Characterisation of Tribological, Mechanical And Microstructurality of Magnesium Based Functionally Gradation AZ31D Incorporated With Titanium Carbide/Carbon Fiber Four Wheeler Steering Yoke Fabricated Through Powder Metallurgy

Karuna kumar G [1]; PNS Srinivas[2] · Dr. K.Syam Sundar[3] , M.Bharath Kishore[4]

[1]Assistant professor, Mechanical engineering Department, Seshadrirao Gudlvalleru engineering college, Gudlavalleru, Krishna district, Andhra Pradesh-521356;

[2]Associate professor, Mechanical engineering Department, Vikas College of Engineering, Nunna, Vijayawada, Andhra pradesh

[3]Controller of examinations; Seshadrirao Gudlavalleru engineering college; Seshadrirao knowledge village; Gudlavalleru; Andhra Pradesh; India-521356

[4]Seshadrirao Gudlavalleru engineering college; Seshadrirao knowledge village; Gudlavalleru; Andhra Pradesh; India-521356

Abstract

The research work emphasizes to synthesize an AZ31D magnesium alloy based steering yole composite with reinforcement titanium carbide (TiC) and carbon fiber in weight proportions of 2, 4, 6 and 8 % using automation equipped powder metallurgy technique. The micro structural implications of AZ31D/TiC/CF steering yoke had undergone through mechanical, microstructural and tribological characterization through the use of specified equipments as per ASTM-391 standardization. With the enhancement of titanium carbide there is a appreciable increase of grain size AZ31D Mg matrix FGM (functional graded material). The TiC has also performed as an prominent element in the momentous changes with regards to microstructural behavior of AZ31D FGM (functionally graded materials) steering yoke composites. The prominent increment in the mechanical and tribological properties is been excellently executed with the increase of addition of carbon fiber of particulate size of 65 microns and the micro hardness of 125VHN and wear rate at its maximum amount of 34 microns operating at 15 m/s is achieved. Further the addition of carbon fiber not only improves the surface properties but also increased the thermal conductivity behavior of FGM. The AZ31D composite with 6% TiC reinforcement depicts that the highest compressive strength of 415.86 MPa. The hardness of AZ31D FGM composite is increased by 32% by the addition of 6% TiC / 8% carbon fiber reinforcement particles. The fractured tensile specimen surfaces of the alloy and the FGM composite are investigated with respect to the fracture failure analysis and depicted that they are capable to withstand a cyclic load of 785 KN. The uniform dispersion of refined TiC and carbon particles and the efficient load distribution between the reinforcements and the matrix elements appears to be playing an extravagant role in the high improved mechanical, micro structural and impact properties of AZ31D functionally gradation composite in turn results in the enhancement of properties of steering yoke used in automobile applications.

Keywords: AZ31D composites, TiC reinforcement, carbon fiber, tribology, SEM spectroscopy, microstructural behavior, compressive strength, steering yoke.

Introduction

The technological world's applications, initiating from domestic to commercial demands, raise production obstacles, which in turn proposes the development of innovative and sophisticated materials. The use of composite materials in the automotive industry has successfully paved the way for the development of newer materials with characteristics like low weight, high strength, and durability, as well as low cost and availability. These smart materials satisfy the demanding industrial applications. Functionally graded materials are a category of advanced composites inspired by metal matrix composites that fill in the gaps and shortcomings of composite materials in a variety of applications, from residential to industrial. These materials designated as functionally gradation materials (FGM), prevent the development of residual stresses and the abrupt interface when material characteristics change, delamination, and debonding, which is treated as the major deficiency and critical in failure criterion of composite materials. There is a significant need in the development and dependability to enhance vehicle efficiency and engine redesigning in the automotive industry due to various advancements and customer stringent requirements. The choice of materials plays a prominent role in the creation of practical, affordable, and environmentally responsible products and services [1,2]. The four wheeler segment apart from other segments in automobile sector is a high demanding and has potential futuristic growth industry which has a high customer demand and requirements. The present research work is focused on development of four wheeler steering yoke due to the reason that in spite of many significant components in automobile such as piston, connecting rod, crankshaft etc the most important role playing automobile component in steering system is steering yoke which fails initially when the steering system is damaged or worn out and also behaves as a barrier to stop the vehicle and human loss. To overcome the deficiencies in steering system steering yoke should be manufactured through advanced manufacturing process apart from present practiced manufacturing systems which not only eliminates the deficiencies in the conventional manufacturing process, increases the reliability of steering system but also saves human life from accidents and hazardous situations. The research concentration on selection of materials is magnesium materials apart from steel and its alloys due to the fact that magnesium is treated as an alternative sophisticated method for cast iron, polymer composites, aluminium alloys, steel and composites. Pure magnesium when used in the purest form without any reinforcements yields poor mechanical & tribological properties as it possess low density and susceptible to heat and brittle in nature. Aluminium and Zinc are employed as alloying components in magnesium material which then improves its mechanical and tribological properties. AZ31 is an magnesium alloy which is available in market and has significant casting and mechanical properties [3,4].

