Numerical Investigation on Induced Residual Stress of Al/Albite Metal Matrix Composites

Chidanand Prasad R, Prof. K. Channakeshavalu, Prof. Krishna M

Department of Mechanical Engineering, Visvesvaraya Technological University (VTU), Karnataka, India

Abstract— *The aim of the work was to investigate residual stress formed during fabrication of Al/albite metal matrix composites (MMCs) using finite element analysis. Optical images of MMCs were extracted from scanning electron microscope (SEM) after fabrication by stir-casting. The collected images and properties were used to determine residuals stresses at the interface using COMSOL multi physics tool. The imported MMCs images modelled and meshed for 5458, 6318 and 7149 elements for 5%, 10% and 15% particle reinforced composites respectively. Geometrical and thermal constraints are applied at the boundaries and difference in temperature T 620 C as a thermal constraint. FE results in the COMSOL multi physics show that residual stress in composites material tested are in the range of 1.55 MPa to 2.84 MPa. Al/albite with 15% albite reinforcement possesses lowest residual stress formation in all 27 cases studied with value of 1.55 MPa.*

Keywords— Composite Materials, Al/ablbite.

I. INTRODUCTION

When a metal matrix composite is cooled down to room temperature from the fabrication or annealing temperature, residual stresses are induced in the composite due to the mismatch of the thermal expansion coefficients between the matrix and particles. Many different types of advanced metal matrix composites are now available, some of which possess functional and mechanical properties. Recent work on particle-reinforced, self-lubricating and self-healing metals and metal matrix composites (MMCs) synthesized by solidification synthesis is reviewed[1]. Particle-based MMCs have been developed by several modern processing tools based on either solid- or liquid-phase synthesis techniques that are claimed to exhibit exciting mechanical properties including improvements of modulus, yield strength, and ultimate tensile strength[2-3]. Now the study is done on what is the effect of residual stresses which are induced on material which is fabricated by stir-casting technique, where the temperature is came down by normal cooling which will cool down the outer surface to inner surface inducing stresses. These stresses are known to be residual stresses which are noticed at the interfaces of the two different materials due to difference in their properties like young's modulus, Poisson ratio[4]. Many researchers [5-9] have studied on behaviour of fibres and whiskers reinforcement. And from a two decades research is going on particle reinforcement type also, but limited to unit cell and cluster of particles and also on systematic arrangement of particle which is not the case in real form. Here the metal matrix composite is having particles which are randomly distributed in matrix. Particle reinforced MMCs are attractive due to their cost-effectiveness, isotropic properties, and their ability to be processed using similar technology used for monolithic materials[10-11].

Review of literature [12-15] indicates that the most of the researcher have done study on representation unit cell (RUC) which is not the real case for the composite. And also the nonlinear case is ignored which reduces the accuracy of the results. Some of the authors also worked on the random distribution of particle reinforcement metal matrix composites, but they didn't get results desired. Hence, this project work will try to get the FE analysis of MMCs for random distribution, using stir casting method for preparation of samples and the COMSOL multi physics is used as a tool to get FE analysis.

II. EXPERIMENTAL STUDY

The material used for the matrix is aluminium which is Al6061 alloy because it has good joining property, combines high strength, high resistance to corrosion readily available. Al6061 is widely used in industries, and its physical, thermal, chemical and composition is shown in Table 1. In the present study albite particles used were nearly spherical in shape ranging from 90-150μ.

Stir casting technique was used to fabricate the Al/albite (MMC. The ingot is taken in a furnace crucible and is kept in the furnace at 750°C for three hours. After the metal is completely melted it is taken out of the furnace using tong, and stirred continuously and the silicon and carbide particles in the predetermined quantity where put in a slow and uniformed manner. Along with this a decasting material is added to reduce the bubble formation. The stirring is continued till the all powder gets mixed well. Then the mixture is poured into the mould cavity which is cleaned and set in position before.

Then it was kept for natural cooling and the cavity is removed after unclamping the clamps of the mould. After the casting, the next step is turning the moulded composite to required dimensions. The rod which is removed from mould cavity it machined using lathe machine to get fine surface finish and the required dimension of 10mm in diameter and length of approximately of 30mm. After successfully completion of turning operation the specimen is now required to go for fine polishing process. Though we have taken care to get best surface finish in turning operation, but it is not enough to get the microscopic image of particle at this stage.

