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Modelling and simulation on mechanical behaviour of aluminium hybrid composites

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ABSTRACT

Aluminium hybrid composites (AHCs) are widely used in automobile, aerospace and marine industries due to their good mechanical properties, better damping capacity, outstanding corrosion and wear resistance. These composites are prepared using the commercially available aluminium alloy LM6 as the base alloy, whereas, the dried powders (60-100µm) of Mg, Ti, Cu and SiC as the particulate reinforcement (1:0.5:1:3) through stir casting route. The LM6 alloy is melted in the graphite crucible in an electrical furnace at 850^{0}C where potassium aluminium fluoride is used as the flux to remove slag and to protect from oxidation. The composite is solidified through the gravity die casting process in the form of cylindrical rods and flat sheets, which are used in different mechanical tests (tensile, compression and three-point bending) on electromechanical universal testing machine at low strain rates/speeds. An experimental investigation on the strain rate sensitivity of the hybrid composite is presented under quasi-static tensile (0.001 s^{-1}), compressive (0.001 s^{-1}) and bending/flexural (1-100 mm/min) loads. The material parameters of six mathematical laws (Holloman, Swift, Ludwik, Ghosh, Voce and Hockett-Sherby) are evaluated by curve fitting method based on the experimental data. Finite element simulation is carried out using ABAQUS software. Relative errors in simulation results compared with the experimental results are 7.51% in tension, 0.85% in compression and 4.17% in flexure. The predicted results of Ghosh and Hockett-Sherby models have good agreement with the experimental results.

Keywords – Aluminium hybrid composites, finite element analysis, material model, stir casting method, strain rate.

1. INTRODUCTION

In modern era, material science research has switched to composite materials, which may be made into lightweight, ecologically friendly, and high-performance goods. Current engineering applications demand the use of materials that are stronger, lighter, and less costly. A good example is the current interest in developing materials with a good strength-to-mass ratio **[1].** The growing demand on a particular stiffness, aluminium hybrid composites (AHCs) are widely employed in the automotive, aerospace, marine, and defence sectors due to better damping capacity, and outstanding corrosion and wear resistance. Aluminium alloy castings made in sand moulds, permanent metal moulds, and die casting machines are usually stronger than lower grade cast iron. Permanent moulds and die castings give a greater surface polish, closer dimensional tolerances, and better mechanical qualities, in addition to cost savings in machining and finishing, when the quantity supports the additional cost of equipment **[2].** They have a low coefficient of friction and significant thermal/electrical conductivity, a less density, strong mechanical characteristics, improved corrosion rate, fatigue, and a poor linear thermal coefficient of effusiveness as compared to standard materials and alloys **[3].** Encourages scientists to explore their mechanical properties in order to create designs and mass produce products. Composite materials now offer a variety of mechanical benefits to satisfy the demands of rapidly evolving technology **[4].** Thermal expansion, failure mechanisms, plasticity, load type sensitivity, fatigue build-up and dispersion, and other characteristics of composites and metals differ. As a result of these fluctuations, the materials are subjected to various design and certification requirements **[5].** In hybrid structure certification, thermally generated loads, there are several failure mechanisms, damage tolerance, buckling and irreversible deformations, material property dispersion, significant load states, and other challenges. Using the appropriate material to build a weight-optimal hybrid construction right position is a design challenge. As the number of hybrid structures increases, these challenges must be addressed **[6].** The structural designs and ease of manufacture of hybrid composites have led to study composite designs include fibre reinforced composites, that have a maximum strength ratio and a structural rigidity ratio. Metal alloys that are similar to because of its remarkable machinability, Composites are frequently worn for compact and complex structures **[7]**. As a result, studying the deformation process of these composites is crucial in order to improve the structure's performance in service. Because of its light weight, Aluminium as well as its alloys are extensively used in a variety of industries. Aluminium alloy strength may often be improved by a variety of means, including (i) Introducing intractable reinforcements to generate composite material. (ii) by grain refinement, (iii) through cryogenic treatments (iv) by coating materials, and so on. Composite materials have sparked considerable attention as a means of improving the mechanical and physical characteristics of aluminium. A composite material is composed with multiple insoluble phases with excellent properties to a component. Aluminium is preferred as most cases, a matrix material situation due to its low density, ease of fabrication, and good engineering qualities **[1]**. Aluminium composite materials are frequently produced via (i) Processes in solidified state (involve-powder planning, diffusion bonding and physical vapour deposition) (ii) Liquified state (stir casting, pressurised die mould, infiltration parameter) In-situ processing (stir casting, pressurised die casting, infiltration method. Researchers determined that stir casting was the most lucrative and promising of these methods. Prior to composite manufacture, certain key factors such as electrifying speed, electrifying duration, melting temperature, process time, electrifying location, design, stirrer movement, die worming up, and augmentation are all things to think about. The quality of composite materials is determined by the suitable selection of these characteristics **[9].** After the pertinent literature review, it is found that there are lots of variation in mechanical properties in available literature. Development of material model is required to predict the flow stress of the material correctly. High strength and lightweight Aluminium hybrid composites are important for crashworthy structures. To develop Aluminium Hybrid Composites (AHCs) through stir casting route. To determine mechanical properties of the developed AHCs under tensile, compressive and flexural (three-point bending) loads. To determine the suitability of the existing material models (Holloman, Swift, Ludwik, Voce, Ghosh, Hockett-Sherby). Numerical simulation on the mechanical behaviour of the aluminium hybrid composite under tension, compression and flexure/bending.

