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A study on the mechanical behaviour of microwave sintered aluminium cenospheres based syntacticfoams

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Aluminium Syntactic Foams(ASF) are metallic foam material that are of great interest to the automobile manufacturers for their light weight coupled with tailorable engineering properties. Sufficient studies have been carried out on development of aluminium cenospheres based light weight syntactic foams which are fabricated through stir casting and melt infiltration techniques but it is seen from the literature that the synthesis of Aluminium Cenospheres metal foams fabricated through Powder Metallurgy (PM) route and densification through Microwave Sintering (MWS) has been less studied.

In this context, ASFs comprising of Aluminium metal matrix embedded with fly lsh cenospheres particulates have been fabricated through Powder Metallurgy (PM) route and sintered through Microwave (MW) sintering process at a temperature of 665° C. Cenospheres ranging from 0 to 50 volume%have been incorporated in the mix. The sintered ASF has been taken up for characterization for the mechanical properties such as Compression and Flexural strength. The compression test samples have also been taken up for Finite Elemental Analysis (FEA) and the Flexural Strength tested samples have been studied for fractography using scanning Electron Microscope (SEM). There sultso btained have been compared with aluminium cenospheres foamsthatwere sintered through conventional sintering process at the same temperature in electrical resistance furnace. Microwave sintered samples have shown better mechanical properties compared to the conventionally sinteredones. The study has been conducted to assess the suitability of using these 'Syntactic Foams' material for applications in automotives and other engineering applications.

Keywords: *Cenosphere , microwave sintering, aluminum metal matrix composite, powder metallurgy, syntactic metallic foams*

1.0 INTRODUCTION

Metal Matrix Foams (MMFs) materials are composites composed of metals like Aluminum, Copper, Iron, Magnesium, Titanium, Cobalt etc as the matrix and having hollow and porous reinforcements such as ceramic, organic materials etc., and they exhibit exceptional engineering properties and aid design of components for specific purposes. Amongst the various metal matrix foams, the Aluminium Metal Matrix Foams (AMF) are known to possess enhanced properties and offers variety of advantages including higher strength, higher stiffness, lower co-efficient of thermal expansion, high fatigue and wear properties, lower density etc., and are cheaper compared to those of other matrix alloys [1].

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In AMF one of the constituent is aluminium/ aluminium alloy, which forms the matrix phase. The other constituent is embedded in this alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic in nature [2].

There has been an increasing interest in the MMFs containing low density and low cost reinforcements. Amongst the various reinforcements, Fly ash based 'Cenospheres' is one of those ceramic materials which are basically aluminp-silicates, having low density and are cheaper. Fly ash cenospheres are the by product of combusted residue of pulverized coal in thermal power plant boilers. They are hollow and porous structured spheres which are in the form of micro balloons. Cenospheres can make an effective reinforcement material in the metal matrix composites[3].

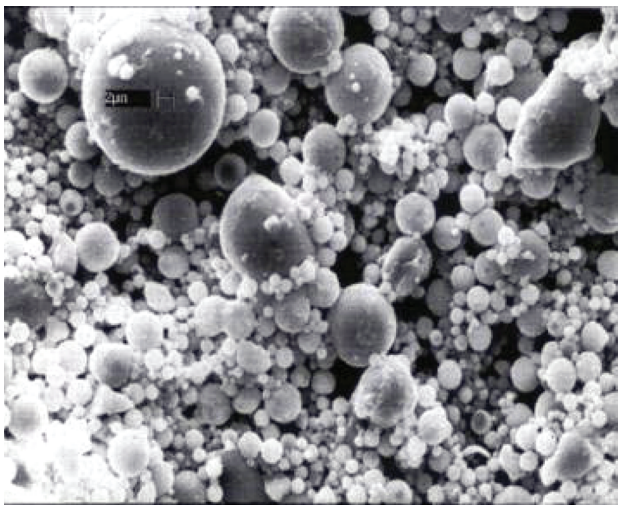


FIG. 1 MICROSTRUCTURE OF CENOSPHERES

MMFs are fabricated through various metallurgical processes such as stir casting, melt infiltration technique, powder metallurgy process etc. Amongst these processes, Powder Metallurgy (PM) is an attractive processing technique to produce near net shape products and is commonly used for the fabrication of engineering components and for particulate reinforced metal matrix composites/ foam fabriction. The basic process involved in PM technology route is mixing and blending of powders, consolidation of the mix and sintering of the consolidated powders for densification. The densification process is generally carried out by conventional methods in an electric resistance furnace or furnaces using various fuels. But other sintering methods such as, plasma arc sintering technique, microwave assisted sintering etc., are gaining importance presently.

Microwave sintering process is quite significant and unique in recent times for sintering material for densification because of its intrinsic advantages such as rapid heating rates, reduced processing times, uniform temperatures with minimal thermal gradients. Microwave sintering process leads to substantial energy savings with high efficiency, improved properties, finer microstructures, environmental friendly process and are less environmental hazards. The composites sintered through microwave process are expected to yield better properties compared to the composite products that are obtained through conventionally sintering methods.

In the present study, Aluminium Metal Matrix Foam Composites (AMFCs) with hollow and porous Cenospheres as reinforcement have been synthesized through powder metallurgy route and sintered rapidly through microwave sintering route for densification. These composites have been studied for mechanical properties. The study indicated that microwave sintered foam composites exhibited enhanced properties in terms of light weight, low density and good mechanical strength compared to conventionally sintered ones. Very less information is available from the literature survey on the study on the synthesis of aluminium based syntactic foams with cenospheres reinforcement that has been sintered through microwave route and studied for their mechanical properties.

2.0 EXPERIMENTAL

2.1 Raw Materials

In this study, atomized Aluminium metal powder of 99.5 % purity from M/s. NICE Chemicals, which had a particle size range of ASTM 200 mesh (75 μm) and Cenospheres obtained from fly-

ash collected from M/s. NTPC Simhadri Thermal Power Station, Vishakhapatnam was used as the matrix material for the study of the composite.

