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Research Article

Fabrication of Mg Alloy-CNT Nanocomposite for Automobile Wheel Rim Applications

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Abstract

This Magnesium with its good strength to weight ratio is one of the candidate materials to realize light weight construction, but it has to compete with various other materials. Today's interest in magnesium alloys for automotive applications is based on the combination of high strength properties and low density. For this reason magnesium alloys are very attractive as structural materials in all applications where weight savings are of great concern. In automotive applications weight reduction will improve the performance of a vehicle by reducing the rolling resistance and energy of acceleration, thus reducing the fuel consumption and moreover a reduction of the greenhouse gas CO2 can be achieved. In automobile wheels rotates continuously during propulsion therefore total load on a vehicle induces alternating fatigue stress in a wheel rim. In order to sustain all loads and practical conditions wheel materials must be of good quality. Magnesium is the lightest of all metals used as the basis for constructional alloys. The requirement to reduce the weight of car components as a result in part of the introduction of legislation limiting emission has triggered renewed interest in magnesium. The growth rate over the next 10 years has been forecast to be 7% per annum. Magnesium has a long history in automotive applications. In this project, we are going to make the hot rolled sheet by using the vacuum stir casting furnace and hot extrusion process. Material used for this process is Mg alloy (AZ91)-Carbon Nano Tube and by comparing the properties with the existing wheel rim material.

Keywords: *Magnesium alloy (AZ91), Carbon Nano-Tubes, FEA of wheel rim, Vacuum stir casting process, Hot extrusion process.*

Introduction

There is increasing interest in light weight construction since the automobile industry's commitment to achieve a 25% reduction in average fuel consumption for all new cars by the year 2005 (compared to levels in 1990). Magnesium with its good strength to weight ratio is one of the candidate materials to realize light weight construction, but it has to compete with various other materials. So the different light metals have to compete not only with each other, but also with polymers and steels. Materials selection is thereby determined by economic issues as much as by materials and components characteristics or properties [M. Sabri *et al.*, 2015].

Magnesium alloys have two major disadvantages for the use in automotive applications; they exhibit low high temperature strength and a relatively poor corrosion resistance. The major step for improving the corrosion resistance of magnesium alloys was the introduction of high purity alloys. Alloying can further improve the general corrosion behavior, but it does not change galvanic corrosion problems if magnesium is in contact with another metal and an electrolyte. The galvanic corrosion problem can only be solved by proper coating systems. Beside the galvanic corrosion problems related with magnesium the low temperature strength is another serious problem, limiting the use of magnesium especially for power train applications. The use for transmission cases and engine blocks requires temperature stability up to 175°C and in some cases even 200°C for engine blocks. The new high temperature resistant alloys are under further development and testing. Few alloys are already available in the market [B. K. Raghunath *et al.*, 2012].

Problem statement

From literature survey, we have seen that till today, there is no use of Mg alloy for automobile wheel rim applications. Hence, in this project, the low carbon steel replaced with Mg-Alloy and Material used for this process will be the combination of Magnesium alloy as

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matrix and Carbon Nanotube as reinforcement for the nanocomposite. After extrusion the hot extruded sheet, will be tested for its mechanical properties like Ultimate tensile strength, Hardness, compressive strength and density of the sheet with the existing material property used for the wheel disc. The aim of the project is to reduce the weight of the wheel disc used for the automobile wheel rim application.

Experimental work

A. Material used for hot extruded Sheet (CNTs reinforced magnesium composites)

Developing lightweight and high strength carbon nano-tubes reinforced magnesium matrix composites through rein-forcing magnesium and magnesium alloys by CNTs have be-come a hot research field. The conventional method for developing CNTs reinforced magnesium matrix composites is stir-ring casting. Since the chemical activity of Mg is high, it can react with many elements easily. When use stirring casting method, the harm from magnesium melt to CNTs is slight [Sourav Das *et al*., 2014]. Magnesium alloys have been increasingly used in the automotive industry in recent years due to their lightweight. The density of magnesium is approximately two thirds of that of aluminum, one quarter of zinc, and one fifth of steel. As a result, magnesium alloys offer a very high specific strength among conventional engineering alloys. In addition, magnesium alloys possess good damping capacity, excellent castability, and superior machinability. Accordingly, magnesium casting production has experienced an annual growth of between 10 and 20% over the past decades and is expected to continue at this rate. However, compared to other structural metals, magnesium alloys have a relatively low absolute strength, especially at elevated temperatures. Currently, the most widely used magnesium alloys are based on the Mg-Al system [S. Ganesh and Dr. P. Periyasamy *et al*., 2014].