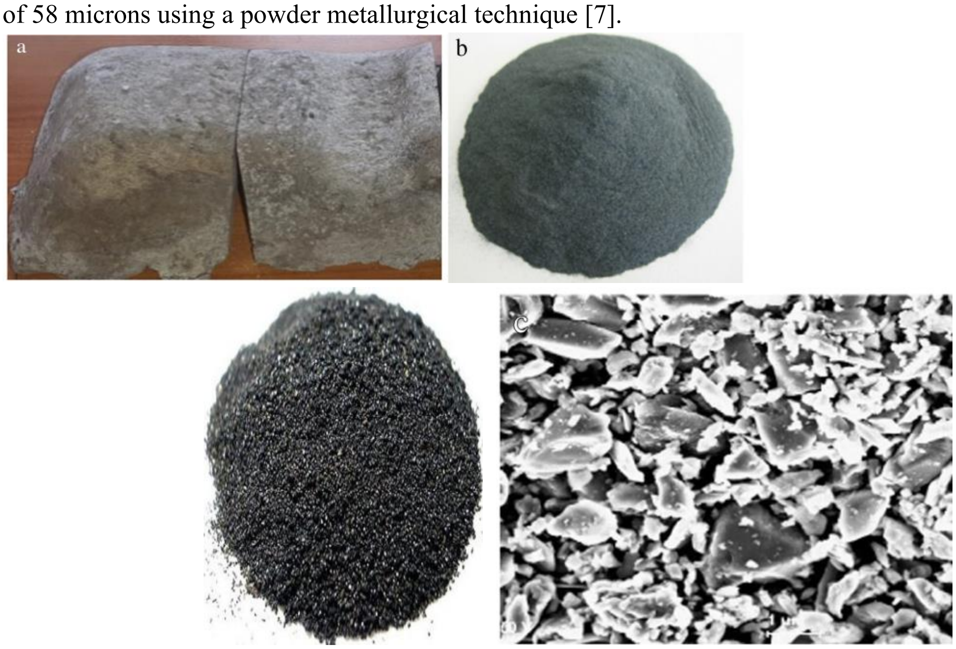
Several manufacturing methods such as powder metallurgy equipped with particulate insertion, powder coating techniques, powder sintering metal spray dispersion and stir casting are adopted as smart manufacturing systems as per automobile sector manufacturing standards. Commercial methods, such as the stir casting method, are suitable for layer-wise deposition of the matrix and the reinforcing elements, but they have many limitations and manufacturing challenges when producing gradation-wise materials, where the matrix and the reinforcing elements should be either in increasing or decreasing manner and to produce desirable and functional properties at the specified location makes the manufacturing process cumbersome in nature. The material's characteristics can be changed at any time or location to perfectly achieve its desired mechanical, microstructural, and tribological qualities while also maintaining the material's economics. When compared to powder metallurgy, stir casting has a higher production rate, but the manufactured components specifically composites, have uniform material properties that cannot be changed or enhanced and become homogenous rather than heterogeneous compounds. The development of FGM composites by the stir casting process is the subject of ongoing research; however the technique is not yet standardized or widely available. The choice of the process variables and the mixing of the materials is a crucial task, and the composites [5,6] that are claimed to be FGM have not been validated in terms of the microstructural and other characterisation processes. Due to their outstanding mechanical, thermal, and electrical conductivities, magnesium-based compounds are becoming increasingly popular in today's technological world. Out of all the techniques mentioned above, the production of FGM steering yoke composite finally proposed the powder metallurgy approach with some unique attachments (Auxiliary, sensor and feedback systems). In our research, we developed an extensive and unique technique that highlights the systematic manufacturing process in terms of powder metallurgy with automatic feed back and sensor mechanism which controls and give regular intervals of compaction and ejection loading to the die as well as validates process parameters of the magnesium-based functional graded composites. The research progression in the magnesium-based gradation material is highlighted in the literature review in a very low manner and the manufacturing process and its methodological plan from selection to materials till the reliability of product is discussed in an negligible amount so far as per the literature survey is conducted.

Material Selection and Manufacturing Methodology

Materials

The most important step in the manufacturing process is choosing the matrix material, which is AZ31D magnesium material, which is commercially available in the market as an ingot compound. This complex compound is purchased from Venuka Engineering Private LTD, Hyderabad. Table 1 lists the elements that make up the matrix compounds with respect to individual weight percent of elements. This work is mainly emphasized to consider TiC(titanium carbide) particles and nano sized carbon fiber are added as reinforcing particulates to the AZ31 Mg alloy compound shown in fig 1. TiC and carbon fiber reinforcements are been procured from Krish Met Tech Limited in Chennai and the reason to choose these particular materials is that titanium carbide is an excellent ceramic material used in super conductive materials and also used in space research vehicles due to its high density and low wear rate ,reliability and on the other hand carbon fiber is chosen to generate specific tensile and fracture and fatigue bearing capabilities. The micro structural behavior of matrix and reinforcements such as AZ31D, TiC and carbon fiber(CF) morphological images through scanning electron spectroscopy (SES or SEM) is shown in Fig. 1, elemental composition stated by the supplier is being checked and verified from the supplier end using EDS (electron dispersive spectroscopy) in Fig. 3.

One of the reinforcing compounds titanium carbide particles has fine surface texture and average grain size of 58 microns using a powder metallurgical technique [7].



(C) *(d)*

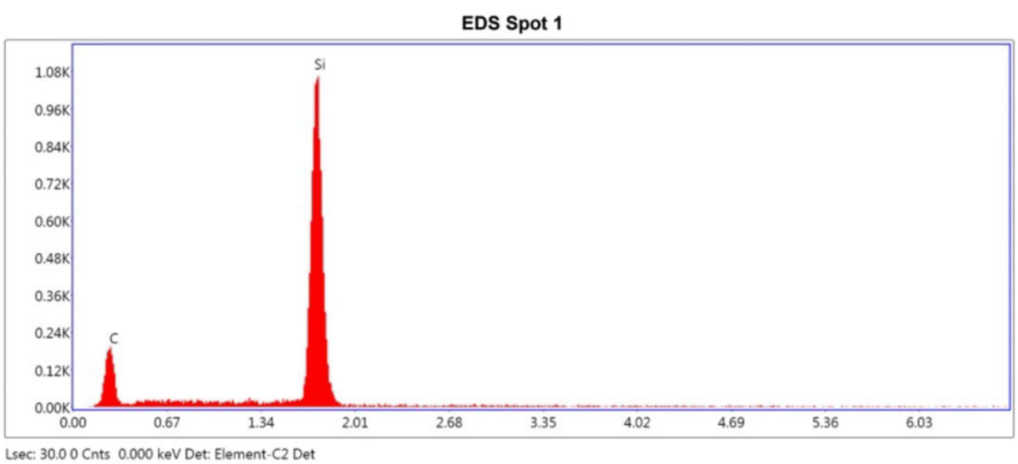
Figure 1: (a) AZ31D ingot (b) Silicon carbide (c) Nickel (all are in powdered form) (d) Silicon carbide morphology through SEM image

Table 1: Elemental chemical composition of AZ31D Mg alloy

Elements	Al	Zn	Mn	Cu	Fe	Ni	Si	Mg
Wt%	3	0.98	0.2	0.02	0.02	<0.001	<0.01	Remaining

Manufacturing of FGM

***Figure 2: (a) Computerised compaction machine (b) AZ31D magnesium FGM* specimens with reinforcements**



eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	34.16	54.82	43.28	13.93	0.0668	1.1153	0.9545	0.1753	1.0000
SiK	65.84	45.18	325.32	3.26	0.6152	0.9369	1.0182	0.9955	1.0020