The fly-ash was processed in the lab for harvesting the cenospheres present in it. The process involved preparation of ash slurry, stirring the same with mechanical stirrer to assist good dispersion of the ash in the slurry. A permanent magnet is introduced into the slurry which removes free form of magnetic iron oxide (Fe_2O_3 + Fe_3O_4) particles present in the fly ash. The agitated slurry was then allowed to settle to a standstill. Later, the light weight floating material of the ash comprising mainly of cenospheres were removed. The removed cenospheres was dried thoroughly in an oven. The dried material was then sieved to remove cenospheres of various size fractions. Cenospheres with an average particle size of 10- 100 µm has been used in this study. The microstructure of cenospheres is depicted in Figure 1.

2.2 Composition

Two sets of composite samples were prepared with 6 mix compositions having 0, 10, 20, 30, 40 and 50 volume % cenospheres and the remaining portion of the mix being aluminium powder. The pressed samples were dried and later taken for sintering for densification through microwave and conventional routes. The samples were coded as 'M' samples for microwave sintered and 'C' samples for the conventionally sintered ones. The samples were designated as 1C, 2C, 3C, 4C, 5C and 6C for the conventionally sintered samples and 1M, 2M, 3M, 4M, 5M and 6M for the microwave sintered samples depending on the cenospheres content varying from 0, 10, 20, 30, 40 and 50 volume % respectively.

2.3 Sample Pressing

The mix was pressed through cold compaction into cylindrical shaped samples of size 40 mm x 8 mm diameter at a pressure of 25 MPa in a laboratory Enkay make hydraulic press through single ended uniaxial compaction.

The cylindrical shaped samples were prepared for evaluating the compression strength, of the composites. Another set of samples of size having length 50 mm x 15 mm width x 12 mm depth rectangular bar shaped specimens were prepared for the evaluation of flexural strength. The green composites were then thoroughly dried in oven at 108° C for 2 hours to remove the moisture prior to sintering. The pressed pellets used for testing are shown in Figure 2.

FIG. 2 PELLETS FORCOMPRESSION AND FLEXURAL STRENGTH

2.4 Sintering

One set of dried samples were sintered in BHEL make Microwave Sintering Facility shown in Figure 3. The microwave sintering facility is rated at 1.1 kW power with microwave frequency of 2.45 GHz, at a power level of 100 %. The samples were sintered at a temperature of 665° C. The sintering cycle for each batch of materials comprised of 90 minutes which included soaking time of 42 minutes at the maximum temperature.

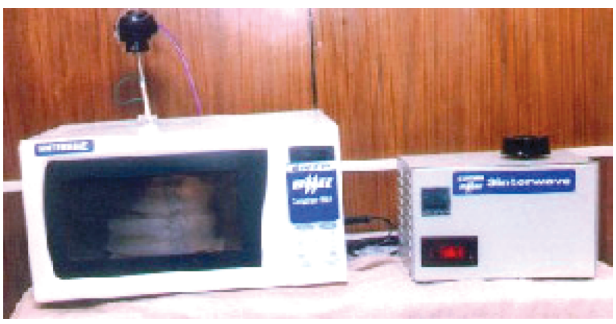


FIG. 3 MICROWAVE SINTERING FACILITY

The other set of samples were sintered separately in a conventional laboratory make resistance type muffle furnace which is heated with kanthal

heating element. The temperature of sintering was also kept at 665° C for the conventional sintering. The sintering cycle comprised of 7 hours with soaking time of 2 hours for the composites at the peak temperature

2.5 Testing

The conventionally and microwave sintered composites were later taken up for evaluation of mechanical properties such as compression and flexural strengthin enkay make hydraulically operated universal testing machine of capacity 100T.

The results of the conventionally and microwave sintered composites samples tested for compression strength was validated through Finite Element Method (FEM). The FEM analysis was carried out using MSC NASTRAN software package (MSC Nastran 2007). The matrix was identified by nodded hexahedron elements called CHEXA8 in NASTRAN.

The test results obtained from the static compression test in the laboratory was used as the input for defining the material. The physical properties, linear elastic and plasticity of the material used were defined for the material in MSC Nastran software simulation. The material had a valid density defined for the explicit or implicit simulation. Isotropic elasticity was used to define linear elastic material behavior by defining Young's modulus and poisson's ratio. However, the plastic deformation was computed by reference to Von Mises yield criterion. The multi-linear isotropic model was used to define the yield stress (σy) as a piece wise linear function of plastic strain, εp. The Load vs. Displacement behavior of both the types of samples sintered differently was also incorporated for the simulation studies.

Compression strength was calculated by dividing the load(kg) at failure, by area(cm^2) of the test specimen represented as kg/cm^2 or MPa.

$$\sigma_{cs} = \text{Load(kg)}/\text{ Area}(cm^2) \quad ....(1)$$

lexural Strength also known as Modulus of Rupture (MOR), bend strength, or fracture strength, is a mechanical parameter for brittle material. This is defined as material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. The Flexural Strength test has been carried out as per the guidelines of ASTM D790 – 15 standards.

Flexural Strength (σ_{fs})is measured in terms of stress $\sigma$was calculated as follows:

$$\textbf{Flexural Strength}\,(\sigma fs) = \frac{3PL}{2BD^2} \quad ....(2)$$

Where P= the actual load(kg) at the fracture point, L is the length(mm) of the supports holding the test specimen, B is the width (mm)of the test specimen and D is the depth or thickness (mm) of the test specimen and the units of flexural strength is kg/cm^2 or MPa. Flexural Strength measurements of the composites were carried out in a laboratory make 3 point bending machine.

The fracture surfaces of the flexural strength tested samples have also been studied for fractography using Scanning Electron Microscope (SEM).