2. MODELLING AND SIMULATION

Modelling is the process of generating a model that represents the design and maintenance of a certain system. A model is analogous to the system it symbolizes, yet it is simpler. A model's objective is to assist the analyst to forecast the impact of system changes. Thus, a modelling is an accurate approximation of the real system, encompassing the bulk of its main features. When genuine results of the testing are unavailable, costly, or takes longer to finish testing, material models are crucial **[10].** Authenticity is a critical feature of modelling. Model validation is on matching modelling outputs to system output at given known input circumstances. A mathematical model for simulation research is one that has been created using simulation software **[8].** A system simulation is a system model's implementation. Simulation is a tool for evaluating the performance of a current or future system under a variety of configurations of interest and over long periods. The Abaqus ability of an enterprise is used to design and analyse the specimen. For modelling the composite row, the finite element analysis (FEA) approach was utilised to assess the Abaqus in-built to create two-dimensional model with a combined with three-dimensional general/explicit model with stress-strain based damage development rules generated using the explicit finite element method, Abaqus-VUMAT **[10].** This programme has mostly been used to analyse various sorts of outcomes when exposed to specified boundary conditions. The suitable material was selected from the built-in ABAQUS SOFTWARE library, and its properties were immediately imported from there. ABAQUS allows researchers to do many investigations at almost the same time. The composite sample dimensions were created using the one-third ratio provided by standard dimensions used for analysis purposes. The required dimensions and parameters have been described in their entirety. The compressive behaviour of the bimetallic composite is dependent on the aluminium matrix. The dissolvable aluminium is exhibited. Intension and compression testing, it has a maximum young modulus, yield strength, and ultimate strength than grid and composite, yet much less expansion. Furthermore, by connecting curves on plots and comparing strains of critical sections using silhouette plots, FEA and DIC have been shown to be good and efficient procedures for modelling, analysing, and verifying experimental data **[11].**

3. TENSILE BEHAVIOUR OF ALUMINIUM HYBRID COMPOSITE

The geometry of the test specimen, as illustrated in figure (3.1), is a rectangular flat specimen of three-dimensional tensile specimen can be created with a thickness of 4 mm, gauge length and breadth are 30 mm and 6 mm, and a holding length and breadth is 25 mm and 10 mm.

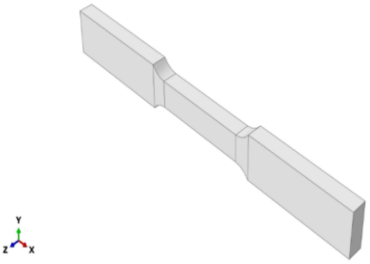


Figure 1: Create 3D Tensile Specimen

TABLE 1: Mechanical properties of Aluminium Alloy.