Figure 3: EDAX image of SiC reinforcement in AZ31D FGM

Utilizing cutting-edge powder metallurgical techniques apart from the conventional powder metallurgy equipment here there is a special provision of auxillary attachment such as computerized view of the compaction as well as ejection process through micro level animation of the specimen to be produced and alarming system giving a buzzer or other indications when the FGM has deformities or any disturbances in process parameters are occurred. There is also provision of automatic sensing and feedback analysis of the process with the size and diameter of the FGM green compacted specimen composites are manufactured. The FGM specimens synthesized are designated as green compacted since there are soft and brittle as it's a solid bonding furnace below the recrystallisation temperature such as cold working process. Ball milling apparatus is used to breakdown the AZ31D ingot material into fine powdered form of required grain size thereby to have desirable manufacturing and characterization techniques, with a grain size of 120 microns, in preparation for usage in powder metallurgy. The ball mill is chosen with great care because it is essential to the manufacturing process. After blending process we proceed to compaction process which is crucial and prominent in the preparation of FGM specimens in layer wise deposition since there should be variant in material properties in an increasing or decreasing manner as we process from top to bottom or from bottom to top in layer wise volume gradient. A system of automatic monitoring and feedback controls process parameters such mixing time, temperature, and particulate size is adopted in compaction and ejection process. To prevent chemical reactions during the matrix and reinforcement's compaction stage, the powders are then taken in fine form and silicon spraying (ASC-350 spray unit) is carried performed. Preheating the compaction die reduces compaction and ejection flaws and cancels out various gases and removal of dust, dirt and also environmental waste which could present in the air. Using a digital weight scale, the matrix AZ31D and the reinforcements TiC and carbon fiber are weight proportionally calculated, and the determined combinations as per rule of mixtures are then placed in separate airtight containers to eliminate oxidation and other chemical reactions. The reinforcements are then added in accordance with the weight proportions shown in table 1 after the matrix compound has been initially introduced and slammed in the compaction die in regular intervals so as to ensure layer wise deposition of matrix and reinforcements to produce functional gradation specimens. Both the compaction pressure and the ejection pressure are kept at 578.25 MPa and 10.27 MPa, respectively. Since the compaction strength of FGM composites heavily influences following processes like sintering and material characterization. The specimens manufactured having the dimensions of 40mm diameter and 10mm thickness. The green compacted specimens are then sintered in a high tubular furnace that is kept at 585°C for 250 minutes before being gradually cooled over duration of 24 hours in the ambient atmosphere. In order to have natural increase in the composite's hardness and prevent the formation of defects, flaws, and structural deformities [8] sintering operation is performed. Strength, hardness, and nullification of internal stress are all greatly improved by the sintering process and thus making ready for the characterization process. Since the green compacted specimens are brittle in nature and they break and deform easily upon the characterization process making them null and void for further development in manufacturing and property validation.

Micro structural characterization

To have deeper analysis of molecular bonding and the grain formation of the matrix with respect to the reinforcements, it is examined on both reinforced and non-reinforced FGM composites. The manufactured dry compacted FGM specimens are polished to a flawless high polished surface finish quality using polishing sheets 1/0, 2/0, 3/0, and 4/0. All of the FGM specimens dipped in etchant ethanol solution (20 ml of distilled water, 90 ml of 95% ethanol, 7.5 g of picric acid) to nullify the oxidation and carbide compounds to have better microstructure through SEM morphological imaging. Electron back scattered diffraction microscopy (EBSD) was used to examine the micro structural grain refinement by analyzing the elemental composition and also to check the formation of foreign materials, chemical decomposition of matrix with the reinforcements are within the same elements and the formation of oxides and carbides.

Mechanical characterization

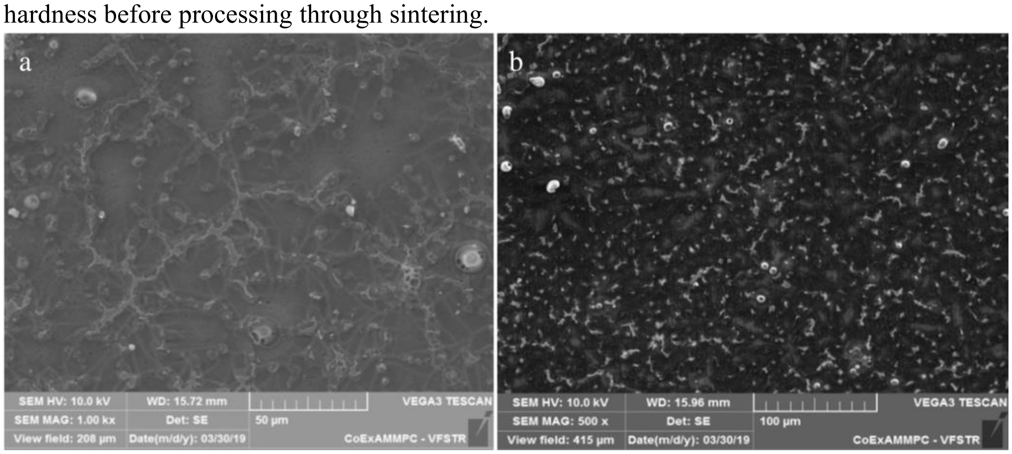
The hardness of FGM are analyzed in terms of macro and micro scale by the usage of equipments such as Brinell harness tester, Rockwell hardness tester of macro hardness determination and the micro scale with the aid of Vickers hardness tester. A dwell time of 25 seconds is considered for an application of 175g of load and micro hardness is characterized. The determinations of tensile and compressive strength are performed on INSTRON 8812 UTM for linear velocity of 3mm/min at room temperature conditions.