3.0 RESULTS

The Figure 4 illustrates the comparison in the compression strength behavior of the conventionally sintered samples 1 C to 6 C and microwave sintered sample 1 M to 6 M. It is seen that the compression strength of the conventionally sintered samples 1 C comprising of pure aluminium powder is 125.0 kg/cm^2. The compression strength reduced to 76.5 kg/cm^2 when 10 vol. %. cenospheres was incorporated in the 2 C sample which is a reduction in the compression strength by 38.8%. When the cenospheres content

was increased to 20 vol. % in the 3 C sample the compression strength further reduced to 71.2 kg/cm^2 which is 43.0 % decrease in the strength compared to pure aluminium sample. Again when the cenospheres content was increased to 30 vol. % in the 4C sample the compression strength further reduced to 67.1 kg/cm^2 which is 46.3% decrease in the strength compared to pure aluminium 1C sample. The cenospheres content when increased to 40 vol. % in the 5C sample the compression strength reduced to 63.8 kg/cm^2 amounting to about 49.0% decrease in the strength compared to pure aluminium sample. And finally when the cenospheres content was increased to 50 vol. % in the 6C sample the compression strength reduced to 62.5 kg/cm^2 which is 50.0% decrease in the strength compared to pure aluminium 1 C sample.

In another set of samples which have been sintered in microwave, it is seen that the compression strength of the microwave sintered samples 1 M which comprises of pure aluminium powder is 140.3 kg/cm^2. The compression strength reduced to 97.6 kg/cm^2 when 10 vol. %. cenospheres content was incorporated in the 2 M sample. This showed a reduction of the compression strength by 30.4%. When the cenospheres content was increased to 20 vol. % in the 3M sample the compression strength reduced to 89.3 kg/cm^2 which is 36.4% decrease in the strength compared to pure aluminium sample. When the cenospheres content was increased to 30 vol. % in the 4M sample the compression strength further reduced to 86.2 kg/cm^2 which is 38.6 % decrease in the strength compared to pure aluminium sample. The cenospheres content was further increased to 40 vol. % in the 5 M sample and the compression strength reduced to 76.6 kg/cm^2 which is 45.4% decrease in the strength. Finally when the cenospheres content was increased to 50 vol. % in the 6 M sample the compression strength further reduced to 71.7 kg/cm^2 which is 48.9 % decrease in the strength compared to pure aluminium 1 M sample.

A progressive decrease in compression strength is observed for the both conventionally and microwave sintered samples as the volume percent of cenospheres increased from 0 to 50 in increments of 10 vol. percent cenospheres. The sample appeared to be more brittle than metallic with the increase in the ceramic phase by addition of cenospheres in both types of samples. Microwave sintered samples showed better compression strength compared to its counterpart, the conventionally sintered ones. The microwave sintered samples had a higher compressive strength by about 10.9%, 21.6%, 20.3%, 22.1%, 16.7 % and 12.8 % for 0, 10, 20, 30, 40 and 50 vol. % cenospheres content respectively which is 26.8% average higher compressive strength compared to its counterpart.

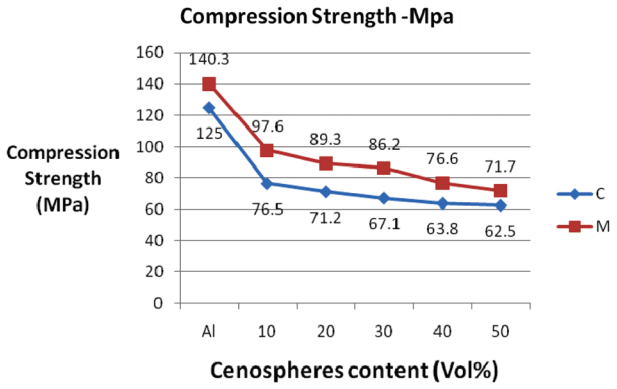


FIG. 4 MEASURED COMPRESSION STRENGTH OF COMPOSITES

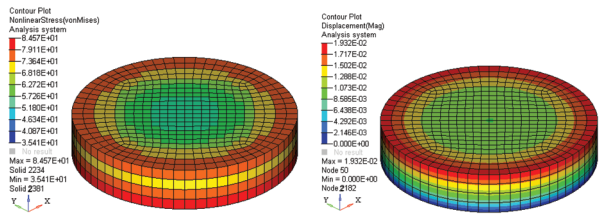
3.1 Finite Element Method (FEM) Analysis of conventionally sintered samples

The compression test results of the conventionally and microwave sintered composites samples tested for compression strength was validated through FEM. The results of the same are discussed. The samples were analyzed for the Stress vs. Displacement behavior of both the types of samples sintered differently.

3.2 FEA Stress vs. Displacement analysis of conventionally sintered 1C, 2C and 5C samples

The Figure 5 depicts the stress vs. displacement plots analyzed for the 1 C samples comprising of only pure aluminium which has been sintered conventionally. It is observed from the plots that

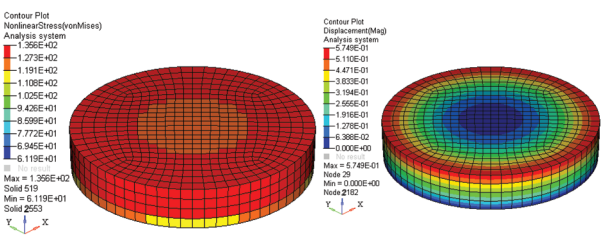
the maximum stress that the sample withstood was 135.6 MPa and the displacement observed to be 0.574 mm. The maximum stress concentration is observed at the periphery at the top edge of the sample. The displacement also appears to be maximum at the periphery, both in the Y axis. The FEM analysis indicates that the calculated compressive stress is higher by about 7.8 % compared to the physically tested samples.



