Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Experimental investigation of high carbon steel MMC for crown pinion gear

R. Charles Godwin *, C. Dhanasekaran

Department of Mechanical Engineering, Vels Institute of Science, Technology & Advanced Studies, Chennai 600117, Tamilnadu, India

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
High Carbon Steel
MMC
Powder Metallurgy
Mechanical Characteristics

ABSTRACT

The implementation of high carbon steel composite is growing continuously in the field of automotive and manufacturing industries because of their superior physical, mechanical and tribological properties as compared to normal steel. In automobiles, the differential plays major role to power transmission from engine to wheel. However, failure of crown pinion observed that the gear teeth have been sheared off by heat failure and edge of pinion gear is worn down caused by lubricant failure. So, this high carbon steel composite (high carbon steel + silicon carbide) could be proposed for crown pinion gear to control material wear and fracture. In this paper, the various proportions of high carbon steel composites were investigated and evaluated the characteristics of material hardness, compressive strength and material wear. The material proportions were 100–0 %, 99–1 % and 97.5–2.5 % of high carbon steel with silicon carbide. By observing experimental results, the high carbon steel with 2 % of silicon carbide have better material characteristics than other proportions and this also suggested to crown pinion gear production.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Engineering Concepts and Technology.

1. Introduction

Life expectancy of mechanical system is always dependent on the most critical component of the system. The crown wheel and pinion gears are one of the critical components in the transmission system of an automobile. Failure of this components has drastic effect on the vehicular movement. This in turn leads to increased downtime for repairs. The cost of these components adds to the criticality in addition to its function.Gear design is commonly bounded by the requirements that gear should carry high loads at high speeds with minimal size and weight. Gear wear refers to the progressive material loss from contacting tooth surface due to the combined rolling and sliding motion under mixed or boundary lubrication conditions. The direct result of gear wear includes dynamic transmission error [1–4]. When one gear is mesh with other in that one is bigger than the other in that mechanical advantages achieve, with the torques and rotational speeds, of the two gears differing in part to their diameters.For gear failure mode occurring tooth bending fatigue, surface scoring and wear, contact fatigue.There are two different types of gear teeth devastation occur in gears under several freight due to fatigue known as tooth breakage in a root and teeth damage, teeth breakage of teeth is clearly worst damage case, the gear hampered operating condition or destroyed, because of this, the localized stresses in a tooth should be conceptually studied in all gear application. The crack imitation period commonly accounts for the most service life of gear, particularly in high cycle fatigue [5–8].The noise and vibrations measured were very low for new set of gears and increased considerably for used gear pairs and there was a very peak rise in noise and vibration level for the damaged gear pair. By studying the sound and vibration spectrum it is possible to know the status of the given spiral bevel gear pair and it is also possible for early detection of failure of given spiral bevel gear pair during operation [9–11]. During study work, it is also seen that, the Gear failures, can be avoided if designers and operators recognize that the crown wheel is an important component of a differential unit and appreciate that the tribology of gearing requires the attention and control of many related factors [12–15]. Successful diagnosis, and especially prognosis, of gear damage based on observed accelerometer responses requires that one have the capability to relate accelerometer response characteristics to physical damage on the subject gears.for the case of tooth bending-fatigue damage,

* Corresponding author at: Department of Mechanical Engineering, Vels Institute of Science, Technology & Advanced Studies, Chennai 600117, Tamilnadu, India.
E-mail address: charles7esmee@gmail.com (R. Charles Godwin).

https://doi.org/10.1016/j.matpr.2022.07.367
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Engineering Concepts and Technology.

Fig. 1. Failure of Crown Pinion.

precision measurements, made on a gear failed in a four-square power-circulating test apparatus, have provided strong evidence that the detectable damage feature prior to tooth breakage is plastic deformation of failing teeth, rather than reductions in tooth stiffness due to root cracks, as is commonly believed [16–19].The component failure occurs in crown pinion gear were discussed by Bensely et al. The failure began in the pinion, causing the crown wheel to fail prematurely wherever the failed tooth made contact with it. The failure mode of the pinion is sub case fatigue caused by inadequate case depth. The crown wheel's failure mode is partial uprooting. As a result, the substitute material must decrease component failure(See Fig. 1).