Parameters	Symbol	Units	Aluminium Alloy
Density	P	g/cm^3	2.7
Youngs modulus	E	GPa	71
Poisson's ratio	µ	--	0.33
Yield stress	σ_y	MPa	260
Ultimate strength	σ_s	MPa	305

After that three basic step is ON and incrementation time can create end continue to scale factor and scale to target time increment, mass scaling has no changes and the last one is other have also no change in figure (3.2). The model is divided into tiny components via meshing. So many more components with smaller sizes can yield more precise results, however this leads in a long solver running time and inaccurate results owing to poor mesh density. In this work, a structured meshing approach is applied in ABAQUS/CAE to construct the most controllable meshing using basic specified mesh topologies. To obtain reliable results, the mesh size is carefully optimized. There is a possibility of element distortion during the simulation. Poor results will be produced by a coarse mesh with distorted elements. Meshing size should be taken as 2 mm in Figure (3.3). The right ingredient for a specific copy is too important for correct findings. Included work, this solid model contains SC8R (Straight 8-node hexahedron, decrease integration with hourglass control), S4R (Straight 4-node general-purpose shell, decrease integration with hourglass control), and C3D8R (8-node straight brick, decrease integration with hourglass control) are all used. The non-default improved hourglass jurisdiction formulation in ABAQUS Software. In figure (3.4) shows the results of this tensile specimen.

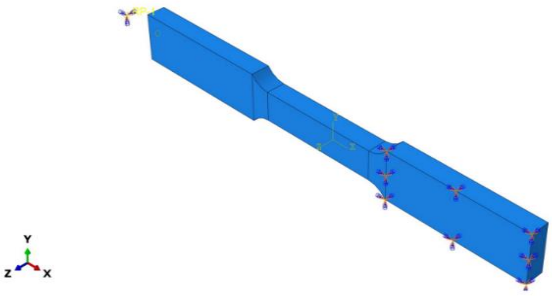


Figure 2: Boundary conditions

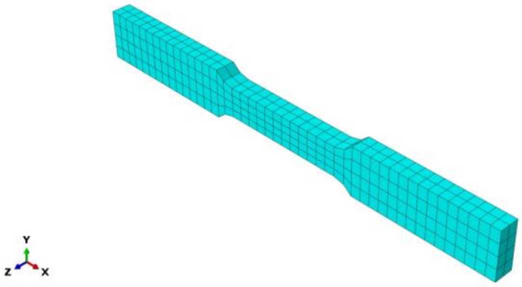
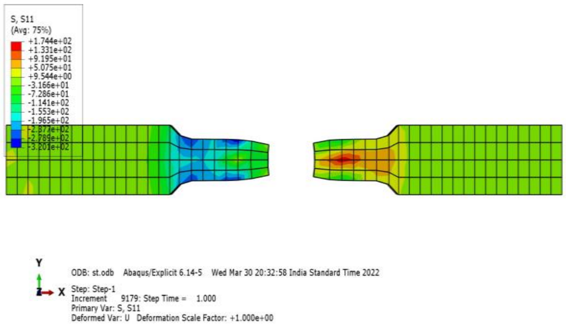


Figure 3: Meshing



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ODB: st.odb    Abaqus/Explicit 6.14-5    Wed Mar 30 20:32:58 India Standard Time 2022
Step: Step-1
Increment     9179: Step Time =    1.000
Primary Var: S, S11
Deformed Var: U   Deformation Scale Factor: +1.000e+00
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Figure. 4: Stress Results