Stress 135.6 MPa, Displacement 0.574mm

FIG. 5 FEA OF STRESS VS. DISPLACEMENT OF 1C SAMPLE

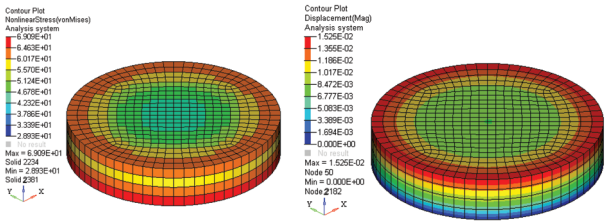
The Figure 6 indicates the stress vs. displacement plots analyzed for the 2C samples comprising of aluminium with 10 vol. % cenospheres sintered conventionally. It is observed from the plots that the maximum stress that the sample withstood was 84.57 MPa and the displacement observed to be 0.0193 mm. The maximum stress concentration is observed to be at the outer top edges of the sample. The displacement value is maximum at the periphery, both in the Y axis. The FEM analysis indicates that the compressive stress has decreased by about 37.6 % compared to 1C sample with increase in cenospheres content, but the compressive stress value by FEA are higher by about 9.50 % compared to tested samples.



Stress 84.57 MPa,Displacement 0.0193 mm

FIG. 6 FEA OF STRESS VS. DISPLACEMENT OF 2C SAMPLE

The Figure 7 shows the stress vs. displacement plots analyzed for the 6C samples comprising of aluminium with 50 vol. % cenospheres sintered conventionally. It is observed from the plots that the maximum stress that the sample withstood was 70.53 MPa and the displacement was observed to be 0.0230 mm. The maximum stress and displacement is observed to be distributed at the outer bottom edges of the sample and outer top edge of the sample in the Y axis respectively. The FEM analysis indicates that the compressive stress has further decreased by about 48.0 % compared to 1C sample with increase in cenospheres content, but the compressive stress values calculated through FEA is higher by about 9.54 % compared to tested samples.



Stress69.1 MPa, Displacement 0.0152mm

FIG. 7 FEA OF STRESS VS. DISPLACEMENT OF 6C SAMPLE

The Figure 8 represents the graph comparing physically tested compression strength of conventionally sintered samples having varied cenospheres content with that of compressive test values obtained through FEM analysis of the same samples.

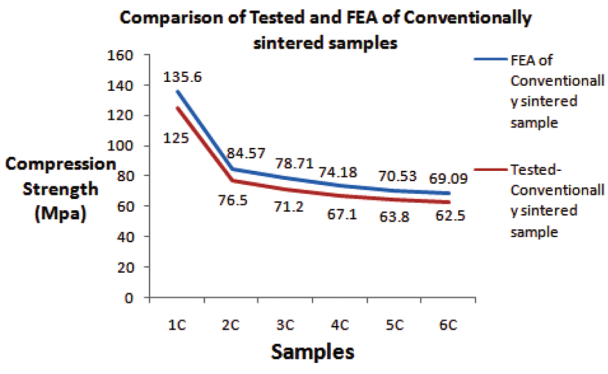
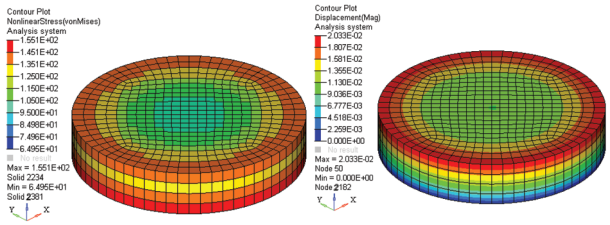


FIG. 8 COMPARISON OF FEA AND MEASURED COMPRESSION STRENGTH OF CONVENTIONALLY SINTERED COMPOSITES

3.3 FEA Stress vs. Displacement analysis of microwave sintered 1 M, 2 M and 5 M samples

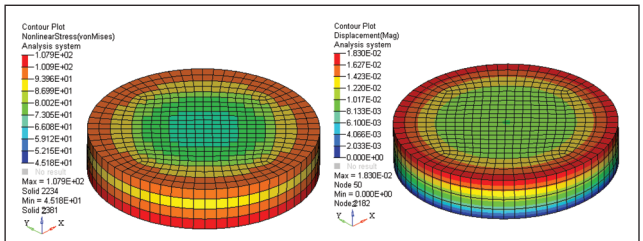
The Figure 9 indicates the stress vs. displacement plots analyzed for the 1 M samples comprising of pure aluminium which has been sintered in microwave. It is observed from the plots that the maximum stress that the sample withstood was 155.1 MPa and the displacement observed to be 0.023 mm. In this analysis too the maximum stress concentration is observed to be at the bottom edge at the periphery of the sample. The displacement also appears to be at the maximum at the top edges of the sample, both in the Y axis. The FEM analysis indicates that the calculated stress is higher by about 9.54 % compared to tested samples.



Stress 155.1 MPa, Displacement 0.023mm

FIG. 9 FEA OF STRESS VS. DISPLACEMENT OF 1M SAMPLE

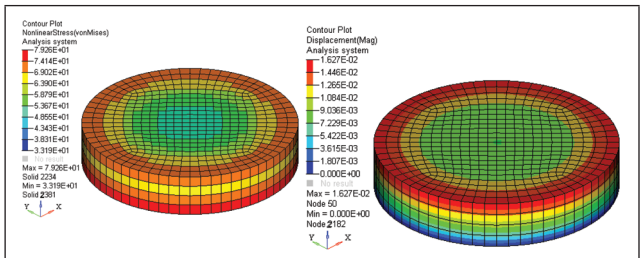
Figure 10 represents the analysis carried out on the microwave sintered 2M sample. It is observed from the plots that the maximum stress that the sample withstood was 107.9 MPa and the displacement observed to be 0.0183 mm. In this analysis the maximum stress concentration is observed to be at the bottom edge at the periphery of the sample. The displacement is observed to be at the maximum at top edge of the sample, both in the Y axis. The FEM analysis indicates that the stress has reduced by about 30.43 % compared to 1M with increase in the cenospheres content. The stress value calculated is higher by about 9.55 % compared to tested samples.



