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MICROSTRUCTURE BASED FINITE ELEMENT ANALYSIS FOR DEFORMATION BEHAVIOUR OF MAGNESIUM BASED COMPOSITES

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ABSTRACT

In Metal matrix composites (MMC) the microstructural aspects such as reinforcement size, shape and distribution plays important role in the deformation behaviour of composites. To study the thermal and structural deformation behaviour of real microstructure, an analytical approach was proposed by developing a two dimensional (2D) model from a microstructure image of magnesium hybrid composites and magnesium CNT composites. Samples of both magnesium hybrid (1%CNT, 2% silicon carbide) and magnesium mono composite (1%CNT) were fabricated using stir casting method. The microstructure images of samples were converted into equivalent CAD format using canny edge detection method. In the present work the deformation behaviour such as the thermal stress and strain and structural analysis were studied by using finite element analysis. Experimental tensile testing of magnesium hybrid composites was also conducted.

Keywords: magnesium, MMCs, microstructure, SEM, FEM, finite element analysis.

INTRODUCTION

Metal matrix composites consist of two or more materials, one of which is a metal (matrix), in which the tailored properties are achieved by the systematic incorporation of different reinforcements. MMCs attribute includes alterations in mechanical properties and other physical properties by the filler phase. The reinforcements size, shape, distribution plays a vital role for improving the mechanical properties of MMC. Microstructure study of composites helps to understand the material properties and morphology [1].

Previously, JayaKumar *et al*. **Error! Reference source not found.**] correlated the material microstructures with their macroscopic properties for understanding the material behaviour of existing materials as well as for developing new materials. Mainly the characterization and modelling of microstructures are important due to the accurate prediction of materials behaviour under external stimuli and the design of new materials with desired properties **Error! Reference source not found.**], Balasivananda Prabu **Error! Reference source not found.**] studied deformation behaviour of aluminium silicon carbide particle reinforced metal matrix composites by creating a two dimensional model for prediction of failure criteria like matrix yielding, interface decohesion from the analysis of real microstructure.

MATERIALS AND FABRICATION PROCEDURE

Carbon nanotubes (CNT) are used as the reinforcement for developing magnesium metal matrix composites. The properties of both magnesium and CNT are listed in Table-1. The sample was fabricated with 1% volume fraction of CNT **Error! Reference source not found.**] by bottom pouring stir casting furnace. A semantic diagram of bottom pouring stir casting furnace is shown in Figure-1.

Table-1. Properties of CNT and magnesium.

Materials	**Density** [g/cm^3]	**Young`s Modulus** [GPa]	**Poisson ratio**	**Coefficient of thermal expansion** [k^{-1}]
Magnesium	1.74	45	0.35	25.2 x 10^{-6}
CNT	2.1	1200	0.22	2.7 x 10^{-6}
SiC	3.1	410	0.14	5.12 x 10^{-6}

Magnesium and CNT are weighted according to their volume fractions. The CNT is preheated to a temperature of 400 ^{o}C and placed in a die **Error! Reference source not found.**]. The molten magnesium was poured into the mold and mechanical stirring was carried out. The pouring temperature of magnesium was in range of 700 ^{o}C-800 ^{o}C and a pressure of 10 MPa was applied using a plung velocity of 5kN/s in order to remove porosity.

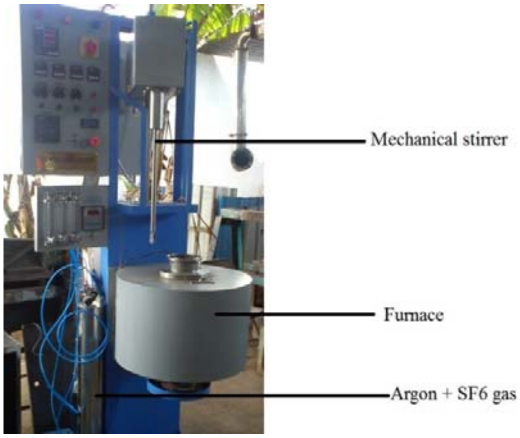

Figure-1. Bottom pouring stir casting furnace.

To prepare metallographic specimens, the samples were mounted on epoxy mounting media and subjected to a wet grinding sequence using silicon carbide papers. Then the specimen to be etched was dipped into the etchant (5% nitol) for 5sec, washed and blow-dried. The microstructure analysis was carried using optical microscope.

Tensile testing

The mechanical properties of the magnesium hybrid MMC were evaluated by tensile testing, which was performed at ambient temperature on an MTS Insight (electromechanical 100KN Standard length) machine equipped with a computer data acquisition system.