2. Material selection

The nature and methodology of the metal matrix composites depicts their performance and characteristics that can be assessed. Some factors for example intrinsic properties, structural arrangement of the reinforcing particles in the matrix system and the relations between the constituents are of great significance. The intrinsic properties of reinforcements and matrix system decide the general order of properties that will play an important role in the composite materials [20–24]. The interaction between the constituents of composite sets the new characteristics that are very crucial for the automotive and aerospace applications. The shape and size of the individual particulate, their structural arrangement, distribution and the relative amount contribute to the whole performance of the composite materials. The important factors determining the properties of composite materials are microstructure, size, volume fraction, homogeneity and isotropy of the system and the technique used to manufacture the component.

2.1. High carbon steel

High-carbon steel is described as steel with a carbon content of 0.55 percent or more. While this is how cast-iron items (wood stoves, cookware) are produced, pushing this material beyond 2 % makes the result highly fragile and of little use [25]. Quite high strength, intense stiffness and wear resistance, and reasonable ductility, an indicator of a material's ability to withstand being deformed without eventually cracking, are all characteristics of high carbon steel.

Table 1
Physical and Mechanical Properties of Proposed Material.

Material / Property	High Carbon Steel	Silicon Carbide
Density (g/cc)	7.54	3.18
Young's modulus (GPa)	200	470
Poisson ratio	0.292	0.36
Thermal conductivity (W/mK)	45.9	110
Tensile strength (MPa)	896	–

2.2. Silicon carbide

The most commonly used source for structural ceramics has been silicon carbide. Low thermal expansion, a large force-to-weight radius, high thermal conductivity, hardness, abrasion and corrosion resistance, and, most notably, the ability to maintain elastic resistance at temperatures up to 1650 °C have contributed to a wide variety of applications [26–27]. The project's key purpose is to examine which material is best for the crown and pinion gears in the differential at higher loads by studying stress, displacement, and weight reduction. Variations in the formulations of high carbon steel and silicon carbide compounds for gears are used to do an investigation.

Table 1 represents the physical and mechanical properties of proposed material for crown pinion gears. Among these materials, different proportions have been chosen to optimize by the FEA analysis of crown pinion are as follows:

1) High carbons steel (100 %) + Silicon carbide (0 %)
2) High carbons steel (99 %) + Silicon carbide (1 %)
3) High carbons steel (97.5 %) + Silicon carbide (2.5 %)

3. Specimen preparation

The test samples of proposed material have been prepared by powder metallurgy method. Powder metallurgy is a relatively common way of producing parts, particularly in the automobile industry, as it enables the high-volume production of small and intricately shaped parts with homogenous structures. In powder metallurgy, mixtures of metal (and sometimes non-metal) powders are compacted and then sintered. The manufacturing process is expensive, but the finished parts have specific advantages over

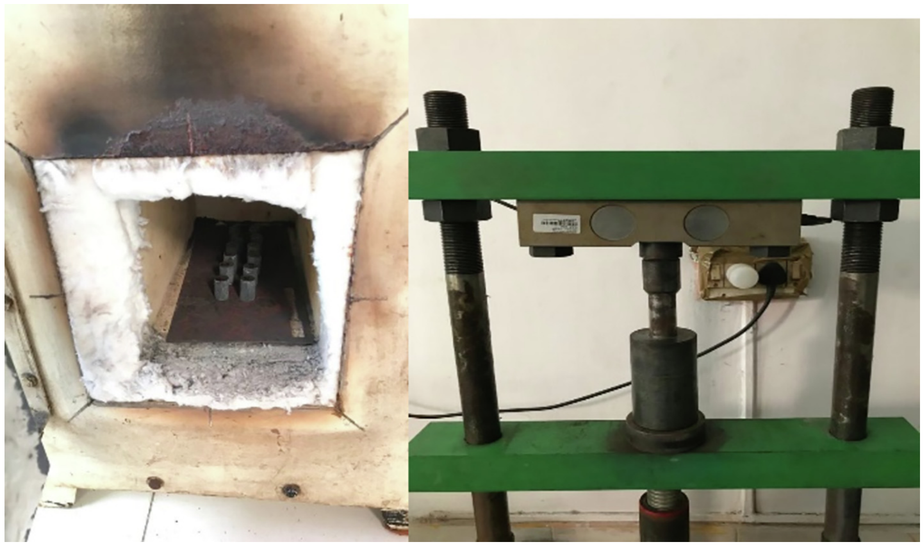

Fig. 2. Material Compaction.