Stress 107.9 MPa, Displacement 0.0183mm

FIG. 10 FEA OF STRESS VS. DISPLACEMENT OF 2M SAMPLE

Figure 11 represents the analysis carried out on the microwave sintered 6M sample. It is observed from the plots that the maximum stress that the sample withstood was 79.26 MPa and the displacement observed to be 0.016 mm. In this analysis also the maximum stress concentration is observed to be at the bottom edge of the periphery of the sample and the displacement also appears to be at the maximum at the top edge of the sample, both in the Y axis. The FEM analysis indicates that the stress is further lowered by about 48.9 % compared to 1M sample which has decreased with increasing cenospheres content. The compressive stress value calculated is higher by about 9.58 % as compared to tested samples.



Stress 79.26 MPa, Displacement 0.016mm

FIG. 11 FEA OF STRESS VS. DISPLACEMENT OF 6M SAMPLE

The Figure 12 represents the graph comparing compression strength of microwave sintered samples having varied cenospheres content with that of compressive test values obtained through FEM analysis of the same samples. It is observed from the plots that the FEM analysis indicates that the compressive stress values are higher by about 9.52 to 9.54 % compared to tested samples for the samples 1M to 5M.

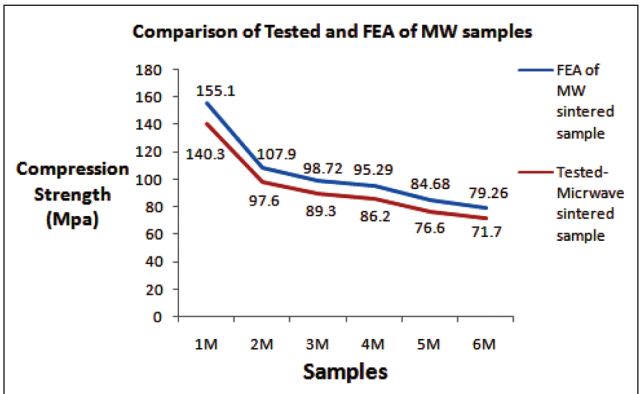


FIG. 12 COMPARISON OF FEAAND MEASURED COMPRESSION STRENGTH RESULTS OF MICROWAVESINTERED COMPOSITES

The Figure 13 illustrates the comparison in the Flexural Strength behavior of the conventionally sintered samples 1C to 6C and microwave sintered sample 1M to 6M. It is seen that the flexural strength of the conventionally sintered samples 1C which comprises of pure aluminium powder is 52.0 kg/cm^2. The flexural strength reduced to 47.7 kg/cm^2 when the cenospheres content was incorporated in the 2C sample to a tune of 10 vol. %. This shows a reduction of the flexural strength by 8.27%. When the cenospheres content was increased to 20 vol. % in the 3C sample the flexural strength reduced to 38.2 kg/cm^2 which is 26.5 % decrease in the strength compared to pure aluminium sample. When the cenospheres content was increased to 30 vol. % in the 4C sample the flexural strength reduced to 27.3 kg/cm^2 which is 47.5% decrease in the strength compared to pure aluminium 1C sample. The cenospheres content further when increased to 40 vol. % in the 5C sample the flexural strength reduced to 14.7 kg/cm^2 which is 71.7% decrease in the strength compared to pure aluminium 1C sample. Further when the cenospheres content was increased to 50 vol. % in the 6C sample the flexural strength further reduced to 8.8 kg/cm^2 which is 83.0% decrease in the strength compared to pure aluminium 1C sample.

It is seen that the flexural strength of the microwave sintered samples 1M which comprises of pure aluminium powder is 71.9 kg/cm^2. The flexural strength reduced to 62.5 kg/cm^2 when the cenospheres content was incorporated in the 2M sample to a tune of 10 vol. %. This shows a reduction of the flexural strength by 13.1%. When the cenospheres content was increased to 20 vol. % in the 3M sample the flexural strength reduced to 49.8 kg/cm^2 which is 30.7% decrease in the strength compared to pure aluminium sample. When the cenospheres content was increased to 30 vol. % in the 4 M sample the flexural strength reduced to 40.8 kg/cm^2 which is 43.25% decrease in the strength compared to pure aluminium 1M sample. The cenospheres content further when increased to 40 vol. % in the 5 M sample the flexural strength reduced to 35.7 kg/cm^2 which is 50.35% decrease in the strength compared to pure aluminium 1 M sample. Further when the cenospheres content was increased to 50 vol. % in the 6 M sample the flexural strength further reduced to 31.5 kg/cm^2 which is 56.19% decrease in the strength compared to pure aluminium 1M sample