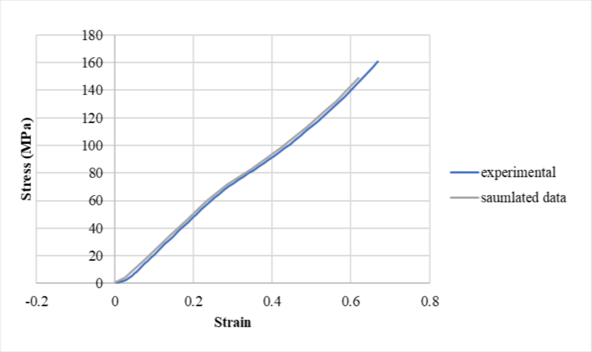


Figure. 5: Comparsion between experimental and simulated data

4. COMPRESSION BEHAVIOUR OF ALUMINIUM HYBRID COMPOSITE

The geometry of the test specimen is cylinder in shape. When compared to real geometry, The compressive test specimen is designed to seem as authentic as feasible length is taken as 10 mm and diameter is taken as 10 mm. l/d ratio is 1. The shell model features a deformable three-dimensional shell tabular characteristic, while the solid model has a changeable three-dimensional solid extrusion characteristic. The stresses, strains, and loads of various model structures are compared using this double geometry modelling. Fill the material property of Aluminium alloy in TABLE 1.1. In the assembly, the different components at the minimum interval of time to require our satisfaction. Compression test step is taken in general/explicit type. We can be defined the increment size and step size according to the experimental results. As indicated in the figure (4.1), In this compression test simulation, the boundary conditions are clamped in the lower grab and fastened in all supervision except the lengthwise direction in which the load is put in as shown in figure (4.2). These adjustments are made to ensure that the compression test is as accurate as possible, with no flexure or revolve. Mesh creation is a most important component of modelling and simulation in software. The mesh can be study minor parts of the simulation. Many elements with minor sizes might provide more precise results, however this leads in a protracted solver running time and erroneous results. ABAQUS/CAE supports a variety of mesh control strategies; in this work, a structured meshing methodology is employed to construct the best controllable meshing utilizing basic pre-set mesh topologies. The mesh size is precisely optimized to obtain consistent results. During the simulation, element deformation is possible. A coarse mesh of the simulation results is not too good as compare to fine mesh. The right aspects for a specific simulation are also crucial for precise results. Elements for the solid model S4R (Straight 4-node general-purpose shell, decreased integration with hourglass control) and the solid continuum shell model SC8R are utilized in this work (linear 8-node hexahedron, reduced integration with hourglass control). The non-default amplifies hourglass control conceptualization. In ABAQUS is only provided for S4R and SC8R components. The improved hourglass standard conceptualization is used in combination with composite models.