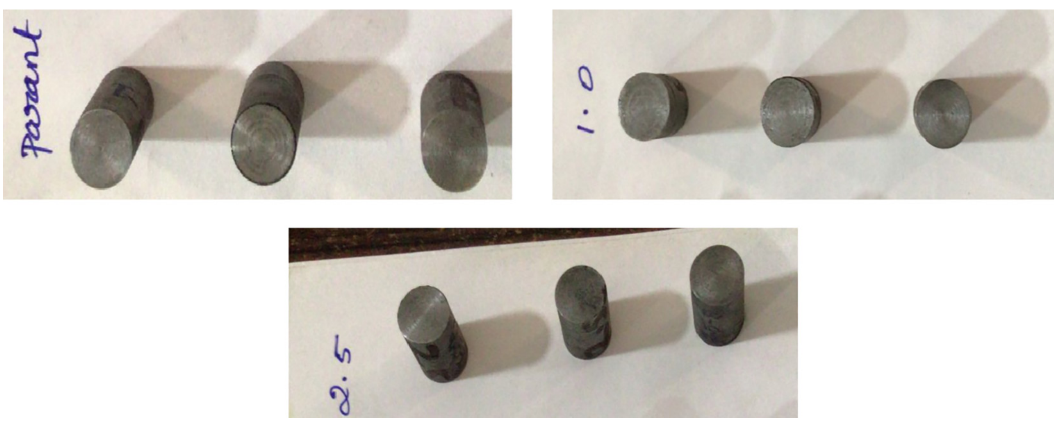

Fig. 3. Sintered Samples.

wrought or cast parts and reduction of machining process that results in a decrease in the cost of production. Powder metallurgy usually proceeds in three main steps: powder preparing, compaction and sintering. This proposed combination of high carbon steel powder has prepared by ball milling process and then compacted by compression machine. Finally, the sintering process done by using box furnace under 1650 °C for required specimen size, shown in Fig. 2 and Fig. 3.

4. Experimentation

4.1. Wear test

In this experimentation, only dry sliding wear will be considered Fig. 4 shows the setup. The actual wear mechanism for dry wear depends on a number of variables including surface finish, surface geometry, orientation, sliding speed, relative hardness,

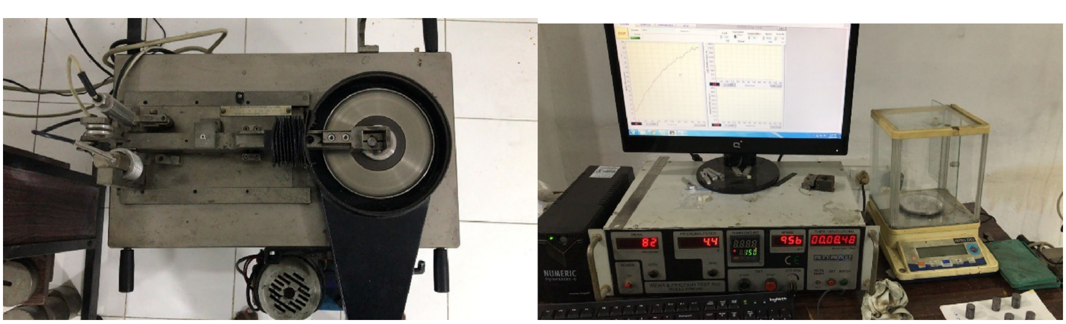

Fig. 4. Pin on Disc Wear Tester Machine.