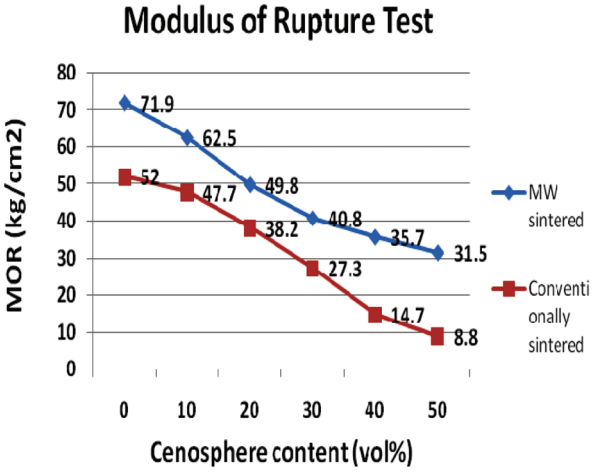


FIG.13 COMPARISON OF FLEXURAL STRENGTH RESULTS OF MICROWAVE AND CONVENTIONAL SINTERED COMPOSITES

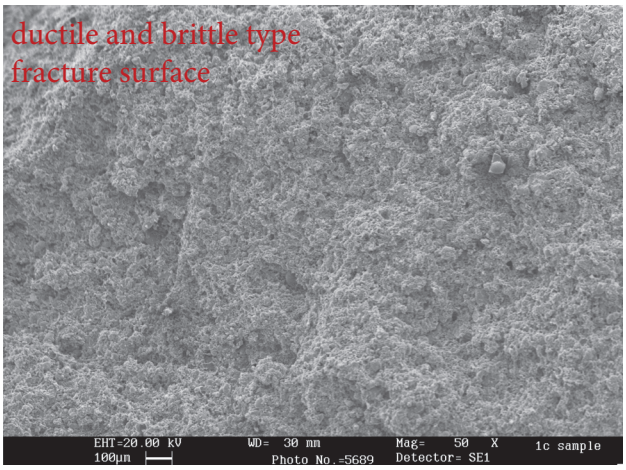
A progressive decrease in flexural strength is observed for the both the conventionally and microwave sintered samples as the volume percent of cenospheres increased from 0 to 50. The sample appears to be more brittle than metallic with the increase in the ceramic phase by addition of cenospheres in both types of samples. The microwave sintered samples had a higher flexural strength by about 27.7%, 23.7%, 23.3%, 33.1%, 58.8% and 72.3% for 0, 10, 20, 30, 40 and 50 vol. % cenospheres content respectively compared to the conventionally sintered ones. Microwave

sintered samples had a overall flexural strength of about 26.8% higher compared to its counterpart, the conventionally sintered ones.

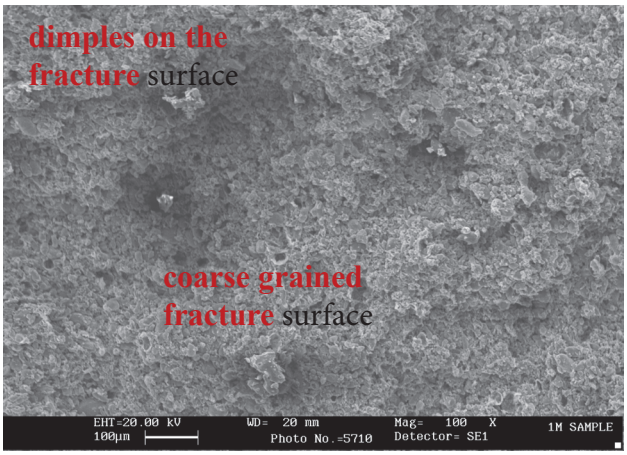
3.4 Study of the Fracture Surface

The microstructure at Figure 14(a) shows fracture surfaces of the 1C composite sample tested for flexural strength respectively. The fracture surface of the composite which comprises of 90 vol. % of aluminium and 10 vol. % of cenospheres and sintered conventionally has been observed in the SEM for the fracture characteristic. The microstructure reveals a mixed mode of fracture surface which comprises of cup and cone type of contour at some places attributed to the ductile material which is aluminium and the fracture happening in the tensile mode and the other type of fracture found is the coarse grained surface type having brittle features contributed by cenospheres which are ceramic in nature, when seen at a magnification of 100 X.

The microstructure at Figure 14(b) shows fracture surfaces of the 1M composite sample tested for flexural strength. Here too the microstructure reveals a mixed mode of fracture surface which comprises of cup and cone type of contour attributed to the ductile material which is aluminium. The other type of fracture i.e. coarse grained surface composed of regions having brittle features contributed by cenospheres which are ceramic in nature, when seen at a magnification of 100 X.



(a)



(b)

IG. 14 COMPARISON OF FRACTURE SURFACES OF (A)1C AND (B)1 M COMPOSITES

The microstructure at Figure 15(a) shows fracture surfaces of the 6C composite sample tested for flexural strength. The fracture surface of the composite which is comprised of 50 vol. % of aluminium and 50 vol. % of cenospheres sintered conventionally has been observed. The microstructure reveals more of brittle mode of fracture and less of cup and cone features representing ductile surface which is attributed to aluminium. The brittle mode seen from the coarse grain line fracture surface is mainly attributed to the materials of ceramic nature- cenospheres. In this case the sample has 40 vol. of cenospheres dispersed in the matrix which is supporting brittle type of fracture.

The microstructure at Figure 15(b) shows fracture surfaces of the 6M composite sample tested for flexural strength. The fracture surface of the composite which is comprised of 50 vol. % of aluminium and 50 vol. % of cenospheres sintered in microwave has been observed in the SEM for the fracture characteristic. Here too the microstructure reveals more of brittle mode of fracture and less of cup and cone features representing ductile surface which is attributed to aluminium. The brittle mode seen from the coarse grain fracture surface is mainly attributed to cenospherew which is a ceramic.