Figure-2. Tensile specimen of magnesium composite.

A sub-size cylindrical tensile specimen (22 mm in gage length G, 4 mm diameter D, 4 mm radius of fillet R and length of reduced diameter A of 30mm) was machined for Tensile testing according to ASTM E8. The tensile properties, including 0.2% yield strength (YS), ultimate tensile strength (UTS), and percentage elongation were obtained. Figure-2 shows tensile test specimen and Figure-3 shows tensile testing machine.

Figure-3. Tensile testing machine.

FEM OF REAL MICROSTRUCTURE

A 2D microstructure finite element model was created from a microstructure image of magnesium hybrid MMC and magnesium CNT composite samples. First the microstructure image which is in raster form has to be converted into vector format by image processing technique known as Canny Edge Detection method.

Canny edge detection method

The Canny edge detection algorithm is known to many as the optimal edge detector. It has three important criteria's, the first is that, edges occurring in images should not be missed and that there are NO responses to non-edges. The second criterion is that the edge points be well localized. In other words, the distance between the edge pixels as found by the detector and the actual edge is to be at a minimum. A third criterion is to have only one response to a single edge. This was implemented because the first two were not substantial enough to completely eliminate the possibility of multiple responses to an edge.

Based on these criteria, the canny edge detector first smoothes the image to eliminate and noise. It then finds the image gradient to highlight regions with high spatial derivatives. The algorithm then tracks along these regions and suppresses any pixel that is not at the maximum (non- maximum suppression). The gradient array is now further reduced by hysteresis. Hysteresis is used to track along the remaining pixels that have not been suppressed. Hysteresis uses two thresholds and if the magnitude is below the first threshold, it is set to zero (made a non-edge). If the magnitude is above the high threshold, it is made an edge.

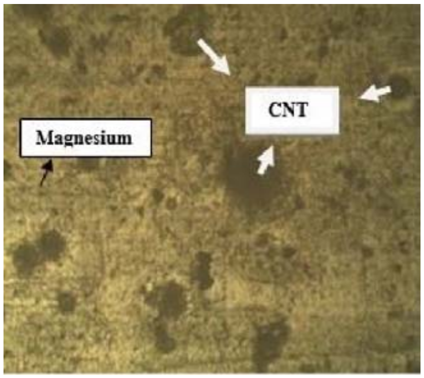

Figure-4. Magnesium CNT microstructure (White arrows shows CNT agglomerations).

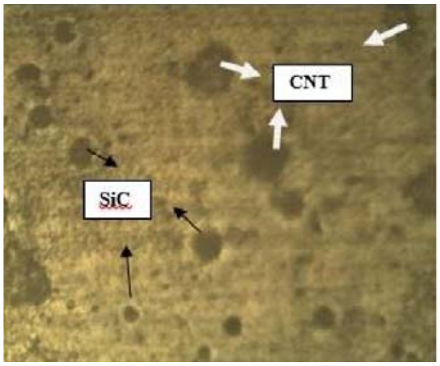

Figure-5. Magnesium based hybrid composite microstructure (White arrows shows CNT agglomerations and Black arrow shows silicon carbide agglomerations).

The real microstructure of magnesium CNT and magnesium hybrid as shown in Figure-4 and Figure-5 above respectively were converted to vector format using the principle of canny edge detection method which were shown in **Figure-6** and **Figure-7** respectively.

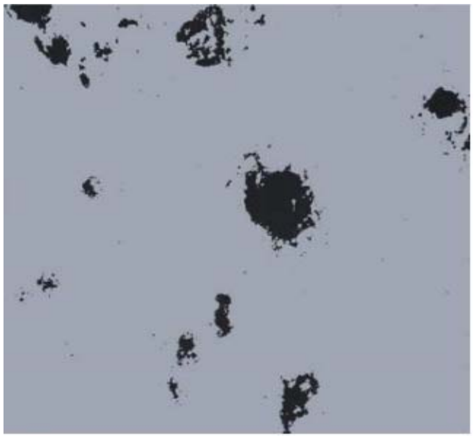

Figure-6. Mg CNT vector format.