Their applications are usually limited to temperatures of up to 120◦C.Further improvement in the high-temperature mechanical properties of magnesium alloys will greatly expand their industrial applications. During the past decades, efforts to develop high temperature magnesium materials have led to the development of several new alloy systems such as Mg-Al-Ca, Mg-Re-Zn-Zr, Mg-Sc-Mn and Mg-Y-Re-Zr alloys. However, this progress has not engendered extensive applications of these magnesium alloys in the automotive industry, either because of insufficient high temperature strength or high cost [N. Satyanarayana & Ch. Sambaiah *et al*., 2012].

B. Finite Element Analysis

Steps for finite element analysis

- Preprocessing
- Creating the model.
- Defining the element type
- Defining material properties
- Meshing
- Applying loads
- Applying boundary conditions
- Solution: Assembly of equations and
- Obtaining solution

Post processing: Review of results.

Modelling

Figure shows the model of automobile wheel rim before optimization.

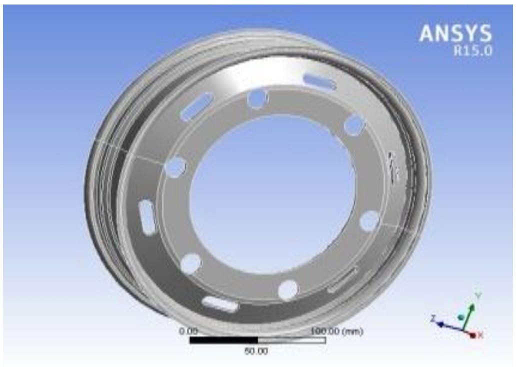


Fig.1 Modelling of Wheel Rim

Meshing

Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the Standard mesh because of wheel structures, so that shape of the object will not alter. The meshing for wheel rim is shown in figure 4.2.
No. of nodes-46549
No. of elements-23466

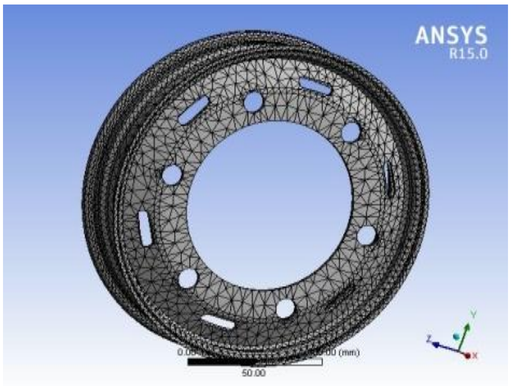


Fig.2 Meshing of model

Boundary Condition

The boundary conditions applied are inflation pressure around the wheel bead and fixed support are given at nut bolt hole as shown in fig 3.

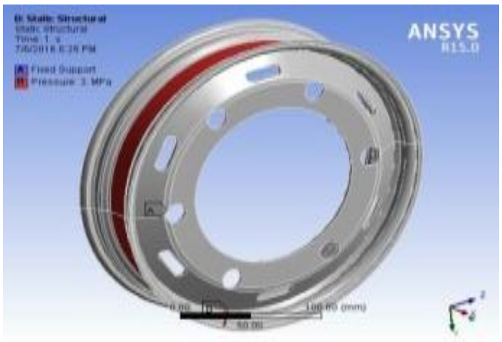


Fig.3 Boundary Condition

Total Deformation:

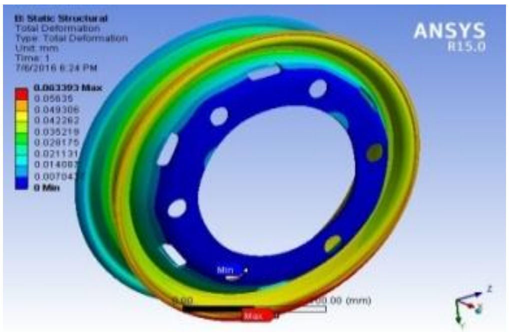


Fig.4 Total deformation 0.063393 mm with Low carbon steel

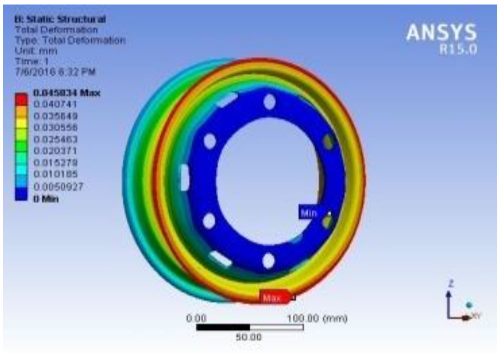


Fig.5 Total deformation 0.045834 mm with Mg-alloy

Von misses Stresses

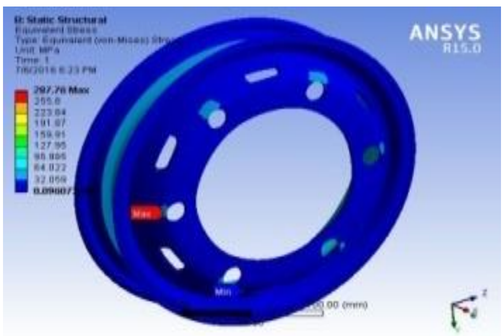


Fig.6 Max. Stress generated 287.76 MPa with Low Carbon Steel

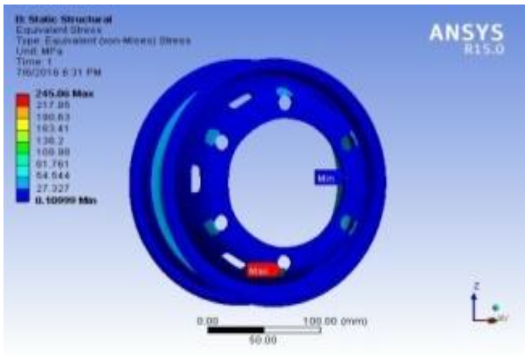


Fig.7 Max. Stress generated 245.06 MPa with Mg alloy

Table 1 Results of FE Analysis

Material	Von mises stress (mpa)	Total deformation (mm)
Low Carbon Steel	287.76	0.063393
Mg alloy	245.06	0.045834

Conclusion-From FE Analysis, it has been noticed that the values of total deformation and von-misses stresses developed in Mg alloy is less than the total deformation and von-mises stresses developed in Low carbon steel (Existing wheel rim material).

C. Vacuum Stir Casting Furnace

In a stir casting process, the reinforcing phases are distributed into molten matrix by mechanical stirring. Stir casting of metal matrix composites was initiated in 1968, when S. Ray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders.

Fig.10 Vacuum Stir Casting Furnace

Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30%volume fractions of reinforcement .The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement.

Results of Vacuum Stir Casting Process

Fig.9 Magnesium block (Before process)

Fig.10 Magnesium rod (After process)

D. Hot Extrusion Process

A compression forming process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape. Keeping the processing temperature to above the recrystalline temperature. Reducing the ram force, increasing the ram speed, and reduction of grain flow characteristics. It is the process by which a block/billet of metal is reduced in c/s by forcing it to flow through a die orifice under high pressure. In general, extrusion is used to product cylindrical bars tubes or for the starting stock for drawn rod, cold extrusion or forged products.

Fig.11 Hot Extrusion Setup

Most metals are hot extruded due to large amount of forces required in extrusion. Complex shapes can be extruded from the more readily extrudable metals such as aluminum. The products obtained are also called as extrusion. The c/s shape of the extrusion is defined by the shape of the die. Due to the high temperatures and pressures & its detrimental effect on the die life as well as other components, good lubrication is necessary [E.H.Han *et al*., 2009].

Hot extrusion die

Fig.12 Solid model of hot extrusion die

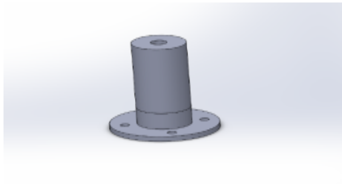


Fig.13 Mg rod before extrusion

After machining the Mg-alloy rod diameter is reduced from 40mm to 30mm for next hot extrusion process.

Fig.14 Extruded sheet after extrusion

Results & Discussions

Tensile Testing

The engineering stress-strain curve specimens used in a tensile test are prepared according to standard specifications. The test pieces are cylindrical. It is gripped at the two ends and pulled apart in a machine by the application of a load.

From tensile testing we get values of yield strength, ultimate tensile strength, % elongation.

Yield strength is calculated from yield load.

$$\%\ Elongatio = \frac{\text{(deformation length}-\text{original length)}}{\text{original length}}$$

Fig.15 Specimen for tensile testing

Fig.16 Tensile testing break specimen

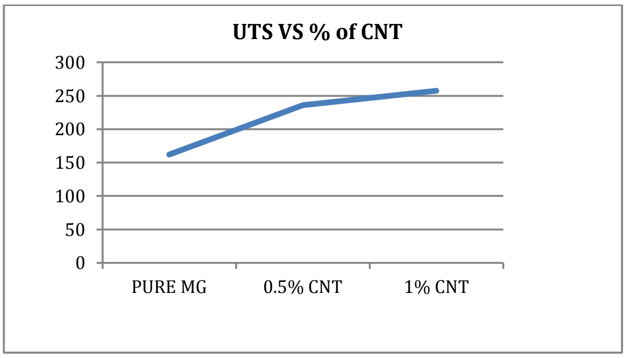
Tensile Testing Results

Ultimate Tensile strength

It is found that the tensile properties of Magnesium matrix are improved with reinforcement of MWCNT. It is found that tensile properties increasing up to 0.5 % of MWCNT and further goes on decreasing with increasing CNTs%. This is happened due to agglomeration of CNTs.

