casting parameters on the hardness was done by analyzing the response surface contour graph. Analysis of variance (ANOVA) is used to check the validity of the model and for finding the significant parameter [8].

RSM design was used to explore the interdependence of the process parameters and second order quadratic model for the prediction of data obtained by conducting the hardness test experiments. The results obtained using statistical tools such RSM were tested using Analysis of Variance (ANOVA) and compared to experimental values [12].

The Material was examined by Scanning Electron Microscope (SEM) & X-ray Diffraction (XRD).

2. MATERIAL, PROCESS PARAMETER AND MEASUREMENT

Composition test (Table-1) was taken from Omega Inspection and Analytical lab, Chennai, supplied by Coimbatore metal mart ltd. TiB_{2p} (powder form table 2) supplied for Alfa Aesar (India) was used as reinforcement.

Stir Cast Process

Production in Aluminium-TiB_2 compositethrough stir casting method.1kg of aluminium was melted in a graphite crucible. For this the melt temperature was raised to 900k. Then the TiB_{2p} weight, varying stirrer speed and composition of Mg (based on Box Behnken design) was added to the aluminium melt for production of 17 different composites. The TiB_{2p} particles were preheated to 573k for to remove the moisture. Commercially pure aluminium was melted by raising the temperature to 950k. Then it is stirred well using a mild steel stirrer.

TiB_{2p} particle and magnesium 1% (added in all composites because due to wettability [9]) were added to the melt at the time of formation of in the melt due to stirring. The melt temperature was maintained 950k during the addition of the particles. Then the melt was casted in a graphite crucible. The particle size analysis for TiB_2p and Chemical composition analysis was done for Aluminium 6061. The micro hardness measurement was carried out all composites hardness testing machine with 0.5kg load and diamond ball intender. The detention time for the micro hardness measurement was 10 seconds. The SEM & XRD was done for all the samples. SEM carries out to find homogeneous distribution and porosity of particle.

Impeller model

Three type’s 4 bladed impeller models as radial flow radial flow were designed and fabricated with 0.7 IOD/CID ratios (Impeller outer dia to Crucible inner dia) [9]. The impeller consists of four blades which are joined together at 180° to each other along a vertical axis and blades are fixed to the hub. A birds-eye view of the impeller models are shown in Fig.2.

Fluid flow pattern (radial flow impeller).

The radial flow impeller crates a radial flow pattern moving away from the impeller, towards the sides of the crucible as shown in Fig. 2. The flow impacts the side and moves in either an upward or downward direction to fill the top and bottom of the impeller [9].

3. RESULTS AND DISCUSSION MICROSTRUCTURES ANALYSIS

The micro structure of two composites has been taken (400rpm with 3% TiB_{2p}(fig 3), 600rpm with 12% TiB_{2p}(fig 4)). In general. Samples of as cast MMCs for metallographic examination were prepared by grinding through different size of grit papers. Then the samples were etched with the etchant i.e. Keller’s reagent (2.5 ml Nitric acid, 1.5 ml HCL , 1.0 ml HF,95.0 ml Water)

The etched samples were dried by using electric drier. The microstructure observed by using scanning electron microscope. The microstructure of the as cast MMCs are shown in Fig.3&4 at different percentage TiB_2p of the casting. The micrograph of MMC castings at different section shows that the distributions of TiB_2 particles are not uniform throughout the casting and segregation of particles are more in the eutectic region.

Porosity normally found in stir casting of AMMC increases with increase in "TiB_{2p}" particles composition in Aluminium matrix especially containing high percentage of alloy addition. The Titanium diboride is not uniformly distributed. But figure.3. Shows microstructure of this composites (400rpm with 3% TiB_{2p}) Titanium diboride distributed in homogenous manner.

X-RAY Diffraction

X-ray Diffraction (XRD) shows the crystalline size of the elements present in the composite. Fig. 5, 6 and 7 shows the XRD results of the prepared composites with their intensity peaks at 3%, 7.5% and 12% wt. % of TiB_2. It is observed that the intensity of TiB_2 was greater in the (101) plane (2θ= 44.723, JCPDS). In addition, the intensity of Al_3Ti and aluminium was observed with different peaks and confirmed through JCPDS software and increased with the weight percentage of TiB_2 in the composite. That increase in the intensity of titanium diboride peaks with in increasing of the composites is evident. A gradual marginal shift of the Al peaks to higher angles with an increase in the weight % of the titanium diboride content is also clear [12].

MICRO HARDNESS

Hardness is one of the most important factors for the selection in stir casting parameters. The study of stir casting characteristics of AMMCs composites depends on many factor and is more influenced by the stir casting parameter like composition stirrer speed, stirrer model, magnesium percentage, pre heating temperature etc… for a given stir casting parameter set up. The fit summary recommended that the quadratic model is statistically significant for analysis of hardness. The result of the quadratic model for hardness in the form of ANOVA is given in table 7.