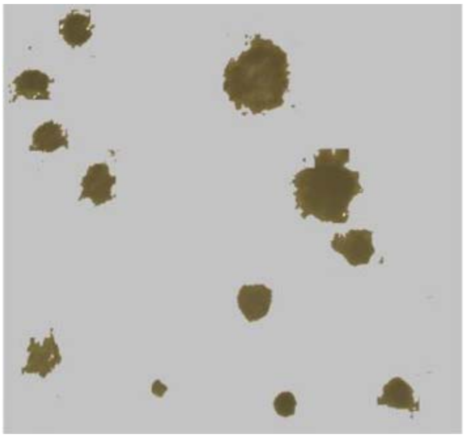

Figure-7. Mg hybrid MMC vector format.

SEM analysis

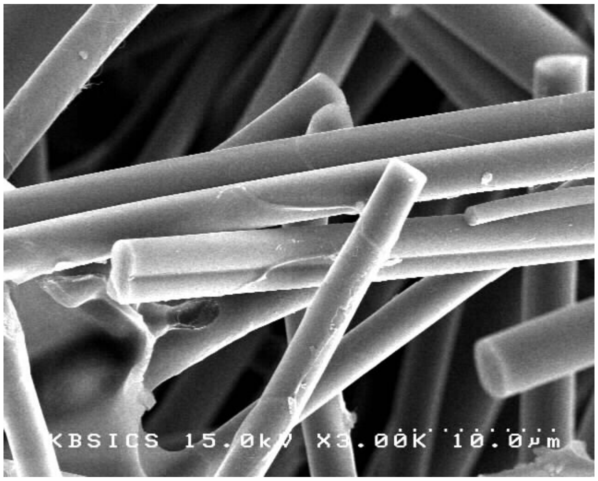

Figure-8. SEM analysis of magnesium CNT composite.

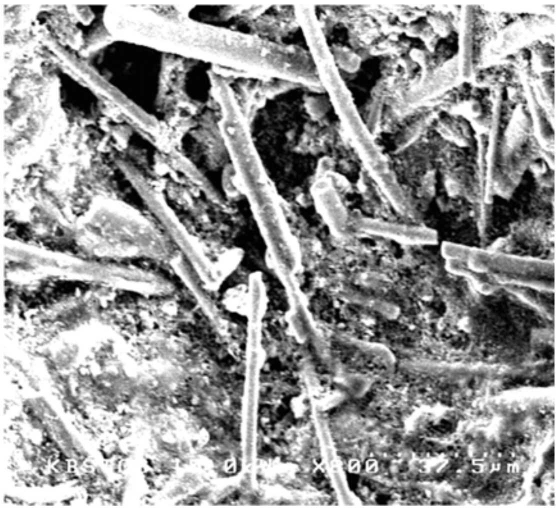

Figure-9. SEM analysis of magnesium hybrid composite.

Figure-8 shows the SEM analyis of magnesium CNT composites where CNT were distributed hetrogeniously.

Figure-9 shows SEM analysis of magnesium based hybrid composites. We can observe the traces of silicon carbide particles attached on carbon nano tubes. We can observe aggromolation of CNT and Silicon carbide in the magnesium matrix which were not properly distributed as mechanical stirrer was used instead of Ultrasonic stirrer **Error! Reference source not found.**] during the fabrication process. This leads to hetrogenoius mixing of the componenets

FINITE ELEMENT ANALYSIS

2D microstructure model meshed properly in HyperMesh and they were imported in Abaqus 6.10 CAE to perform further analysis. Element type of C3D8 was taken for both magnesium and CNT for structural analysis and for thermo mechanical analysis DC3D8 element type was chosen. All elements were defined as homogeneous, isotropic, and linearly elastic. The material properties of the magnesium and carbon nanotube are listed in Table-1.

RESULTS AND DISCUSSIONS

For thermal analysis constant load of 500 N was applied for different temperatures and corresponding thermal strains and stresses were found out.

Transient thermal analysis has been conducted for magnesium CNT composite and magnesium hybrid MMC for the same loading condition. Thermal strain for magnesium CNT composite at 100 ^{o}C to 500 ^{o}C temperature was determined.

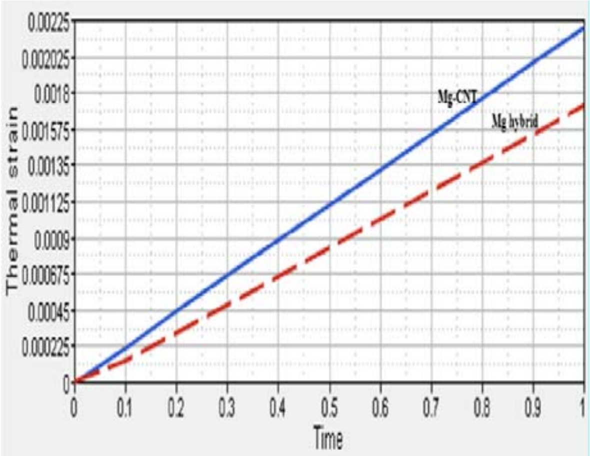

Figure-10. Thermal strain vs time graph.