Table 2 Ultimate Tensile strength of specimen

Material	UTS of Sample 1 (MPa)	UTS of Sample 2 (MPa)	Avg. value of UTS (MPa)
Pure Mg	155.36	168.4	161.88
Mg alloy AZ91+0.5%CNT	241.23	230.65	236.01
Mg alloy AZ91+1%CNT	260.38	269.14	264.76



Graph 1 UTS Vs % of CNT

Table 3 Yield stress of specimen

Material	Yield stress of Sample 1 (MPa)	Yield stress ofSample 2 (MPa)	Avg. value of yield stress(MPa)
Pure Mg	148.59	145.33	146.96
Mg alloy AZ91+0.5%CNT	212.03	199.38	205.70
Mg alloy AZ91+1%CNT	209.36	249.49	229.42

Table 4 Percentage elongation of specimen

Material	Elongation of Sample 1	Elongation of Sample 2	Avg. value of elongation
Pure Mg	2	1.9	1.95
Mg alloy AZ91+0.5%CNT	2.4	2.5	2.45
Mg alloy AZ91+1%CNT	3	3.2	3.1

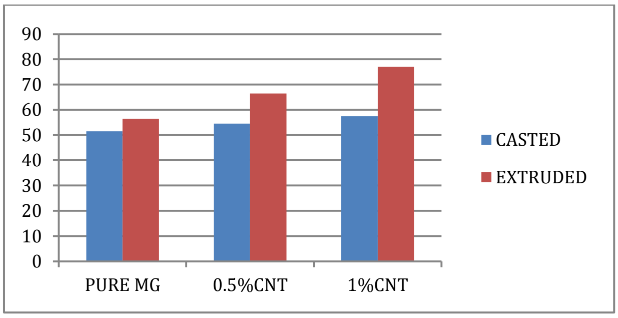
Hardness testing

Table 5 Hardness of specimen before extrusion

Material	Hardness of Sample 1 (HRB)	Hardness of Sample 2 (HRB)	Avg. value of hardness (HRB)
Pure Mg	60	61	60.5
Mg alloy AZ91+0.5%CNT	62	62	62
Mg alloy AZ91+1%CNT	64	64	64

Table 6 Hardness of specimen after extrusion

Material	Hardness of Sample 1 (HRB)	Hardness of Sample 2 (HRB)	Avg. value of hardness (HRB)
Pure Mg	63	64	63.5
Mg alloy AZ91+0.5%CNT	67	69	68
Mg alloy AZ91+1%CNT	74	76	75



Graph 2 Hardness Vs % of CNT

Density Testing

Experimental density is calculated by using the Archimedes's Principle. When an object dipped in liquid there is an upward force produced by the liquid bon the object. This force exists because of pressure in the surrounding liquid increase with depth below the surface.

Fig.17 Density Measurement

Table 7 Density of specimen

Sample	Density(gm/cm³)
Pure Mg	1.4708
Mg alloy+AZ91+0.5%CNT	1.5933
Mg alloy+AZ91+1%CNT	1.7902

Table 8 Comparison of properties (Low carbon steel & Mg alloy-CNT)

Material	Ultimate tensile strength, (MPa)	Yield stress, (MPa)	Density, (gm/cm^{3})	Hardness, (HRB)
Low carbon steel	280-380	240-290	7.8	78 – 82
Mg alloy AZ91+1%CNT	264.76	229.42	1.7902	75

Conclusions

1) The hot extruded sheet of Mg alloy-CNT can be done by using vacuum stir casting furnace and hot extrusion process with weight fractions of MWCNTs 0.5%, and 1% were added to the matrix of Mg alloy.
2) From FE Analysis on ANSYS software, total deformation (0.045834 mm) in Mg alloy is less than the total deformation (0.063393 mm) in low carbon steel.
3) Max. stress generated in Mg alloy (245.06 MPa) is less than the max. stress generated in low carbon steel (264.76 MPa) for the same pressure.
4) From tensile testing and hardness testing, Values of Ultimate tensile strength (264.76 MPa) & hardness (76 HRB) of Mg alloy-CNT is very near about to the values of ultimate tensile strength (280-380 MPa) & hardness (78-82 HRB) of low carbon steel.
5) Density (1.79 gm/cm^{3}) of Mg alloy is much less than the density (7.8 gm/cm^{3}) of low carbon steel.
6) From above results, it has been noticed that the Mg alloy-CNT Nanocomposite is the best suitable material for the two wheeler vehicle.

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