Results & Discussion

Microstructural analysis

As depicted in Figure 4, to assess the micro structural bonding of matrix and the reinforcements within the molecular structural this characterization plays a crucial role in the validation of the manufacturing process. This technique emphasizes that the secondary phases of the grain boundaries of the reinforcements are in aligned with the dendritic phase formation of the magnesium metal depicted through SEM microscopic image the formation of interdendrite structures within the pores of the FGM composite are depicted through Figure 4.The formation of null and void agglomerations within the FGM structure shows clearly that there is an uniform dispersion of reinforcements into the matrix phase and very less formations of cracks and deformities are as symbol of accurate control of process parameters during the manufacturing process. Figure 4(b,c) points the microscopic images containing titanium carbide in 4% weight proportion and also the combination of titanium carbide and carbon fiber (2%) in equal proportions. Figure 4(d) shows the interfacial region between the matrix and the reinforcements with 96% of AZ31D and 4% TiC shows a layer wise volume gradation material property phase separation. Chemical characterization with respect to material composition in being analyzed through EDS evaluation of the reinforced FGM. The gradual dispersion of titanium in gaseous dispersion throughout the compaction process designated as peaks during the image detection as depicted in figure 5.

The usage of silicon spray during the compaction process makes FGM to withstand against fracture and crack propagation as it's a serious issue which causes ultimate failure of the material which is treated as one of the limitation of the powder metallurgy. This allows the FGM specimens to achieve pre strength and hardness before processing through sintering.



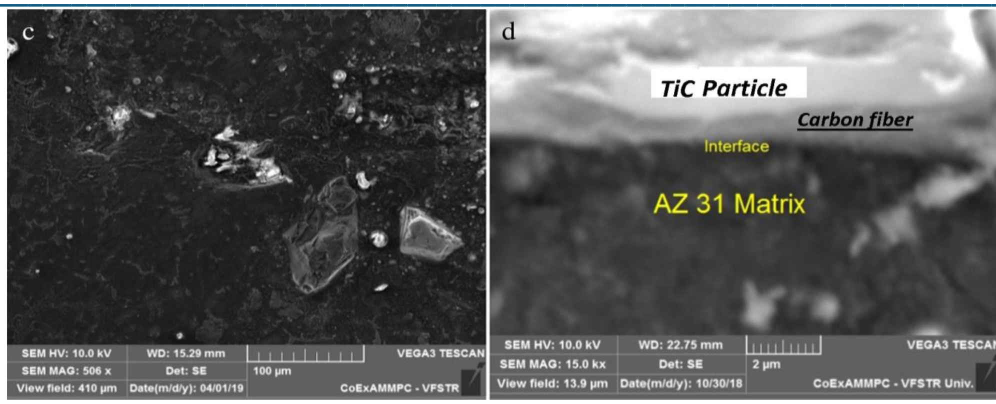


Figure 4 (a) SEM image of AZ31D alloy (b) SEM image of AZ31D with 4% Tic © SEM image of AZ31D with 2% TiC & 2% CF (d) SEM image of 4% TiC

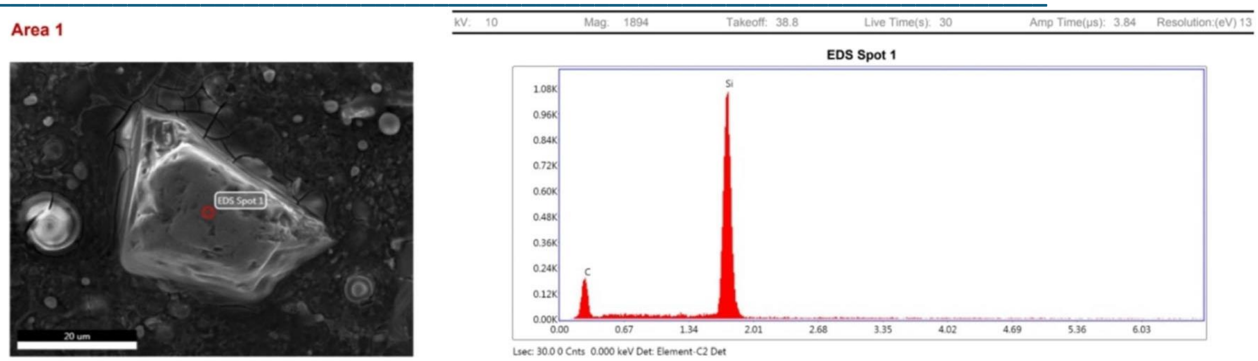
Electron back scattered diffraction analysis (EBSD)

The shift of axis pattern from the central bond within its microstructure is been determined with the aid of EBSD evaluation for the synthesized FGM and the ingot of magnesium AZ31D alloying material as shown in Figure 6.Eventhough how finer form the matrix and the reinforcements are utilized but there is a coarse grain structure formation at the interstitial micro level boundary formation when these materials are being combined below the recrystallisation temperature. There is a shift of energy from the matrix to the reinforcement's particulate which is analyzed by EBSD images as there is a drop of chemical composition of the matrix. There is an representation of angular deformities greater than 230 degrees in the AZ31D alloy within its grain boundaries. The formation of lower grain size of acceptable range within less porosity structure itself suggests that there is a considerable decrease in the misorientations. The transformation of disorientations from 230 to 75 shows a greater refined structure of the FGM structure in the separable region. The decrement of misorientations be therefore suggests that there is high enhancement of strength and hardness in the boundaries as well as the interfacial region.

Transmission electron microscopy analysis

The evaluation of the microstructural grain structure within the molecular structure and the transformational phase from tetrandite to metadendritic structure. The important phase transformations and misalignment is detected through small imaging spectroscopy designated as transmission electron microscopy (TEM). Since this phases are crucial in determining the microscopic images in combination of misalignment and errors during the microstructure development. The solidification at a rapid rate is been investigated as the phase of $Al_2Mg_5Zn_2$ which existed at the melting region at eutectic point in the gaseous form formed as a precipitate from the solid alloy metal.

The phase and grain transformational change evaluation and analysis for the formed FGM is been investigated by TEM which is shown in Figure 5.



eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	34.16	54.82	43.28	13.93	0.0668	1.1153	0.9545	0.1753	1.0000
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Figure 5: EDS microscopy image of AZ31D alloy with SiC reinforced FGM

Microscopic images of AZ31D alloy with three layered grain boundary formation depicted through microstructural analysis through SEM shows that there is a greater enhancement of mechanical properties such as compressive strength and hardness. Morphological images of FGM specimen with 6 different weight proportions are been analysed as per the dislocations in the granular structure depicts the low porosity due to the perfect bonding of the matrix and the reinforcement constituents leaving behind ambiguities in manufacturing process which is shown in figure.