For the same loading condition and temperature, thermal strain for magnesium CNT composite and magnesium hybrid MMC with respect to time were noted and plotted in a graph as shown in Figure-10. The thermal strain for magnesium CNT was found to be more when compared to magnesium hybrid MMC. The thermal strain rate was less for magnesium hybrid MMC due to the presence of more agglomeration.

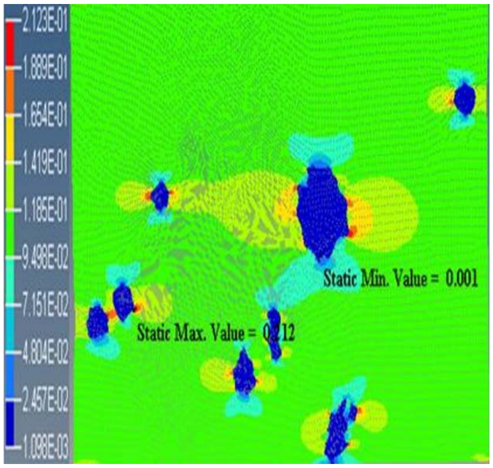

Figure-11. PEEQ equivalent plastic strain of mg CNT composites at 500 ^{o}C.

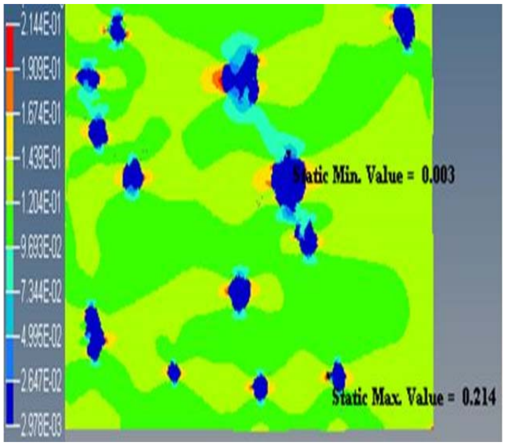

Figure-12. PEEQ equivalent plastic strain of mg hybrid MMC at 500 ^{o}C.

Figure-11 and

Figure-12 shows equivalent plastic strain of magnesium CNT composite and magnesium hybrid MMC respectively.The plastic equivalent strain value of magnesium hybrid was found to be more compared to magnesium CNT composite.

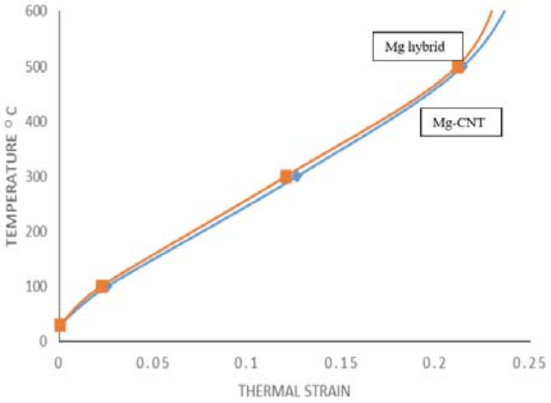

Figure-13. Temperature-thermal strain graph.

From Figure-13 above, it can be seen that with the increase in temperature the thermal strain for magnesium CNT composite was found to be less compared to magnesium hybrid composite MMC, as the thermal strain was directly proportional to the temperature and coefficient of thermal expansion as formulated below:

Thermal strain
$\varepsilon_{th}=\alpha*\Delta t$ (1)
where,
ε_{th}= Thermal strain
α= coefficient of linear thermal expansion
Δt= temperature difference

The coefficient of linear thermal expansion values of magnesium, CNT, silicon carbide were tabulated in Table-1. The thermal strain of magnesium hybrid MMC were more than magnesium CNT composite due to the presence of three expansion coefficient as the thermal strain is directly proportional to coefficient of linear expansion and temperature difference.