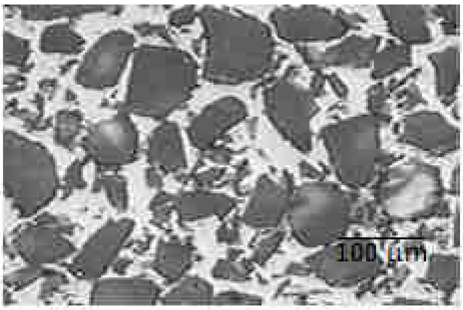

Fig. 1: Microstructure of Al/15%albite MMCs

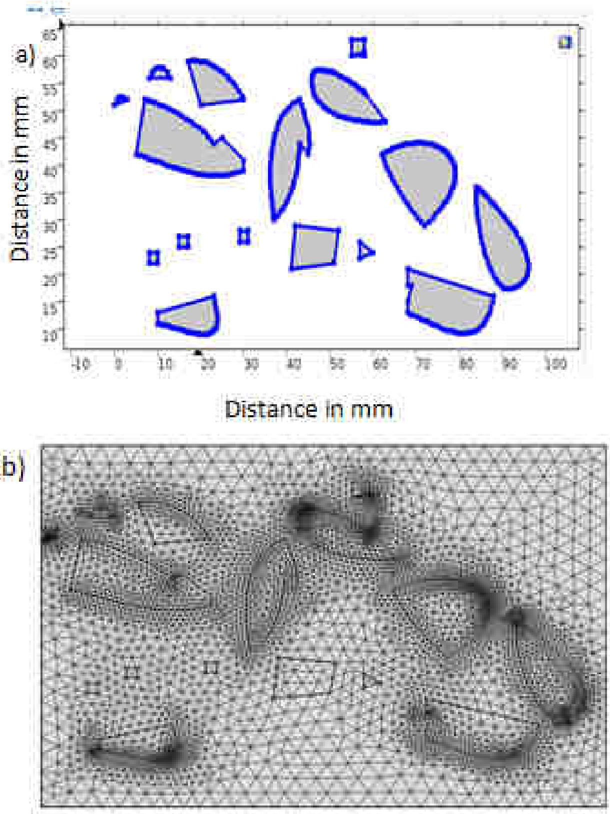

Fig. 2: a) Mathamatical Model of microstructure and b) Meshing of microstrutre

Therefore the polishing is done initially by using grit of size 100, 200, 400, 600, 800, and 1600 in an order given. The specimen is rubbed against grit in an indirection so that the scratches form on it are seen and evenly patterned. This process is repeated for all size of grit up to 1600 and for all samples to be prepared.Fine polishing was performed using magnesium oxide paste followed by diamond paste using polishing machine.

The final experimental step is to get microscopic images of the sample created by using the Scanning electron microscope (SEM). The SEM is conducted to get the particle position and the arrangement for all three samples i.e. 5%, 10%, 15%. A typical image is given in Fig.1. These images where then transfer to COMSOL multiphysics software tool.

III. NUMERICAL STUDIES

The geometry of SEM image has to be transformed to this software exactly the same position and the shape and size. This can be done using two methods. One is to directly transfer the image to the COMSOL format and import it. Second is to transfer all particles on it to the tool exactly same by using tracing paper and get the coordinate points and accordingly draw the particles. Figure 2(a) shows the example of the geometry to be drawn by importing the image. The dimension of matrix is 70m x100m. This sub category allows adding thermal property to the material and the initial condition to be applied. The initial temperature of reinforcement is at room temperature whereas the matrix will be at elevated temperature of about 700°C.

The mesh formation is important aspect in finite element analysis, as mesh is dividing total area into small parts which is solved individually and then integrated to get the final result. Types of meshes are free triangular, free quad, mapped and some more. COMSOL has auto mesh generation system which allows the system to mesh the geometry automatically according to shape and dimension of geometry. Here we are using auto mesh option, so sequence type should be physics-controlled mesh and the element size is selected as finer so to get more accurate result. But this results in delay in output time. Mesh generated is shown Figure 2.

IV. RESULTS AND DISCUSSION

Residual stress in metal matrix composites (MMCs) has been found using Finite element analysis (FEA). The FE tool COMSOL multiphysics 4.0 is used and the materials are drawn from library stored material. The residual stress of 5% composite for the Al/albite is given in Figure 3(a). The stress developed here is $1.73x10^6$ N/m^2. It can be noticed that the stress formation is more at the interface of the matrix and the reinforcements. The residual stress of 10% composite for the Al/albite is given in Figure 3(b). The stress developed here is $1.81x10^6$ N/m^2. It can be noticed that the stress formation is more at the interface of the matrix and the reinforcements. The residual stress of 15% composite for the Al/albite is given in Figure 3(c). The stress developed here is $1.55x10^6$ N/m^2. It can be noticed that the stress formation is Less at the interface of the matrix and the reinforcements.