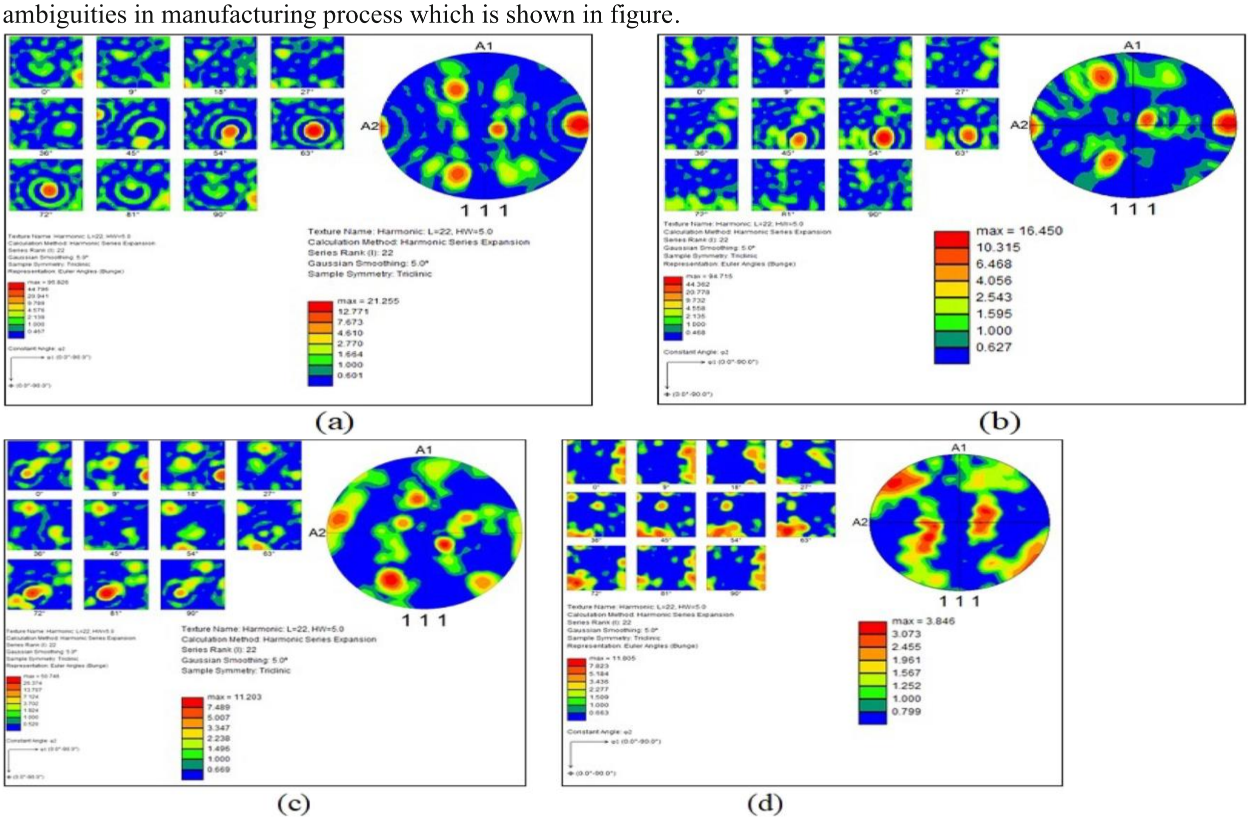

Figure 6: EBSD images for (a) AZ31D magnesium alloy (b) 2% SiC weight reinforcement FGM (c) 2% SiC weight +2% Ni FGM (d) 4% SiC weight FGM composites

Figure 7: TEM microscopic image sample preparation polishing system

Mechanical characterization analysis

The mechanical characterization initiates with the determination of densities of the FGM specimen through computerized density apparatus which is depicted in table 2 with respect to theoretical and calculated densities of magnesium alloy and FGM composites. FGM structures with low are an indication of successful manufacturing methodology. But when we compare the calculated densities through apparatus found to have lower value than the literature survey.

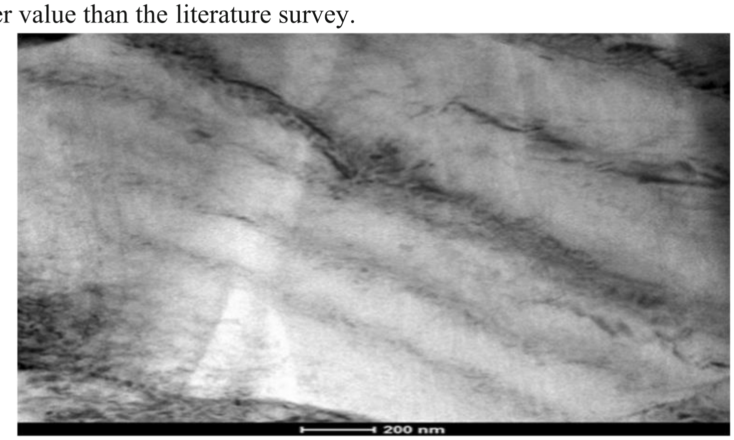

Figure 8: TEM microscopic image of 4% SiC reinforcement and particulate matrix reinforcement interfacial zone

Compressive strength evaluation

The enhancement of titanium carbide increased the compressive strength of FGM which is analyzed through the values found out by compression testing machine due to the impingement of carbide into the pores of magnesium matrix. The development of the granular structure of the reinforcements namely the titanium carbide and the carbon fiber and also the interfacial region between the matrix and reinforcements forms a basis for the increase of FGM compressive strength. Table 3 displays the behavior of titanium carbide particle in compressive strength enhancement of FGM. The interfacial bonding between the matrix and the reinforcements mainly the TiC and carbon fiber has reached a significant degree. A value of 189.75 MPa is been depicted as the peak value for AZ31D alloy with representation of compressive strength. But when its performed on FGM composites results in a maximum value of 397.25 MPa for 6% weight TiC and 2% carbon fiber with an error of +/-5% of all measured FGM. The reduction of ductility is mainly due to the impingement of ceramic reinforcements and hence tensile strength of the FGM decreases and raises the compressive strength.