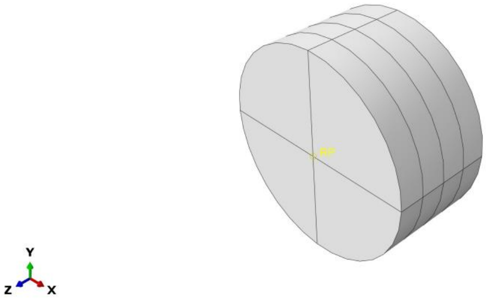


Figure 6: Create 3-D Compression specimen

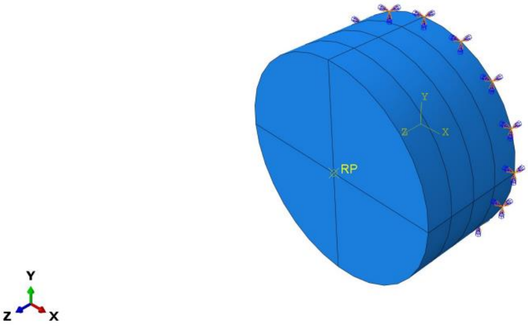


Figure 7: Apply boundary conditions

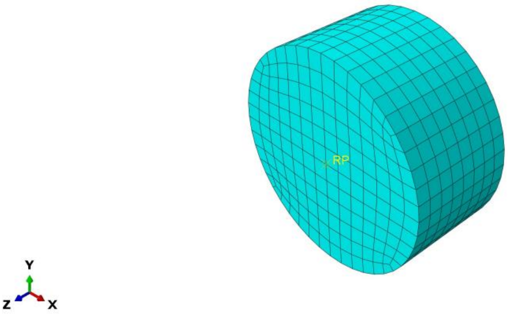


Figure 8: Meshing

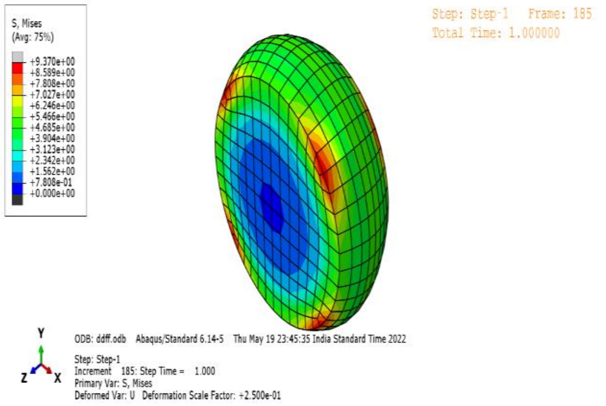


Figure 9: Results

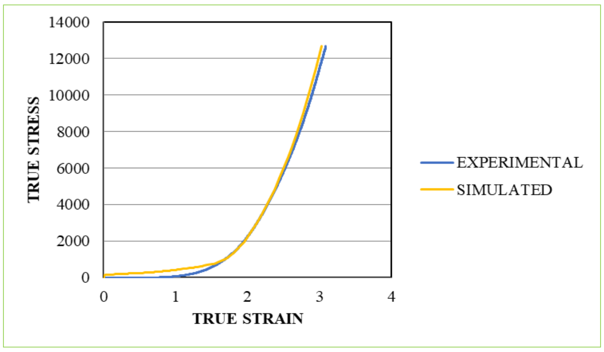


Figure 10. Comparison between the experimental and simulated data

5. FLEXURAL BEHAVIOUR OF ALUMINIUM HYBRID COMPOSITE

Flat specimen is created with length is 120 mm breadth is 10 mm and height is 5 mm in three dimensional after creating parts fill the basic mechanical properties according to table 1.1. Loading part is created can be assemble. Base of the flat part is combined with the reference point of the loading part. It is a general static process with a small increment size for the specimen. Various steps have been created in the Step Module. For using reference point these steps created Step Manager, a Field Output Manager, and a History Output Manager. Two points can be fixed, and at the center applied downward force. The applied load is 5 KN and picked a meshing size of 2 since mesh creation is a critical component of simulation. The mesh can be used to study accurate results when it divides the model into smaller parts. Too many elements with smaller sizes might provide more precise results, however this leads in a protracted solver running time and erroneous results. ABAQUS/CAE supports a variety of mesh control strategies; in this work, a structured meshing methodology is employed to construct the best controllable meshing utilising basic pre-set mesh topologies. The mesh size is precisely optimised to produce accurate results. During the simulation, element deformation is possible. Poor outcomes will be produced by a coarse mesh with distorted sections. The appropriate ingredient type for a given counterfeit is as well critical for precise results. This research utilizes elements from the exterior model S4R (Straight 4-node general-purpose shell, decreased integration with hourglass control) and the solid continuum shell model SC8R. (straight 8-node hexahedron, decrease amalgamation with hourglass jurisdiction).