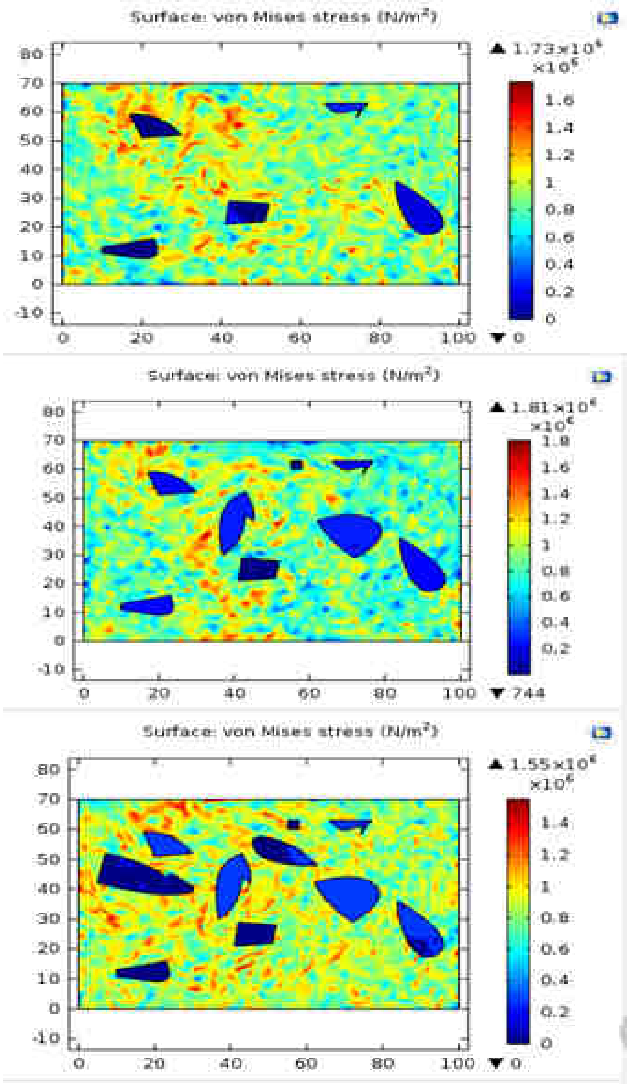

Fig. 3: Developed residual stress in the matrix during solidification (a- 5%, b-10% and c-15% of albite composites)

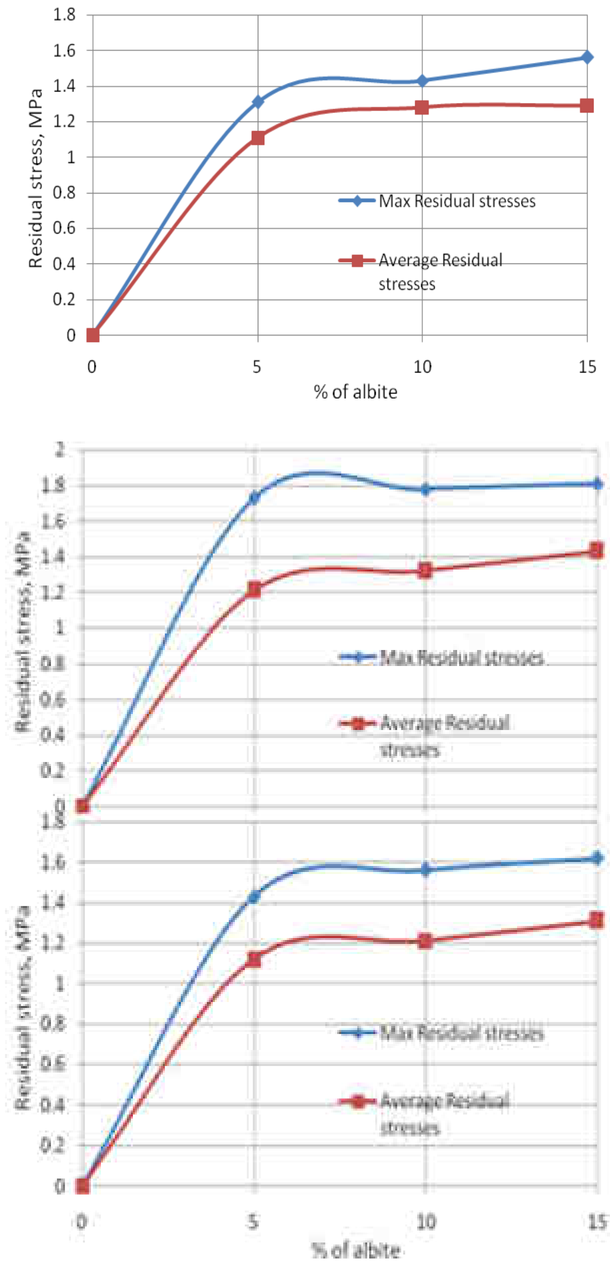

Fig. 4: Induced residual stresses in composite during solidification a)σ_{xx} , b) σ_{yy} and c) τ_{xy}.