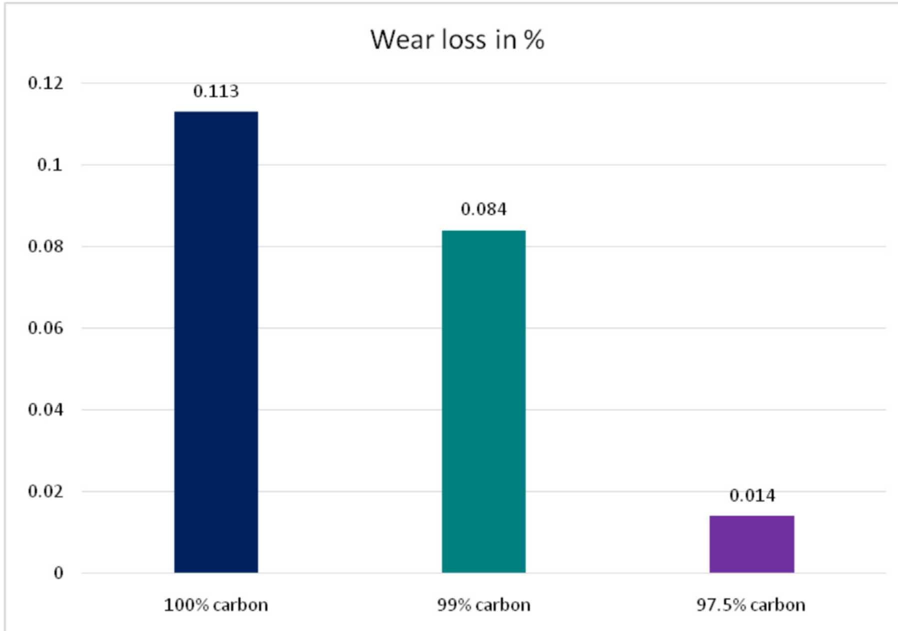

Fig. 5. Wear Loss in Percentages of Crown Pinion at 5 N.

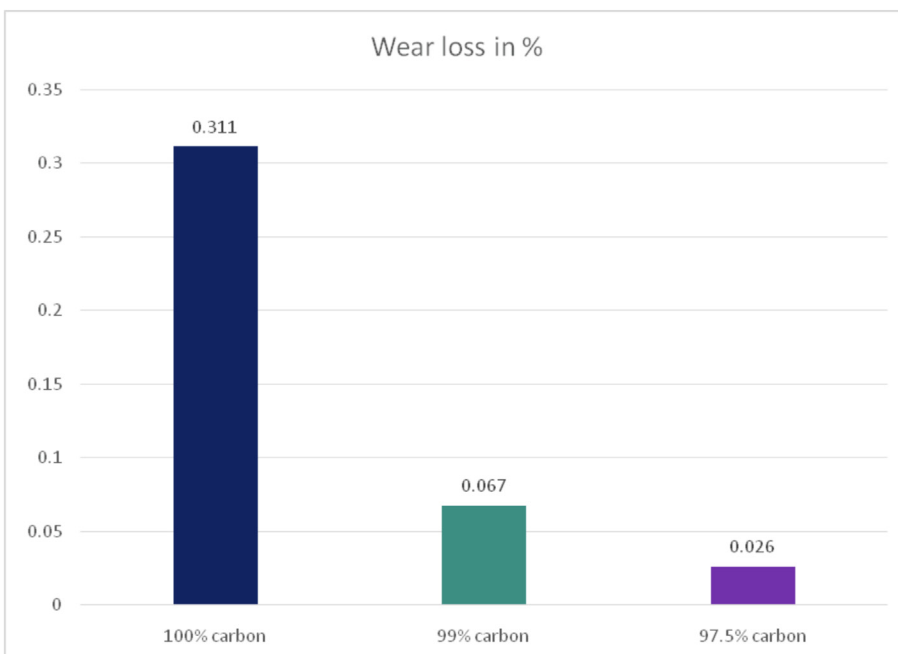

Fig. 6. Wear Loss in Percentages of Crown Pinion at 10 N.

material microstructure, and more. From this variable, it can be seen that wear rate is not pure material property and does not always occur uniformly, this experimental setup is pin on disc machine. During the wear test, loads can be applied at either 5 N, 10 N or 20 N respectively. The speed of the rotating disc is 955 rpm and the disc diameter is 30 mm. During the testing process, the rotating disc can be controlled by electric motors, which permits continuous rotary motion of disc. During the testing procedure, sliding velocity is 1.5 m/*sec* and sliding distance is 1000 m. Friction force at the time of testing was measured with the help of a torque transducer.

The below Figs. 5, 6 and 7 representing the wear loss in percentages for 5 N, 10 N and 20 N respectively. Based on that results that 97.5 % high carbon and 2.5 % silicon carbide mixture of composite material have much more wear resistance than the others. From results, the above Fig. 6 shows that the sample with 97.5 % high carbon steel is having better wear characteristics while compared to other samples with 99 % and 100 % high carbon steel at the condition of 5 N load and 1.5 m/*sec* sliding velocity.

4.2. Compression test

In a compression test, the material is compressed or crushed because of opposing pressures pushing inward from opposite sides. The applied force is delivered across the full surface area of two opposing faces of the test sample and then the plates are pressed