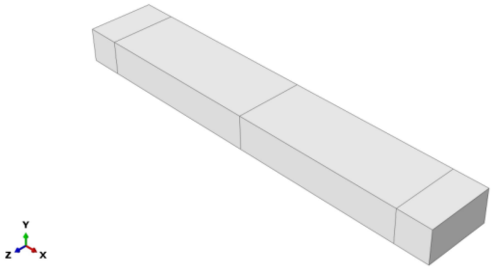


Figure 11: Create planer part

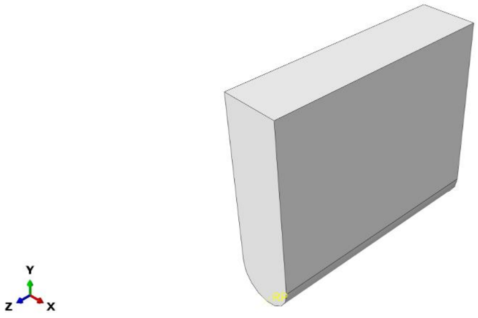


Figure 12: Create loading part

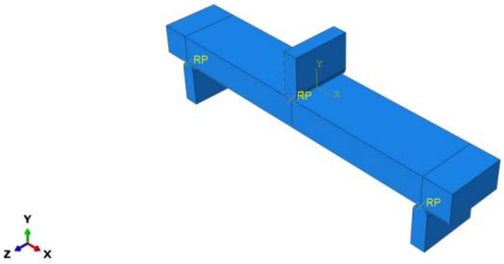


Figure 13: Applied boundary conditions

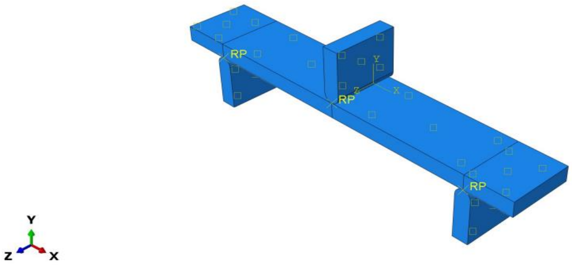


Figure 14: Surface interaction

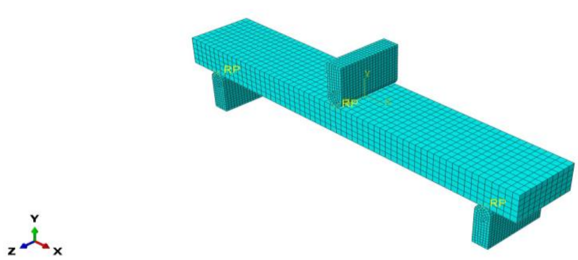


Figure 15: Meshing

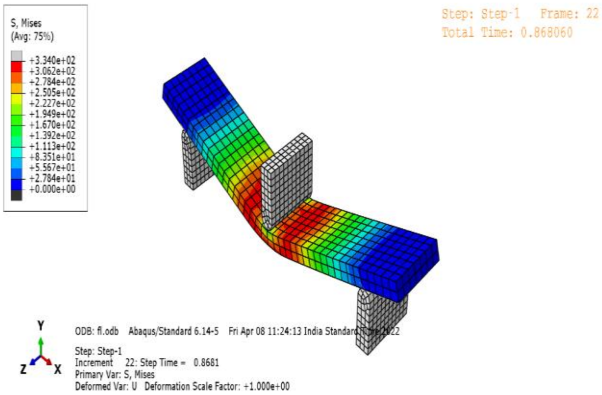
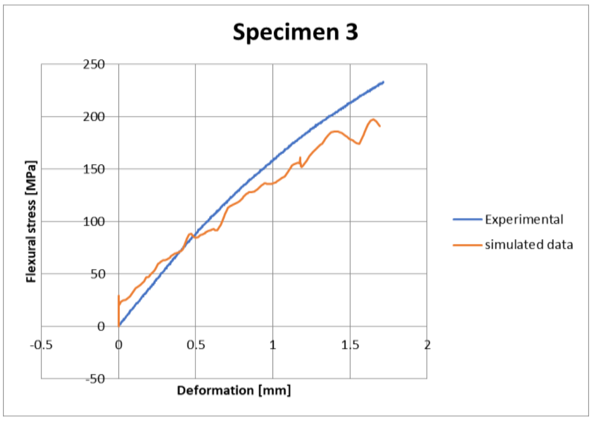


Figure 16: Results



Figue 17: Comparsion between flexural and simulated

6. EVALUATIONS OF MATERIAL MODELS

The stress-strain plots of different standard material models with experimental results are compared and shown in Figures. From the results, it can be observed that Ghosh and Hockett-Sherby models well matched with the experimental data.