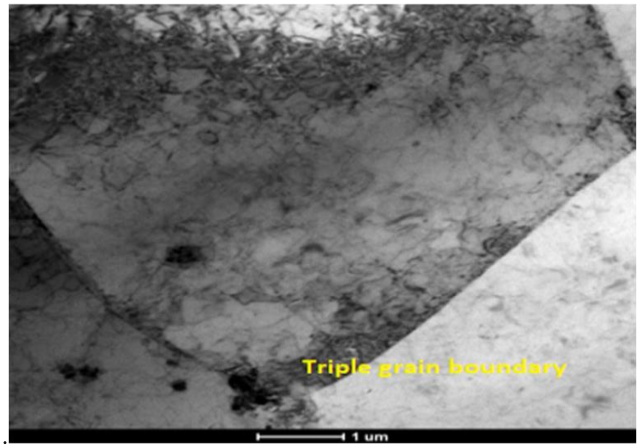

Figure 9: Triple boundary interfacial region of AZ31D Magnesium alloy

Macro and Micro structural Hardness

Table 3 shows the microhardness for the alloy and the various weight ratios of the reinforcements. The samples are produced in accordance with ASTM E10 standards. It was shown that increasing the number of reinforcing particle fractions improved hardness. At its microstructural region, the hardness value of pure AZ31D alloy is calculated to be 70.59 VHN. However, whilst the value is increased to 82.69 VHN by including only titanium carbide particles at a 6 percent weight level, the micro hardness is increased to 97.28 VHN when both titanium carbide and carbon fiber are included. On a FGM specimen, measurements are made using an average of 5 tests with a load of 150 grams. The graphical interface of hardness variations for the alloy and FGM composite is shown in Figure 13. The addition of TiC reinforcements with their homogeneous dispersion into matrix area elements is what has caused the hardness value to increase. The increase in hardness, which is confirmed by EBSD spectroscopy, illustrates the microstructural grain refinement of the structures.

Table 2: The density of AZ31D alloy and FGM composite their respective densities

Material	Measured density(g/cc)	Theoretical density(g/cc)
AZ31D Mg Alloy	1.787	1.82
AZ31D +2% TiC	2.83	2.84
AZ31D +2% TiC+2% CF	2.854	2.842
AZ31D +4% TiC+4% CF	2.876	2.869
AZ31D +4% TiC	2.849	2.867

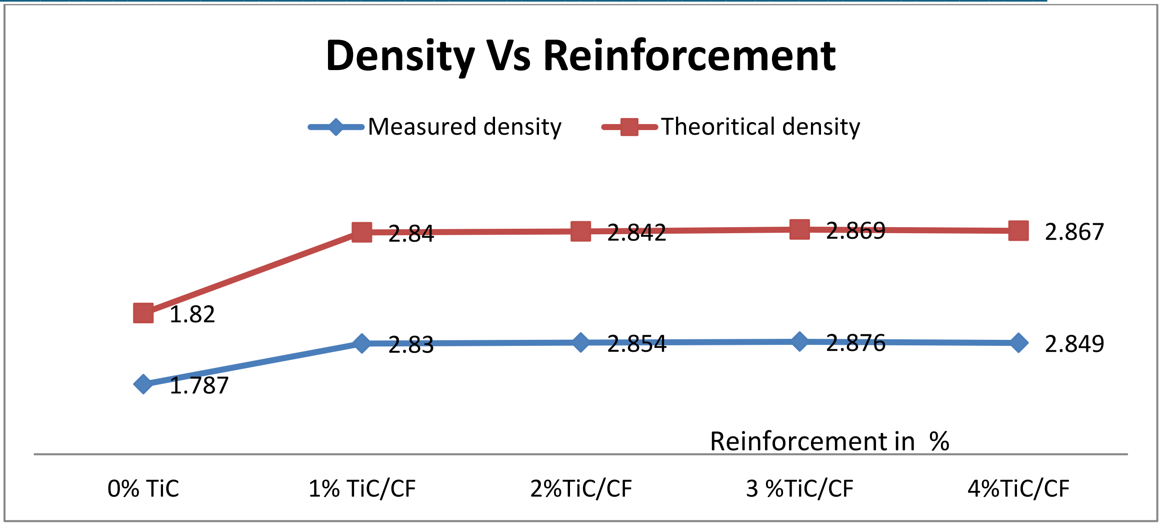

Figure 10: Graphical representation of Density variations in composites Vs Reinforcement wt %

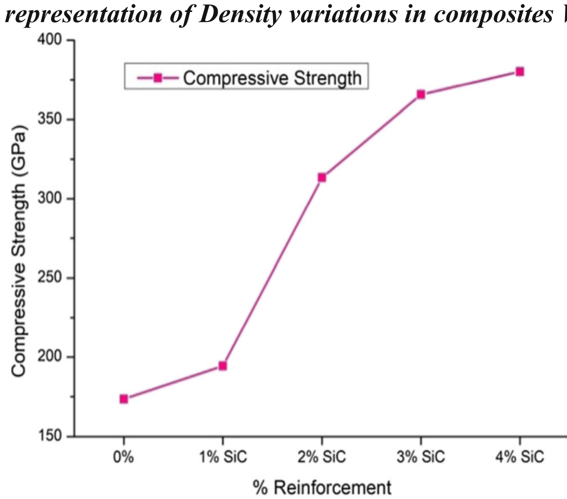

Figure 11: Graphical representation of Comparison of compressive strength Vs Reinforcement

Tensile strength characterization

To assess the ductile nature of the FGM specimen they are extensively delivered through universal testing machine(UTM) which is a universally adopted machine and its universal because it is treated as the first test which should be done for all known materials or new materials which will then will be a validation for its manufacturing process. Due to the limitations in actual size of specimen we are using extensometer attachment in UTM INSTRON testing apparatus. According to ASTM standardization they are strength characterized as per sub category E9 which is depicted in figure 12 (a & b). Figure 12(b) shows for compressive strength. The plots between stress and strain are generated in an automatic manner as it's equipped with data acquisition system. The depiction of the values are been represented in Table 3 designates the tensile strength. Out of all material compositions FGM with 6%TiC/4% CF results in maximum tensile strength of 890 MPa and also showed considerable ultimate and yield strength.