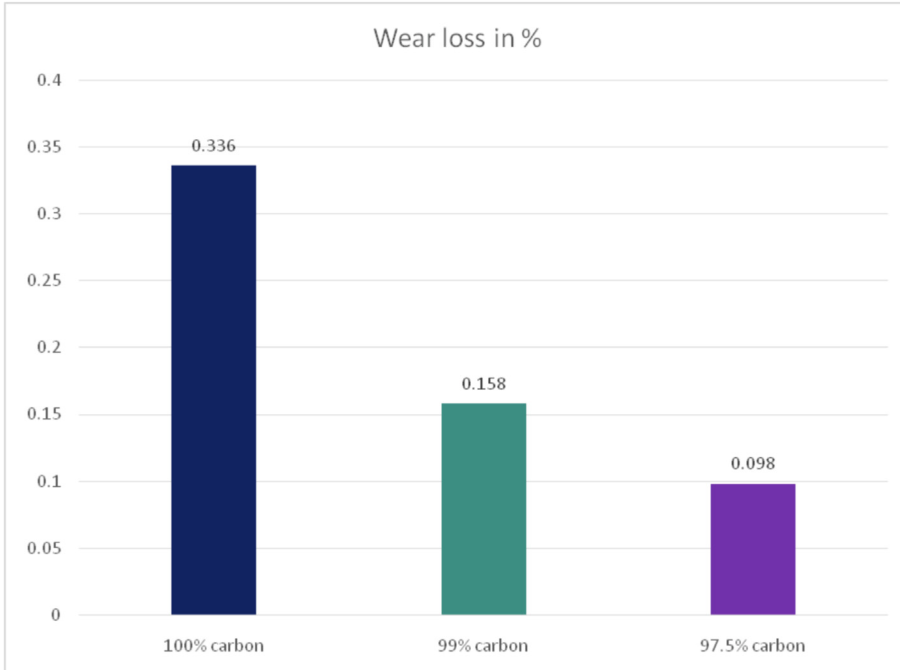

Fig. 7. Wear loss in percentages of crown pinion at 20 N.

Table 2
Results of Compression Test.

Sample No.	**C.S Area** (mm^2)	**Load** (KN)	**Load** (N)	**Compressive Strength** (N/mm^2) / (MPa)
1	148.92	138.75	138,750	931.7082998
2	134.78	117.97	117,970	875.2782312
3	147.84	150.71	150,710	1019.412879

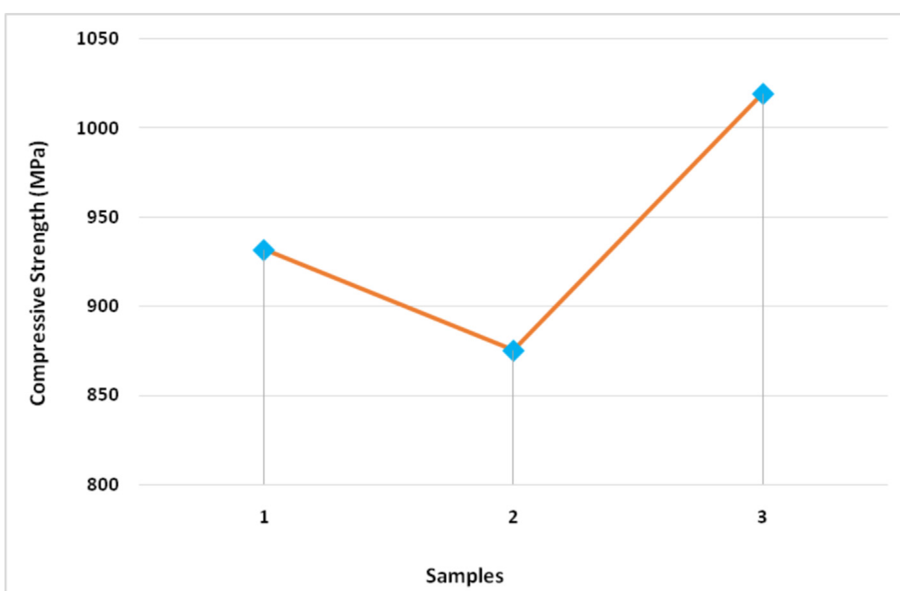

Fig. 8. Comparison of compression result.

together by a universal testing machine. This experiment was carried out for proposed high carbon steel samples and the obtained results has discussed Table 2. Comparatively, the third sample attained maximum compression strength of 1019.4 MPa (i.e., the composition of high carbon steel 97.5 % with 2.5 % silicon carbide). By reinforcing silicon carbide with carbon steel, the material strength is increased. Fig. 8 shows that the comparison of compressive strength of high carbon steel composites.