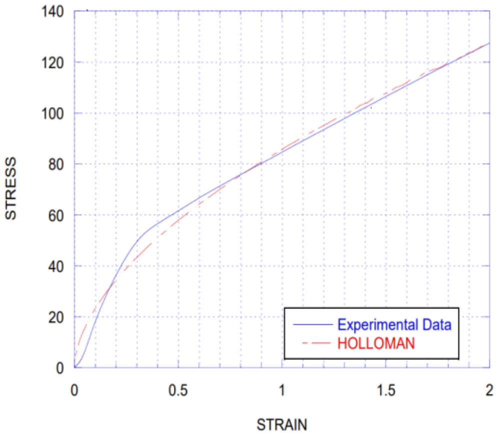


Figure 18: Comparsion of holloman and experimental

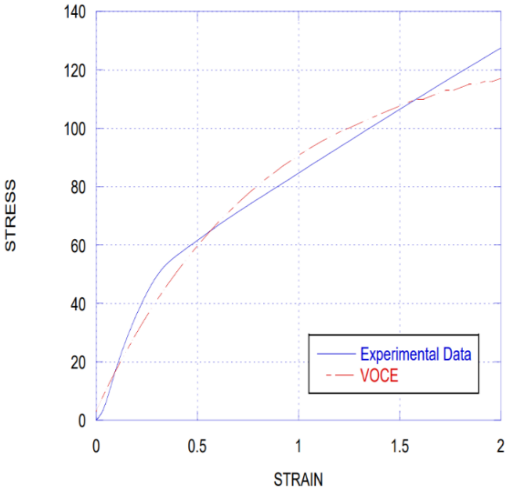


Figure 19: Comparsion of voce and experimental data

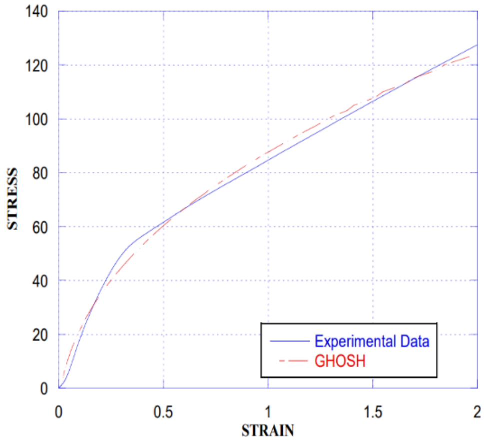


Figure 20: Comparison of Ghosh and experimental data

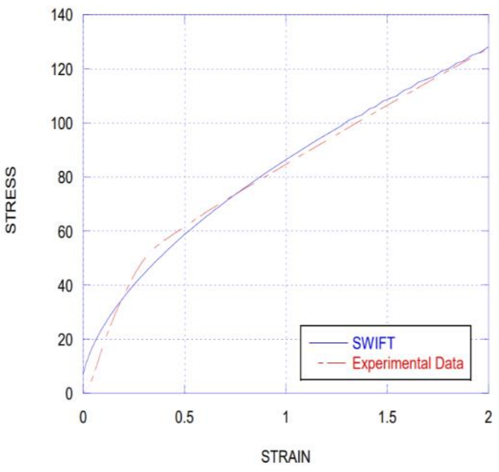


Figure 21: Comparsion of Swift and experimental data

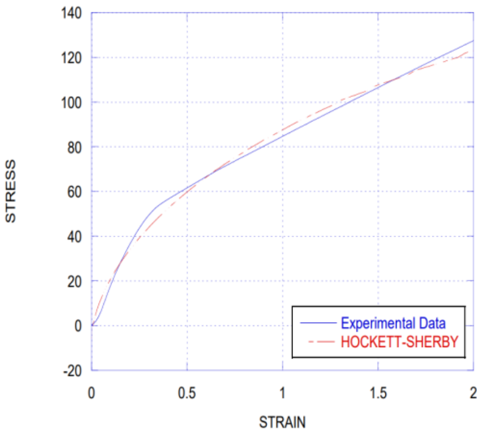


Figure 22: Comparison of experimental results with Hockett-Sherby model

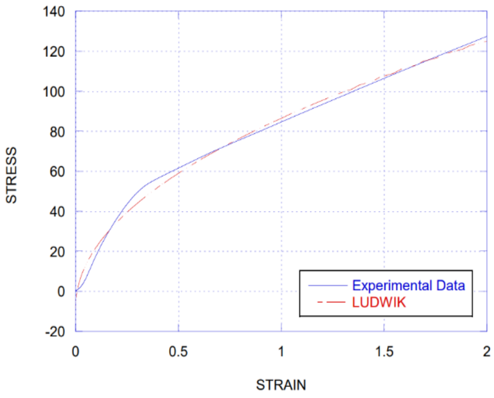


Figure 23: Comparsion of experimental results with Ludwik model

TABLE 2: Parameters of different materials models.

Holloman	K=85.74	n=0.5684	R=0.9945		
Swift	K=85.73	ε_0=1.3E-05	n=0.5684	R=0.9945	
Ludwick	σ_0 = -8.5148	K=95.037	n=0.4933	R=0.9941	
Ghosh	K=108.06	ε_0=1.3E-05	n=0.4239	C=21.54	R=0.9973
Voce	σ_0=3.2037	K=125.01	A=1.2029	R=0.9923	
Hockett-Sherby	σ_0=-5.6696	K=259.72	A=0.4450	n=0.6160	R=0.9968

5. CONCLUSIONS

Stir casting method is used to develop Aluminium Hybrid Composites (AHCs) in which aluminium alloy (LM6) is matrix and dried powders Mg, Ti, Cu and SiC are particulate reinforcement. Thereafter, tensile, compressive and flexural behaviour of the composites are studied at strain rate $0.001s^{-1}$. Electromechanical universal testing machine is used to perform the mechanical tests (tension, compression and bending/flexure) using suitable fixtures at room temperature. Six material models (Holloman, Swift, Ludwik, Voce, Ghosh, and Hockett-Sherby) are evaluated based on experimental results. Finally, numerical simulation on the mechanical behaviour of the composites is done using ABAQUS 6.14.5. Tensile strength of the composite is 160.88 MPa at strain rate $0.001s^{-1}$. Compressive strength of the composite is 120 MPa at strain rate $0.001s^{-1}$. Bending/Flexural strength of the composite is 232.43 MPa at strain rate $0.001s^{-1}$. The predicted results by Ghosh and Hockett-Sherby models fitted the experimental results very well. Results of numerical simulation have good agreement with the experimental results.

ACKNOWLEDGEMENTS

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