(a) (b)

Figure 12: (a) Tensile test using Instron machine (b) Compression test machine test Rig

When we analyze table 3 it clearly depicts that FGM specimens exhibits excellent tensile properties when compared with the initial alloy material which is taken as matrix material namely the magnesium metal. Defau et.al [9] in his research investigations on the manufacturing of FGM has analyzed that by the addition of titanium carbide increases the load bearing capacity as 60% of load or stress is transferred from the matrix to the reinforcing agents. In his research findings he also depicted that by the addition of 6% TiC there is an enhancement of 25% in the matrix material of tensile and compressive strength.

Kim et al. [10,13] in his research investigations on Al6061 combined with silicon carbide grains found out that there is an significant increase of volume fraction of prepared functional composites which further analyzed impacted the modulus of elasticity. Samuel et al. [12] has done extensive research on FGM synthesis and depicted that decrease in tensile strength of final specimens is due to the increase in compressive strength of the reinforcing constituents such as ceramic constituents namely titanium, zirconium and silicon. Even though how controlled process parameters there are formation of crack like deformable structures and porosities which ultimately leads to the failure of the component which is analyzed in fracture analysis which is depicted in figure 15. The crack deformities and grain dislocations are depicted when there is an reinforcement of titanium carbide in weight proportion of 4%. SEM microscopic images depicts that addition of TiC and carbon fiber particulates enhances the tensile strength as the fiber particles spreads into the molecular structure of matrix material.

Rohtagi et al.[12] came to the conclusion that the dynamic strain hardening[14,15] in the vicinity of the matrix is caused by the underlying phases of the deformation zone. The final fracture of the composites is also caused by a ductile mechanism involving the evolution and nucleation of voids in the matrix, which adds to the larger voids that originated surrounding the larger voids finally in similar molecular bonding of the deformed structure.

Table 3: Depiction of compressive & tensile strength with respect to material composition

Material composition	Compressive strength (MPa)	Tensile strength (MPa)
AZ31D Mg Alloy	176.87	104.87
AZ31D +2% SiC	318.95	134.65
AZ31D +2% SiC+2% Ni	395.18	142.15

AZ31D +4% SiC+4% Ni	412.85	174.32
AZ31D +4% SiC	405.24	170.57

Table 4: Micro hardness determination with respect to material composition

Material composition	Micro level hardness(VHN)
AZ31D Mg Alloy	72.45
AZ31D +2% SiC	83.57
AZ31D +2% SiC+2% Ni	87.93
AZ31D +4% SiC+4% Ni	102.54
AZ31D +4% SiC	98.95

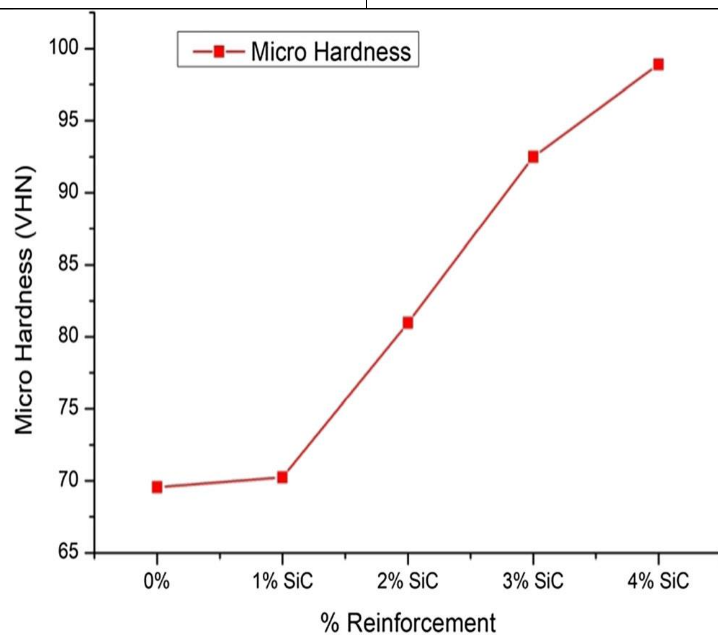

Figure 13: Micro hardness comparison graph Vs Reinforcement Weight percentage

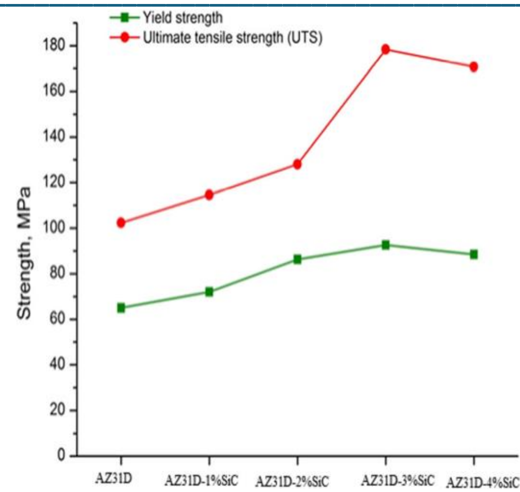

Figure 14: Yield strength comparison graph Vs Reinforcement Weight percentage

Fractography evaluation

After viewing the cracked SEM imaging, we could see how the tensile characteristics had improved. We could also see information about the development of micro level cracking and curvilinear-like formations [16,17], which are shown in the accompanying pictures (a&b).

Microlevel cracking

When fractographic pictures were shown, it was possible to see the development of microcracks on the fracture surface region of AZ31D, which is a blatant sign of brittle deformation. In their research on alumina nano particle-reinforced AZ31 composites, P.Srinivasa Rao et al. [18] noted the development of micro cracks on the fracture surface of the interface region of matrix and reinforcements. At the interfacial region of secondary stage particles, micro voids of the majority region are seen. Additionally, crack initiations are shown, which supports the production of twin structures. According to Nguyen et al., the creation of micro cracking and space confinements in deformation in the plastic zone are the results of their research on AZ31B-1.5 Al2O3-3.18 Ni. Additionally, similar research on the AZ31B-1.5 Al_2O_3-3.18 Ni characterization data reveals that there are various micro cracking forms and fractured nickel particles, which are important in space confinement plastic deformation [19,20].