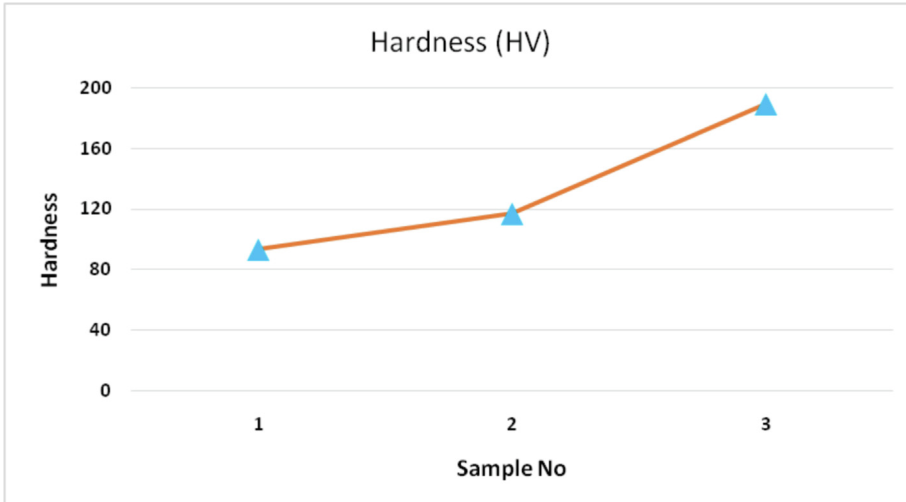

Fig. 9. Variation of hardness value for different samples.

Table 3
Hardness Test Data for High Carbon Steel Composite.

Sample No	Material Hardness (HV)			
	Trail 1	Trail 2	Trail 3	Average
1	94.6	86.9	98.6	93.36666667
2	115.9	134.8	100.6	117.1
3	142.5	162	263.7	189.4

4.3. Hardness test

Hardness is a material attribute, not a basic physical property. It is defined as indentation resistance and is assessed by measuring the permanent depth of the indentation. Simply said, when a constant force (load) is applied to a specific indenter, the smaller the indentation, the harder the material.The Vickers hardness test method was referred in this study and applied load of 0.5 kgf for the time of 10 s. The obtained results were tabulated in Table 3 and the variation has been highlighted in the Fig. 9. Comparatively, the sample 3 (97.5–2.5 %) achieved greater hardness value than other samples.

5. Conclusion

This investigation describes about the characteristics of high carbon steel composite material that was proposed to crown pinion gear in differential unit.The implementation of carbon steel material has been raised in field of automobile to avoid component failure due to heat. This present study shows the importance of material selection for heavy duty application by investigating the proposed materials (i.e., high carbon steel with reinforcement of silicon carbide). The thermal analysis of wear test, structural analysis of hardness and compression were experimented. Comparatively, the material with presence of silicon carbide has achieved better characteristics than other proportions. The targeted results of experiment were described in above manuscript. However, the better outcome has summarized as below:

- The wear resistance of high carbon steel in addition of 2.5 % SiC achieved 0.098 % of material loss for maximum load 20 N.
- The maximum compression strength of 1019.41 MPa has obtained for induced load of 150 kN.
- The maximum material hardness of 189.4 HV attained for combination of carbon steel with 2.5 % SiC.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

All persons who have made substantial contributions to the work reported in the manuscript (e.g., technical help, writing and editing assistance, general support), but who do not meet the criteria for authorship, are named in the Acknowledgements and have given us their written permission to be named. If we have not included an Acknowledgements, then that indicates that we have not received substantial contributions from non-authors.