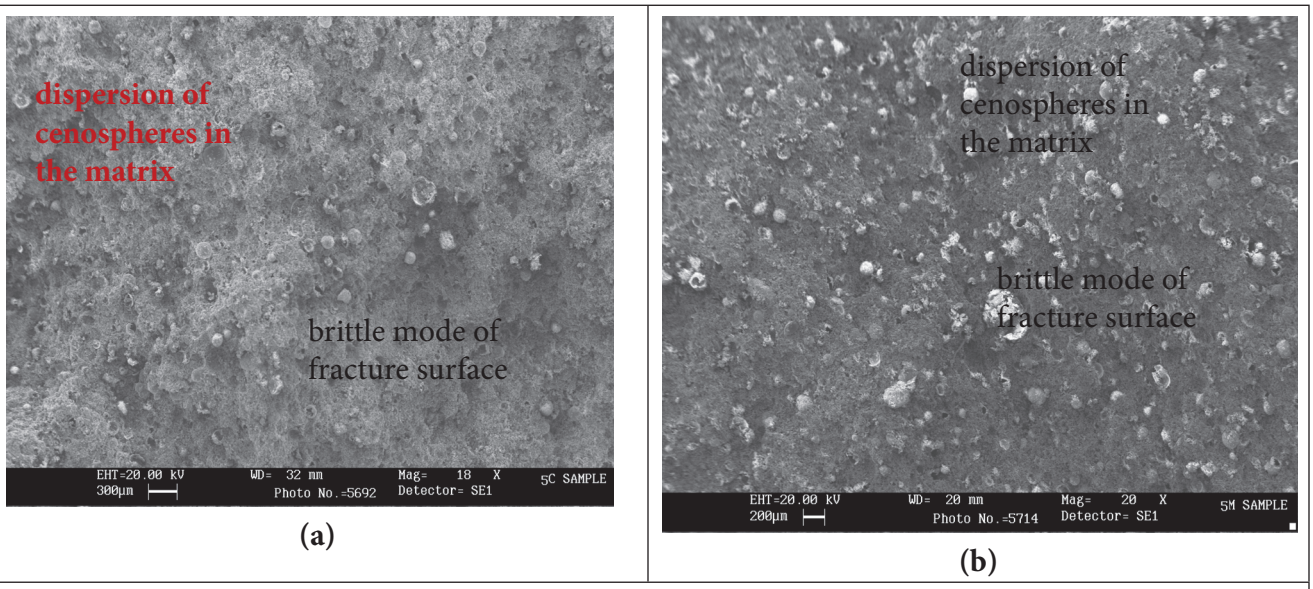


FIG. 15 COMPARISON OF FRACTURE SURFACES OF(A) 6C AND (B) 6 M COMPOSITES

4.0 DISCUSSIONS

During compression testing it was observed that as the deformation increased, the external walls of the composite began to detach from the main body revealing the internal core of the material. This behavior may be attributed to the inhomogeneous distribution of porosity, since the walls and the bottom of the composite were less dense compared to the specimen's core.

Some reports also suggest that behavior of the fracture modulus E_f is mainly related both to the bonding between matrix and the reinforcement particles after sintering and to the volume fraction of the cenospheres in the composite. The ductility also reduces with increasing cenospheres content in the matrix there by leading to brittleness. The presence of micro-porosity (unintended porosity) from the composite as well as porosity from cenospheres interferes adversely to the sintering process because the distance between the matrix and the particle is increased, and it is likely that cenospheres as well as fractured cenospheres enhance imperfections in the composite, which can prevent a number of matrix particles to bond mechanically with the reinforcement prior to sintering. The above reasons result in insufficient bonding between aluminium matrix and the cenospheres particles after sintering, which leads to the reduction of the ductility of the composite. [4].

Since cenospheres are ceramic and brittle in nature, this brittle phase can lead to poor interfacial stress transfer and is detrimental to the quality of the composite in terms of mechanical strength[5].

The extent, to which the compressive stress has reduced in the composite on increasing the cenospheres content after yielding, is either a measure of the degree of agglomeration or the tendency of breakage and collapse of cenospheres during yielding. At this condition, the cenospheres within in the composite deforms elasto-plastically which would lead to strain hardening in the matrix. But because of the mechanical bonding between cenospheres and the matrix, and also the porous nature of the cenospheres, the strain hardening is not so significant. The interface at cenospheres surface in the aluminium matrix as well as the porous nature of cenospheres shells acts as dislocation sink sites and thus the matrix strain hardening is expected to be very marginal or low.

Additionally, on application of load, the cenospheres shells also gets sheared and starts fracturing which results in the reduction in modulus and thus the stress starts decreasing. The cenospheres fraction in the matrix get sheared, broken and collapsed and the matrix starts yielding as soon as the stress levels reach to that extent at which the next series of cenospheres starts cracking and shearing. Since the composites

are also highly porous in nature, the deformation is also expected to be highly inhomogeneous and localized. The collapse of cenospheres, shearing of the matrix around the cenospheres and compaction of the cenospheres and the pores take place simultaneously during deformation of the composite during loading.

At the initial stage, during yielding a major fraction of cenospheres may get sheared, broken and collapsed leading to greater degree of stress reduction and hence reduces the compressive or flexural strength. During the deformation process, matrix undergoes strain hardening and as a result there would be a steady increase of stress with strain while deforming. This is attributed to the fact that collapse and breakage of cenospheres and in due course its densification nullifies the effect of strain hardening and is responsible for decrease in stress values. [6]

The metal matrix composites behave like any other foam when loaded in compression. During compression testing, there are three regimes of behavior when loading in compression. The first regime initially starts with a linear elasticity. On further loading, the linear elastic regime is followed by the second regime, the plateau strength. The third regime is the final regime which ends by the densification strain. The failure behavior of the metal matrix composite may be different either due to its compositions. The failure is controlled by the different plastic characteristics of the matrix and the reinforced material. The failure may be either due to ductile mode of failure, or may be collapsing of the structure of the cenospheres on loading. The failure may also occur due to shearing mode due to the crushing of the cenospheres which are ceramic in nature [7].

The three factors affect the failure behaviour of metal matrix foam namely ductility of metal matrix, structure of ceramic cenospheres and, thirdly the volume fraction of ceramic cenospheres and metal matrix. It is also reported that the behaviour of metal matrix composite's performance failure depends on the type of the metal used for the matrix. Further it is stated that the strength of the cenospheres has also an effect on the strength of metal matrix composites[9].

At higher temperatures of sintering, pores become more closed because micro pores vanish during the sintering process of the material. The sintering temperature and the process influence the bulk density, mechanical strength, thermal stability, porosity and shrinkage of the samples [8]. The development of physical and mechanical properties is related to the phases formed due to reaction sintering between alumina and alumino-silicates and formation of compact microstructure [9].