Relation between induced residual stress and percentage of albite content in MMCs were ploted in Fig. 4. The residual stresses such as σ_{xx}, σ_{yy} and τ_{xy} are plotted in Fig. 4(a), 4(b) and 4(c) respectively. The stresses increases with albite content but less significant increament was seen above 5% reinforcement. The residual tensile stress remained in the matrix material due to mismatch properties between reinforcement and matrix materials. The mismatch properties such as thermal coefficient expansion and mechanical strength enhance the induced residual stresses. The result suggests that it be necessary to consider the penetration depth.

V. CONCLUSIONS

Residual stress is an important property needed for reliable design of any component. As the residual stress formation is due to the thermal parameter which is caused during fabrication of material where the temperature of two materials is different at the point of mixing. In this project COMSOL multiphysics tool, to know the residual stress and compared the obtained results. The fabricated material is turned, machined, polished and then extracted the microscopic images, which were studied for residual stress analysis under FE tool. Residual stress obtained for aluminium and Albite component are most reliable and well suited considering the stress obtained. Albite with 15% reinforcement possess lowest residual stress formation in all 27 cases studied with value of 1.55 MPa.

REFERENCES

[1] RecepEkici, Kemal Apalak M, Mustafa Yıldırım and Fehmi Nair "Effects of random particle dispersion and size on the indentation behavior of SiC particle reinforced metal matrix composites",*Materials and Design* ,vol.31,2010, pp. 2818–2833.

[2] RecepEkici, Kemal Apalak M and Mustafa Yıldırım "Indentation behavior of functionally graded Al–SiC metal matrix composites with random particle dispersion",*Composites: Part B*, vol.42,2011, pp. 1497–1507

[3] S. BalasivanandhaPrabu and L. Karunamoorthy "Microstructure-based finite element analysis of failure prediction in particle-reinforced metal–matrix composite",*journal of materials processing technology*, vol.207,2008, pp. 53–62

[4] F. Fritzen and T. Bohlke "Homogenization of the physically nonlinear properties of three-dimensional metal matrix composites using the nonuniform transformation field analysis",*Composites: Part B*, vol.48,2009, pp. 1457–1508

[5] Gregory J. Tilton "Finite element modelling of Thermal Expansion in Polymer/zrw2o8 Composites",*The University of Toledo*,December 2011.

[6] Tran HuuNama, Guillermo Requena and Peter Degischer "Thermal expansion behaviour of aluminium matrix composites with densely packed SiC particles",*Composites: Part Applied science and manufacturing*, vol.39,2008, pp. 856–865

[7] A. H. Rashed "Properties and Characteristics of Silicon Carbide",*journal of materials processing technology*, vol.217,2008, pp. 553–624

[8] F. Teixeira-Dias and MenezesL.F "Numerical determination of the influence of the cooling rate and reinforcement volume fraction on the level of residual stress in Al-SiC composite",*Computational material science*, vol.21,2001, pp.26-35.

[9] Z.F.Yue, Eggeler. G and Stockhert B "A creep finite element analysis of indentation creep testing in two phase microstructure",*Computational material science*, vol.21,2001, pp.37-55.

[10] F. Teixeira-Dias and Menezes L.F "A kinematic and incremental integration model for the micromechanical numerical analysis of dual-phase materials",*Computational material science*, vol.25,2002, pp.237–245

[11] HalilAykul and Sami Kaya "An elastic–plastic and residual stress analysis steel reinforced thermoplastic composite cantilever beam", *Materials and Design*, vol.31, 2010, pp.3474-3481

[12] CHEN Guo-qin,XIU Zi-yang, YANG Wen-shu,JIANG Long-tao and WU Gao-hui, "Effect of thermal-cooling cycle treatment on thermal expansion behaviourof particulate reinforced aluminium matrix composites", *transaction of nonferrous metal society of China*,vol.20, 2010, pp.2143-2147

[13] Na Chen, Hongxiang Zhang, MingyuanGu and Yanping Jin "Effect of thermal cycling on the expansion behaviour of Al/SiCp composite", *journal of materials processing technology*, vol. 209, 2009 pp. 1471–1476

[14] M. Schobel, H.P. Degischer, S. Vaucher, M. Hofmann and P. Cloetens"Reinforcement architectures and thermal fatigue in diamond particle-reinforced aluminium" *ActaMaterialia*, vol.58, 2010, pp.6421–6430

[15] Tran Huu Nam, Guillermo Requena and Peter Degischer "Thermal expansion behaviour of aluminum matrix composites with densely packed SiC particles", *Composites: Part A*, vol.39,2008, pp.856–865