References

[1] A. Bensely, S. Stephen Jayakumar, D. Mohan Lal, G. Nagarajan, A. Rajadurai, Failure investigation of crown wheel and pinion, Eng. Fail. Anal. 13 (8) (2006) 1285–1292.
[2] Munde Rahul M andKamble D P, “Experimental investigation and FEA of wear ingear at torque loading conditions”, IJARIIE, Vol-3 Issue-4, 2017, pp: 2283 – 2296.
[3] I. Bhavi, V. Kuppast, S. Kurbet, Determination of Fatigue life of Spiral bevel gears used in automotive differential gearbox, IJERA 07 (06) (2017) 49–52.
[4] Prerana U. Jiwane, Prof. (Dr.) Prashant D. Deshmukh and Dhiraj K. More, “Review on Failure Analysis of a Differential Crown Gearin Rear Axle of an Automobile”, JETIR April 2018, Volume 5, Issue 4, pp: 761 – 763.
[5] W.D. Mark, C.P. Reagor, Static-transmission-error vibratory-excitation contributions from plastically deformed gear teeth caused bytooth bending-fatigue damage, Mech. Syst. Sig. Process. 21 (2) (2007) 885–905.
[6] Rohit Sreekumar and Prof. Jeyapoovan T, “Design and Analysis of a Composite Bevel Gear in An Automobile Differential Gear Box”, International Journal of Engineering Sciences & ResearchTechnology, May, 2016, pp: 248 – 257.
[7] J. Kumaraswamy, V. Kumar, G. Purushotham, Thermal analysis of nickel alloy/Al2O3/TiO2 hybrid metal matrix composite in automotive engine exhaust valve using FEA method, J. Therm. Eng. 7 (3) (2021) 415–428.
[8] S.S. Bagewadi, I.G. Bhavi, S.N. Kurbet, Design and analysis of crown pinion of adifferential gear box for reduced numberof teeth to improve torque transmitted, Int. J. Mech. Eng. Robot. Res. 3 (4) (2014) 188–194.
[9] Jaehoon Kim, Jaebong Jung, Taejoon Park, Daeyong Kim, Young Hoon Moon, FarhangPourboghrat and Ji Hoon Kim, “Characterisation of Compressive Behaviour of Low-Carbon and Third Generation Advanced High Strength Steel Sheets withFreely Movable Anti-Buckling Bars”, Metals (2022).

[10] G. Kishore, A. Parthiban, A.M. Krishnan, B.R. Krishnan, V. Vijayan, Experimental investigation of mechanical and wear properties of AL7075/Al2O3/MICA hybrid composite, J. Inorg. Organomet. Polym Mater. 31 (3) (2021) 1026–1034.
[11] Kishore, G., Parthiban, A., Mohana Krishnan, A., Radha Krishnan, B., Investigation of the surface roughness of aluminium composite in the drilling process.
[12] G. Bhaskara Rao, A. Parthiban, Study on cold room enhancements for commercial applications -review, Mater. Today:. Proc. (2022).
[13] M. Prabhu Deva, A. Parthiban, B. Radha Krishnan, A. Haile, W. Degife, Titanium diboride reinforced AMMC composites, Adv. Mater. Sci. Eng. 5144010 (2022).
[14] R. Raja, A. Parthiban, S. Nandha Gopan, D. Degefa, T. Varol, Investigate the process parameter on the friction stir welding of dissimilar aluminium alloys, Adv. Mater. Sci. Eng. 2022 (2022) 1–8.
[15] K. Jayappa, V. Kumar, G.G. Purushotham, Effect of reinforcements on mechanical properties of nickel alloy hybrid metal matrix composites processed by sand mold technique, j.asep 14 (1) (2020).
[16] S. Khelge, V. Kumar, V. Shetty, J. Kumaraswamy, Effect of reinforcement particles on the mechanical and wear properties of aluminium alloy composites: review, Mater. Today:. Proc. 52 (2022) 571–576.
[17] V. Shetty, S. Shedthi B, J. Kumaraswamy, Predicting the thermodynamic stability of perovskite oxides using multiple machine learning techniques, Mater. Today:. Proc. 52 (2022) 457–461.
[18] G. Kishore, A. Parthiban, A.M. Krishnan, B.R. Krishnan, V. Vijayan, AL7075/Al2O3/MICA hybrid composite, J. Inorg. Organomet. Polym Mater. 31 (3) (2021) 1026–1034.
[19] G. Kishore, A. Parthiban, A. Mohana Krishnan, B. Radha Krishnan, Investigation of the surface roughness of aluminium composite in the drilling process, Mater. Phys. Mech. 47 (5) (2021) 739–746.
[20] A. Parthiban, V. Vijayan, T. Sathish, S. Dinesh Kumar, L. Ponraj Sankar, N. Parthipan, D. Tafesse, M. Tufa, S.J.S. Chelladurai, Parameters of porosity and compressive strength-based optimization on reinforced aluminium from the recycled waste automobile frames, Adv. Mater. Sci. Eng. 2021 (2021) 1–10.
[21] S. Khelge, V. Kumar, K. J, Optimization of wear properties on aluminum alloy (LM22) hybrid composite, Mater. Today:. Proc. 52 (2022) 565–570.
[22] A Parthiban., R Ravikumar, ZH Abdul, D M., Experimental investigation of CO2 laser cutting on AISI 316L sheet, Journal of Scientific & Industrial Research 73, 387-393, 2014
[23] Baskar, S., Venkatraman Vijayan, S. Saravanan, A. V. Balan, and A. Godwin Antony. "Effect of Al2O3, aluminium alloy and fly ash for making engine component." Int. J. Mech. Eng. Technol.(IJMET) 9, no. 12 (2018): 91-96
[24] A. Parthiban, R. Ravikumar, B.S. Kumar, N. Baskar, Process performance with regards to surface roughness of the CO2 laser cutting of AA6061–T6 aluminium alloy, Lasers Eng. 32 (3) (2015) 327–341.
[25] S. Srikanth, A. Parthiban, Microstructural analysis of Nd: YAG laser welding for Inconel alloy, Mater. Today:. Proc. 21 (2020) 568–571.
[26] Harish R S, Sreenivasa Reddy M, Kumaraswamy J, Wear characterization of Al7075 Alloy hybrid composites, Journal of Metallurgical and Materials Engineering, Vol. 28, pp. 1-8.
[27] S. Saravanan, A. Godwin Antony, V. Vijayan, M. Loganathan, S. Baskar, Synthesis of SiO2 nano particles by using sol-gel route, Int. J. Mech. Eng. Technol. 1 (2019) 785–790.