Aluminium cenospheres metal matrix composite have similar structural characteristics as those of metal matrix syntactic foams. Under compression loading they may have different failure modes such as ductile which forms due to the collapse and crushing of the cenospheres, brittle mode wherein the failure is due to shear failure or in the form of fracture which is caused due to initiation of cracks while loading the sample. The fracture mode of failure very much agrees with that of Griffith's Rupture theory. The main criteria available to predict the failure mode of MMCs under compression is the ductility nature of the metal matrix, volume fraction of matrix and the inner structure of the reinforcement particle[10]. It is also reported that the pure aluminium matrix fails by ductile plastic deformation whereas the aluminium alloy based composites failed by shear fracture. The matrix to reinforcement ratio has a bearing on the failure mode of the composite. The increase in the reinforcement content to that of matrix leads to the failure of the composite in the brittle mode while the increase in the matrix component leads the composite to fail in ductile mode. The reinforcement having varied structure and porosities may fail in different modes[11].

Metal matrix composites (foam) are particularly suited to applications where permanent deformation at low stresses is undesirable. To summarize, the Aluminium Cenospheres MMFs manufacture by different methods have different microstructures and properties. The manufacturing of the MMFs

through melt Infiltration casting , though a simple process has a disadvantage of its inability to vary the volume faction of the cenospheres[10].

The compressive strength of MMFs not only depends on the strength of the metal matrix but also on the ceramic reinforcement and its volume fraction, structure and distribution in the matrix. The interfacial bonding between the matrix and the reinforcement, amount of the defects present also have a bearing on the compressive strength of the composites. In metal matrix syntactic foams, both the metal matrix and the ceramic particles contribute to the compressive strength of the composite.

The same metal matrix in different forms and the different heat treatment procedures can also result in the difference in the compressive strengths of the composites. For example an aluminium MMF fabricated through stir casting route may have different compressive strengths compared to the PM fabricated ones. [10].

The compressive yield strength of the Aluminium matrix syntactic foams increase with increasing particle size of the ceramic spheres, while others have reported that larger ceramic spheres are had high compression strength. However, the variation in compressive strengths in both the cases were attributed to the different void contents in different sized ceramic cenospheres instead of different geometries[12]. Porous cenospheres can also be used in producing MMFs with the same composition and porosity; however, porous ceramic spheres are much weaker than hollow cenospheres. The Aluminium matrix syntactic foams containing porous ceramic spheres have much lower compressive strength than those containing hollow ceramic spheres. [10].

The aluminium cenospheres MMFs, produced by stir casting can have variable volume fractions of reinforcement but the distribution of the distribution of the same is inhomogeneous leading to varying properties which are not consistent and lacks repetability of the process for consistent product. The production of aluminium cenospheres MMFs through liquid sintering can produce metal matrix composites with variable amounts of uniformly distributed ceramic particles. However, it has a high production cost and the as-produced syntactic foams often contain structural defects [10].

All the properties of a given material are determined by its microstructure. The critical issue in micro structural development is the densification of the material and coarsening. The micro structural development depends on the parameters such as optimized temperature, sintering time, heating rate and the pressure. The rapid heating rate is the key to produce products with a high sintered density for a given microstructure and grain size compared to slow heating for the same sintered density. Conventional sintering has definite disadvantages accompanied with difficulties since conventional sintered product have differential sintering that give rise to differential densification leading to inconsistent properties. In this context, microwave sintering is an alternative sintering technique to overcome these problems of conventional sintering. Since microwave sintering is a non-contact sintering technique in which heat gets transferred to the product through electromagnetic radiation. By microwave sintering large amount of heat can be transferred to the material's interior which reduces differential sintering to a large extent. The microwave sintered products also have finer micro-structural development, with average grain size and higher density which result in enhanced mechanical properties as compared to the conventionally sintered ones[8]

Microwave sintering effectively assist the forward diffusion of ions which accelerates the sintering. This results in matrix densification by grain growth process. Sintering process aids re-crystallization, grain growth and densification at high temperatures in the body that is being sintered. This densification mechanism is strongly dependent on diffusion of ions between the same sample particles. The mechanism of grain growth rate is assisted by the grain boundary diffusion process. It has been found that intense microwave field concentration is active around the particles of the sample while sintering. The power of

this microwave field between the particles of the sample in the bulk of the material is about 30 times higher than the external field and this is sufficient to ionize the sample particles at its surface. This accelerates ionic diffusion which promotes rapid densification of the material is promoted under microwave sintering. [8]

Apart from the microwave radiation, the surrounding electromagnetic field also effectively enhances the ionic diffusion kinetics near the grain boundaries. The kinetic energy of the ions at the grain boundary increases which thereby decrease the activation energy required for the forward ion jump and in the process increases the barrier height for the reverse jump. This mechanism promotes forward diffusion of the inter grain ions which accelerates the grain growth during sintering, thereby leading to enhanced properties.

5.0 CONCLUSIONS

1. The aluminium powder in the mix does not get converted into alumina (oxide of aluminium) when sintered in microwave or conventional sintering at temperatures above 665° C. The matrix is metallic in all the composition of the foam composites sintered both types of sintering. The microwave sintering has shown that the sintering takes place uniformly throughout the bulk of the material. The sintering process is rapid, has high heating rates, reduced processing times, uniform temperature throughout with minimal thermal gradients.
2. Aluminium metallic foams can be fabricated through powder metallurgy route sintered in microwave sintering which is found to be adoptive & effective rapid sintering method for development of aluminium-cenospheres foams at lower temperatures. The properties of these foam material match with those conventional materials that are being presently used for applications in automotives.
3. The compression strength of the composites containing was found to decrease from 140.3 to 71.7 MPa with the increase in cenospheres content from 10 vol. % to 50 vol. %, for microwave sintered samples. For the conventionally sintered composites the strength reduced from 125.0 to 62.5 MPa. The compressive strength of microwave sintered samples was higher by 12.8 to 22.2 % compared for 10 to 50 vol. % of cenospheres compared to the conventionally sintered samples.
4. The flexural strength of the conventionally sintered composites was seen decreasing from 52 to 8.8 MPa while Flexural strength of microwave sintered composites were decreasing from 71.9 to 31.5 MPa as the cenospheres content increased from 10 to 50 vol %. MW sintered samples showed increased flexural strength by about 23.7 to 72.1 % compared to the conventionally sintered composites.

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