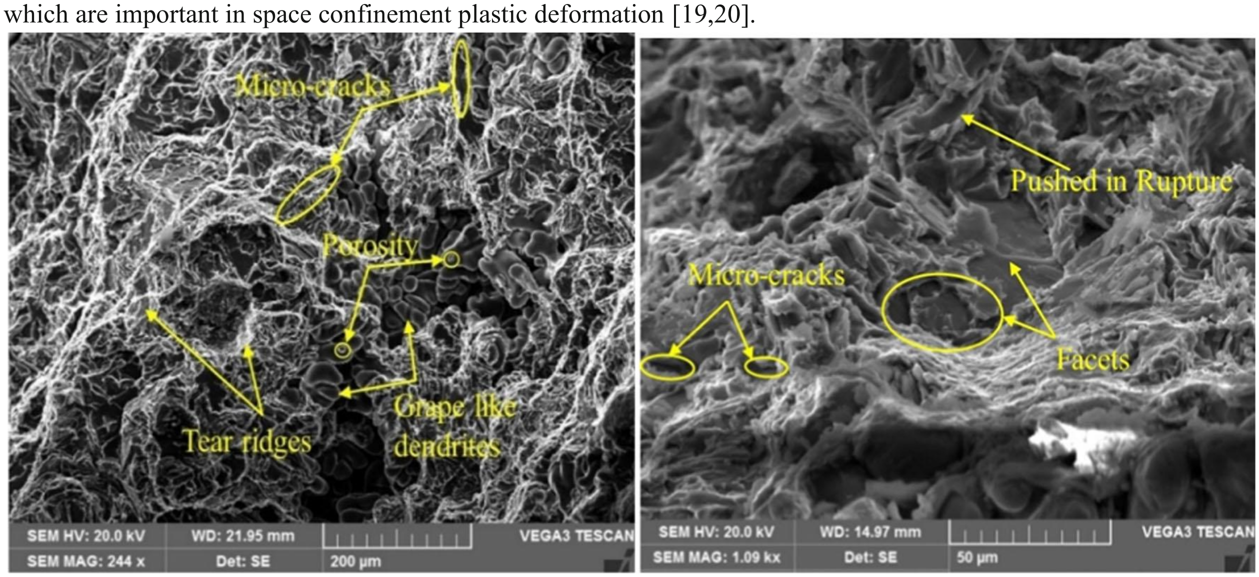

Figure 15: (a) SEM microscopic imaging for AZ31D fractured specimen
(b) SEM image of AZ31D with 2% Silicon carbide weight fraction

Concavity resemblance structures

These structural developments in AZ31D FGM composites point to greater plastic deformations. Functional composites are referred to as having plastic twining if they exhibit brittle deformation, low levels of micropores, nullification of microcracking, and concave structures in the vicinity of cracks [21].

Investigation on the TiC and carbon fiber particulates.

Regarding the incorporation of silicon carbide and nickel as reinforcing particles, the structural and dynamic properties of AZ31D are examined. The presence of silicon carbide initially reduces the production of FGM grains during the compaction process. Subsequently, when silicon carbide inclusion increases the volume fraction, the composite grain boundary becomes smaller. The addition of SiC reduces the initiation energy due to all the impacts on the grain boundaries and volume fraction [22By including silicon carbide and nickel particles, it is possible to increase load bearing capacity while reducing local dislocalities and deformation irregularities [23,24]. The FGM is able to achieve a surface property in which it surpasses molecular dislocations and generates uniform stress transfer, thereby reducing the localized matrix deformities. This is made possible by the entry of TiC into the matrix constituents. Tables 4 and 5 show the causes of the improvement of numerous AZ31D magnesium FGM composite properties [26,27,&28]. Due to defects in the plastic region, the reinforcing particles, specifically silicon carbide, act as a limiting mechanism. The advancement of silicon carbide into the deformities region allows the region to enter a modified stage, relieving internal tensions and localization stresses, and achieving uniform particle distribution. This mechanism helps the molecular structure of the particle to generate interfacial debonding and crack initiation. Therefore, based on these conclusions, we may say that the addition of silicon carbide raises localized stresses, which in turn raises the volume rate of SiC and lowers tensile strength.

Conclusions

AZ31D magnesium composites reinforced with silicon carbide and nickel particulates yields the following conclusions

- Through the use of an innovative powder metallurgy technology and under strict control of the process parameters, AZ31D magnesium FGM composites are created.
- Images from electron diffraction spectroscopy (EBSD) showed evidence of nickel and SiC inclusion in the magnesium matrix of AZ31D. Due to the impingement of silicon spray during the compaction process, there are no signs of oxygen peaks in either the alloy or the FGM composite.
- The homogeneous dispersion of TiC and carbon fiber particulates in the matrix region can be seen by SEM microscopy and is revealed to be intra granular in nature. It is easy to see that there is interfacial bonding at the contact between the matrix and the reinforcements.
- The finer grain refinement of TiC and carbon fiber particles is readily visible in the EBSD images, and the uniform particle distribution makes it so that the relationship between the grain size of the matrix and the particulate size of the reinforcements is linear in nature. With an increase in reinforcements, the composite's grain structure becomes more refined.
- Because titanium carbide particulates produce an excellent property of transfer of load from the magnesium matrix to the reinforcements, thereby enhancing its hardness and transfer of loading properties, which are observed at the interfacial bonding region, the hardness of the FGM is significantly increased by their addition.
- The presence of dislocations is seen in TEM images (tunnelling electron microscopy) in the area of the magnesium matrix, and the interfacial bonding is shown to be excellent and well bonded. Also shown is how Al2Mg5Zn2's phase transformation remains either in the solidification stage or as a precipitate from the solidify zone.

- By enhancing grain boundaries and increasing grain size while reducing dislocations and voids, the presence of nickel particles near the magnesium matrix enables the material to exhibit electrical and thermal conductivities.
- Both the tensile strength and hardness are improved by the addition of silicon carbide and nickel. By incorporating TiC and carbon particulates, the FGM composite's grain refinement is achieved, and as a result, the material's mechanical characteristics are significantly improved.

Acknowledgement

The authors of the manuscript are grateful to Vardhaman College of engineering Hyderabad for their solitcitful guidance and support. The faculty and technicians of Bapatla college of Engineering, Bapatla has provided all the necessary equipments such as compaction machine, compaction die and sintering machine. We are grateful to Vignan University, Vadlamudi, Andhra Pradesh for providing SEM.EDAX, XRD and TEM images.

Conflict Of Interest Statement

The authors of the research work all by knowledge and belief declare no conflict of interest and all authors are actively participated from the research experimentations till the draft of the manuscript.

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