APPENDIX I

SIMULATION RESULTS

Table A1. Results of Design with Elevation at Static Load Condition

Material	Deformation (mm)	Equivalent Elastic Strain	Equivalent stress (MPa)	Normal Elastic Strain	Normal stress (MPa)
Sample A	0.026626	0.00041667	57.524	5.43E-05	21.965
Sample B	0.019419	0.0003046	57.646	3.85E-05	21.432
Sample C	0.019484	0.00030364	57.295	4.19E-05	22.973
Sample C1	0.019404	0.00026946	57.431	4.04E-05	22.376
Sample C2	0.019273	0.00030105	57.425	4.02E-05	22.402
Sample C3	0.019143	0.00029899	57.419	4.00E-05	22.429
Sample C4	0.019015	0.00029696	57.413	3.98E-05	22.455
Sample C5	0.018889	0.00029496	57.407	3.96E-05	22.481

Table A2. Results of Design with Elevation at Tangential Load Condition

Material	Deformation (mm)	Equivalent Elastic Strain	Equivalent stress (MPa)	Normal Elastic Strain	Normal stress (MPa)
Sample A	0.0031602	1.02E-04	13.138	1.23E-05	3.8894
Sample B	0.0023046	7.41E-05	13.146	9.00E-06	3.8329
Sample C	0.0023131	7.47E-05	13.123	8.97E-06	3.9959
Sample C1	2.30E-03	7.42E-05	13.132	8.95E-06	3.9329
Sample C2	0.0022877	7.37E-05	13.132	8.89E-06	3.9357
Sample C3	0.0022723	7.32E-05	13.131	8.83E-06	3.9385
Sample C4	0.0022571	7.28E-05	13.131	8.77E-06	3.9413
Sample C5	0.0022422	7.23E-05	13.131	8.71E-06	3.9441

Table A3. Results of Design without Elevation at Static Load Condition

Material	Deformation (mm)	Equivalent Elastic Strain	Equivalent stress (MPa)	Normal Elastic Strain	Normal stress (MPa)
Sample A	0.027498	0.00052653	70.917	6.25E-05	24.392
Sample B	0.020061	0.00038527	71.341	4.44E-05	23.806
Sample C	0.020112	0.00038306	70.132	4.80E-05	25.505
Sample C1	0.020036	0.0003828	70.594	4.65E-05	24.845
Sample C2	0.0199	0.00038015	70.574	4.62E-05	24.874
Sample C3	0.019766	0.00037753	70.553	4.60E-05	24.903
Sample C4	0.019633	0.00037495	70.533	4.57E-05	24.933
Sample C5	0.019503	0.0003724	70.512	4.55E-05	24.962

Table A4. Results of Design without Elevation at Tangential Load Condition

Material	Deformation (mm)	Equivalent Elastic Strain	Equivalent stress (MPa)	Normal Elastic Strain	Normal stress (MPa)
Sample A	12.383	0.0084481	843.57	3.27E-03	481.17
Sample B	9.021	0.006203	851.09	2.38E-03	481.32
Sample C	9.0835	0.0061058	829.66	2.40E-03	480.88
Sample C1	9.0335	0.0061255	837.84	2.39E-03	481.06
Sample C2	8.9729	0.006082	837.48	2.37E-03	481.05
Sample C3	8.913	0.0060391	837.12	2.35E-03	481.04
Sample C4	8.854	0.0059968	836.75	2.34E-03	481.03
Sample C5	8.7957	0.005955	836.39	2.32E-03	481.03