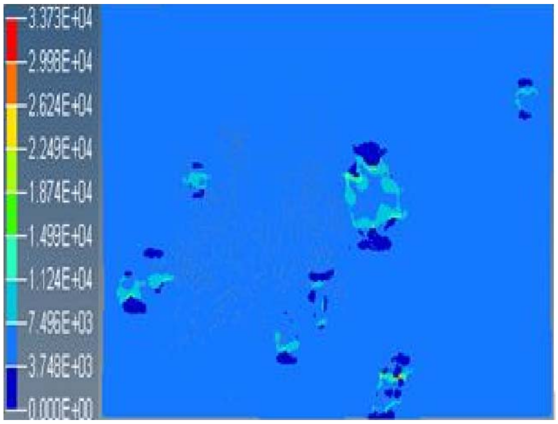

Figure-14. Stress component of magnesium CNT composite.

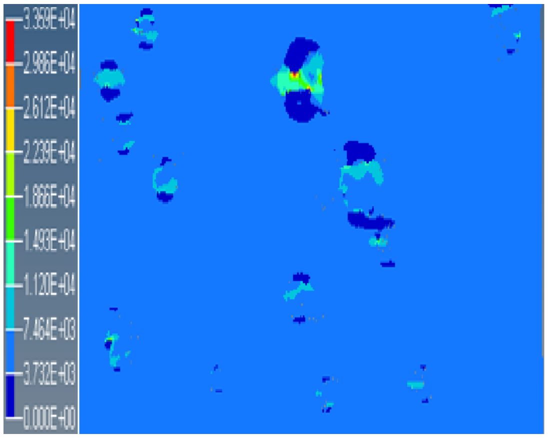

Figure-15. Stress component of magnesium based hybrid composite.

The stress component of magnesium CNT composite was found to be slightly more compared to magnesium hybrid metal matrix composite at elevated temperature which are shown in Figure-14 and Figure-15 respectively. The reason for less stress component than magnesium CNT composite is due to the presence of more residual stress in magnesium hybrid MMC than magnesium CNT composite. Due to three different coefficient of thermal expansion in hybrid composite i.e. (magnesium, CNT, silicon carbide) the residual stresses were found to be more compared to magnesium CNT composite.

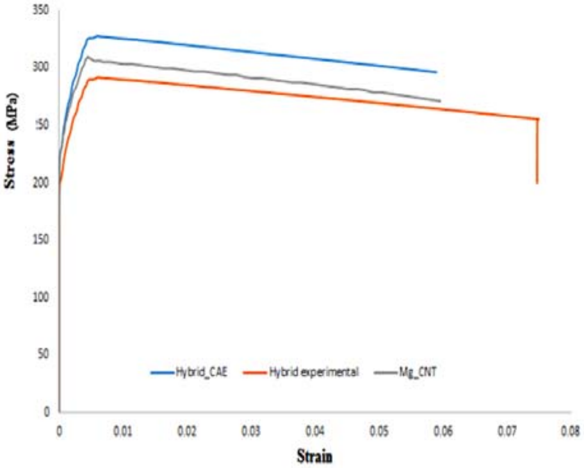

Figure-16. Stress strain curve of magnesium based mono and hybrid composites.

Further structural analysis has been done using Abaqus 6.10 with element type C3D8 for magnesium CNT composite and magnesium hybrid metal matrix composite. The ultimate tensile strength of magnesium hybrid MMC was found to be 328 MPa, whereas the ultimate tensile strength of magnesium CNT was 310 MPa which was correlated with [3,4] for 1% CNT.

Experimental tensile testing was performed for magnesium hybrid MMC sample using MTS Insight (electromechanical 100 kN Standard length) machine equipped with a computer data acquisition system, the tensile strength was found to be 292 MPa as shown in Figure-16. Stress strain curve of magnesium based mono and hybrid compositeswas less compared to FEA value due to the presence of porosity and CNT agglomerations.

CONCLUSIONS

Microstructure based finite element analyses for mono composites and hybrid composites have been studied from literature. Magnesium hybrid composites and magnesium CNT mono composites were fabricated using stir casting method. 2D models have been using canny edge detection method created also structural and thermal analyses have been conducted. It could be observed from the study that the thermal strains of mono composites (Mg CNT) were less compared to magnesium based hybrid composites for same boundary conditions. From the structural analysis the ultimate tensile strength of magnesium based hybrid composites was found to be 328 MPa and for magnesium CNT mono composites it was 310 MPa. The Young's modulus of magnesium based hybrid composites was 47.5 GPa and for magnesium CNT mono composite it was 45.3 GPa. The experiment tensile strength of magnesium hybrid MMC was found to be 292 MPa which was less than FEA value due to the presence of porosity and CNT agglomerations.

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