The value of R^2 and adjusted R^2 for hardness are 99.86 and 99.68 percentage respectively. This means that regression model provides an excellent explanation of the relationship between the independent factor and the responses. The associated p value for the model is lower than the model is considered to be statically significant. Further factor A and A^2 only have significant parameter for the hardness. The results show that the composition of TiB_2 is more significant parameter for the micro hardness, when compared with the stirrer speed and composition of Mg because of very high F-value. The other model terms are said to be insignificant. The lack of fit was found to less than F0.20 [8] in present research work study and, hence the developed model may be accepted. The experimental values are analyzed using response surface analysis and the following relation has been established for hardness of AMMC.

Final Equation in Terms of Coded Factors:

Hardness =+75.20+5.38* A-0.16* B+0.11*C+0.000* A *B+0.050*A*C+0.12* B * C-1.44* A^2-0.36*B^2-0.26*C^2

Final Equation in Terms of Actual Factors:

Hardness=60.51528+2.23704* Composition of TiB2+5.18750E-003* Stirrer speed+0.82917*Composition of Mg+1.85037E-018* Composition of TiB2 * Stirrer speed +0.011111* Composition of TiB2 * Composition of Mg+6.25000E-004*Stirrer speed* Composition of Mg-0.070988* Composition of $TiB2^2$-9.06250E-006*Stirrer $speed^2$-0.26250 * Composition of Mg^2

Figure.9. shows the correlation between the predicted and the experimental value for hardness of AMMCs composites. The influence of different casting process parameter on AMMC composites are studied by using response graph and response table. The influence of casting parameters on hardness is shown in figure 8. And the main effects are shown in graph.1. From the figure it is observed that the hardness value increases with increases composition of TiB_{2p}, compared with 200rpm and 600rpm of stirrer speed in 400rpm gives better hardness and 2grams composition of Mg gives better hardness[9]. from the responses table.6, it is asserted that composition of TiB_2 is main parameter which affects the hardness followed by stirrer speed and composition of Mg.

1. **EVALUATION OF COMPOSITION TiB_2 AND STIRRER SPEED**

Figure 10 and 11, shows the effect of composition of TiB_2 and stirrer speed on the hardness. According to this figure 10 and 11, the effect of composition of TiB_2 is not enhanced as the effect of stirrer speed. This is consistent with the result from the study.

Also the optimum hardness appears above 77.2HV while composition of TiB_2 is 9.75% and the stirrer speed is in the range 400rpm.

2. **EVALUATION OF COMPOSITION OF TiB_2 AND Mg.**

Figure 12 and 13, shows the effects of the composition of Mg and the composition of TiB_2 on the hardness of the composites. However, the effect of the composition of Mg is not as pronounced as the effect of the composition of TiB_2

According to Figure 12 and 13, as the composition of TiB_2 increase with 2% of Mg, resulting in optimum hardness.

3. EVALUATION OF COMPOSITION OF Mg AND STIRRER SPEED

Following figure 14 and 15, shows the relationship between the composition of Mg and stirrer speed on hardness.

According to this figure 14 and 15, the effect of stirrer speed and composition of Mg is not much significant when compared with the effect of composition of TiB_2 in the composites.

From the response diagram of ANOVA Table 6 and 7, as would be expected, it was found that the 4 bladed radial flow impeller as the optimum model in obtaining the maximum mechanical properties of composite [9].

Influence of Mg

The optimum value was obtain Mg content was found to be 2%. The fabrication of AL-TiB_2 composites by stir casting route is the more difficulty of wettability between the aluminium 6061 and TiB_2. The addition of Mg plays the formation of liquids reaction elements and increases dynamic viscosity of composites slurry which reduces the floating of TiB_2 particles [9].

When the content of Mg is heat above 700°C TiB_2 powder tent to react with aluminium forms intermediate state compound like Al_3Ti. Which implies the hardness of composites are increases and also the TiB_2 agglomerates in the aluminium composites again.

CONFIRMATION TEST

The error values for hardness are calculated and presented in table 9. The above hardness model was validated using a confirmation test and error was found to be within ± 0.8 percent. The model is demonstrated a feasible and effective way evaluation hardness factor for stir casting fabricated composites.

4. CONCLUSION

Based on this study, the following conclusions have been summarized.

- Study on particle reinforcement revealed that highest amount of particles are entrapped and distributed uniformly at stirring speed 400 rpm and 3% composition of Mg.
- The hardness tends to increase steadily with an increase in the composition TiB_2.
- The value of hardness increases much as the composition of TiB_2 increases and the optimum hardness is obtain in stirrer speed 400 rpm and 2% composition of Mg.
- Porosity of the Al-TiB_2 composite increases with the increase of stirrer speed.

- ❖ Mechanical properties are increased through addition of increasing Mg into the composite. Due to addition of Mg up to 2% slurry increases at the same time wettability properties increased due to strong interfacial bonding.
- ❖ The developed mathematical model successfully predicted the hardness using stir casting parameter.
- ❖ The developed second order response surface model was validated using confirmation test and the error was found to be within ± 0.8 %.

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