CASTING AND EVALUATION OF PROPERTIES FOR AN ALUMINIUM ALLOY MATERIAL AND OPTIMIZING THE QUALITY CONTROL PARAMETERS

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***Abstract*: The rising cost of steel has had a substantial impact on manufacturing costs in the automobile and household industries, making a compelling case for replacing steel with materials that are lightweight and have a high strength-to-weight ratio. Aluminum and its alloys have exceptional features such as light weight, wear durability, and corrosion resistance, making them ideal for a wide range of industrial applications. In today's industry, customer perception of quality is critical, especially with the increased competition. The engine industry is an illustration of how customer expectations in terms of quality and cost are rising across the world. Pistons must meet two important material specifications. One is deformation resistance, or strength when subjected to high combustion pressures and cyclic loads. This is necessary to execute at a high compression range without becoming fatigued, maintaining safe working conditions. Another necessity is high-temperature toughness. This is essential to work at high temperatures without creep in locations where there is a lot of flames. At high temperatures, an aluminum metal alloy containing reinforcing particles demonstrates excellent performance. The stir casting procedure was used to create base aluminum metal alloy matrix LM30+1 percent Graphene+0.8 percent Nickel, LM30+1.5 percent Graphene+0.8 percent Nickel, LM30+1 percent Flyash+0.8 percent Nickel, LM30+1.5 percent Flyash+0.8 percent Garnet. This paper compares the mechanical, chemical, and aluminum alloy of the LM series to meet specified quality control parameters, focusing on the results of impact strength, tensile strength, and hardness. Taguchi methods and other optimization approaches are used to discover the optimal sample that is suitable for use.**

Keywords: **Aluminum, Compositions, Mechanical properties, Taguchi methods, Automobile**

I. INTRODUCTION:

For most technical applications nowadays, Aluminum LM 30 are the most used materials because their strength and other mechanical properties outperform traditional materials. New materials are created via intrinsic or extrinsic change of existing materials [1]. Only modest alloying changes are made during intrinsic modification. The extrinsic modification involves adding external alloy to the parent material to change its properties to satisfy the design requirements. Extrinsic modification is used in composition materials. The most common reason for the change is to improve the qualities of current materials [2]. Aluminum is one of the most used matrix materials due to its qualities such as high strength, low density, durability, machinability, availability, and low cost when compared to other competing materials [3]. Engine blocks, cylinder heads, pistons, wheels, and suspension components are all made of aluminum castings. Because of their small weight, good mechanical properties, and abundance, aluminum-silicon alloys are commonly utilized in MMCs. The addition of silicon improves fluidity, reduces cracking, and improves feeding to reduce shrinkage porosity. Many automotive, maritime, and aerospace applications rely on corrosion resistance.[4-5] Aluminum alloy LM30 is a cast alloy used in the automobile industry for applications like pistons, piston rings, engine blocks, brakes, and so on. Because LM30 is a hypereutectic alloy, it has unique qualities that make it ideal for applications requiring high wear resistance. In the LM30 base metal, zircon powder is utilized to make a composite with varying weight percentages. One of the most critical aspects of material deterioration is abrasion. Design of Experiments employing Taguchi principles contributes to the development of quality, which is defined as performance uniformity. The S/N ratio is used in Taguchi design to determine the value of characteristics. There are three types of quality features: smaller is better (minimize), larger is better (maximize), and nominal is best, which entails charting the effects and visually identifying the main components. To obtain the multi-objective characteristics, the MINITAB software was used to examine the mean influence of the Signal-to-Noise (S/N) ratio.

2. Taguchi's Approach:

The Taguchi method is a well-known process optimization technique that provides a systematic and effective framework for developing high-quality systems. For users with a basic understanding of statistics, the Taguchi technique for experiment design is straight forward to learn and use, and as a result, it has gained universal acceptance in the engineering and scientific sectors. Methodology for creating high-quality items at low development and production costs by attaining product and process conditions that are least responsive to various sources of variation.[6-8] The signal-to-noise ratio and the orthogonal array are two essential strategies in robust design. The S/N ratio characteristics can be divided into three groups when the characteristic is continuous:

nominal is the best, smaller is better, and larger is better. "Smaller is better" is the solution for the lowest cutting temperature, and the S/N ratio is determined using the following equation: A popular way to think about quality is in terms of conformance to specifications. Taguchi, on the other hand, proposes a different understanding of quality, one that links it to cost and financial loss, not just for the producer at the time of production, but also for the consumer and society. "Up until the point where the product is disseminated, the loss is generally considered as an additional manufacturing expense," explains Taguchi. The energy consumption or power demand in machining is affected by noise elements that are classified as inner, outside, and between product sounds. To mitigate the consequences of these noise elements, some counter measures may be adopted. The first is by design, which entails 1) the design of the system. 2) Parameter design and 3) tolerance design

The Taguchi Approach is a standardized experimental design technique that involves using robust experiment design to reduce process variation. The method's overall purpose is to offer the maker a high-quality product at a low cost. Dr. Genichi Taguchi of Japan developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process works [6]. The analysis of variance can be calculated using a variety of methodologies, including general linear models, the Statistical Package for Social Sciences (SPSS), and Minitab. [12]Minitab is an application that allows you to enter statistical data, alter it, spot trends and patterns, and then extrapolate answers to your problem. That's a clumsy way of explaining this vital and quite valuable tool.

3. Sample Compositions:

3.1 Aluminum alloy LM30 :

LM30 is a new alloy that was created specifically for a die-cast aluminum vehicle engine that does not need the traditional iron cylinder liner. Hypereutectic Aluminum-Silicon alloys, such as LM30, have the potential to be used in a wide range of castings where high wear resistance and lightness are required, and especially where the economies of the die casting process can be taken advantage of. However, if the machining practice is like that used for the more common Aluminum alloys, the surface finish and tool life will be inferior. However, machining LM30 alloy castings should not provide a significant challenge if the machining method devised for these high Silicon alloys is followed and the castings have a well-defined microstructure. Cutting speeds that are far greater than those feasible with grey cast iron are possible.

Element	Cu%	Mg%	Si%	Ni%	Al
Composition	5.02	0.65	17.54	0.8	Balance

Table: 1. composition of aluminum LM30

3.2 Graphene powder:

Carbon atoms are organized in a honeycomb pattern on a one-atom-thick sheet of graphene. Graphene is the world's thinnest, strongest, and most electrically and thermally conductive substance. All these features are attracting the attention of scientists and businesses throughout the world since graphene has the potential to change whole sectors in the domains of electricity, conductivity, energy generation, batteries, sensors, and more.

APS (nm)	**Purity**	**Molecular weight(g/mol)**	**Form**	**Density (g/cm3)**	**solubility**	**Melting point**	**Color**
80-100mm	99.9%	12.01 g/mol	Powder	2.26 g/cm3	Insoluble water	3690◦c	Black

Table: 2. Composition of graphene

3.3 Garnet powder:

Garnet powders, a waste product of the garnet polishing industry, are potential materials for use in concrete, like pozzolanic materials like silica fume, fly ash, slag, and other pozzolanic minerals. These materials can be used as a filler to reduce the number of voids in concrete.

APS (µm)	**Purity**	**Molecular weight(g/mol)**	**Form**	**Density (g/cm3)**	**solubility**	**Melting point**	**Color**
80-100	99.9%	225.295	Powder	4.45	Insoluble in water	1950◦c	Brown, Red

Table No:3. composition of Garnet

4. Sample preparation Procedure:

The LM30 Al alloys is used to prepare sample specimens with combination of Graphene and garnet.

4.1 Crucible Induction Furnace :
A crucible induction heating furnace is essentially a water-cooled induction coil surrounded by a refractory ramming compound lined oven. The lining acts as a crucible for melting the metal. The electromagnetic forces created by the magnetic field interacting with electrical currents raise the temperature of the bath and agitate the cast metal. The lower the frequency, the higher the agitation, and the more consistent the bath. Steel and iron mills employ these furnaces, although they can also be used for nonferrous metals. Casting precious metals is usually done in a medium-frequency graphite crucible induction furnace. For specific casting applications, the crucible and inductor can alternatively be put in a vacuum chamber.

4.2. Sample Compositions:
The stir casting method was used to make LM30 material compositions containing graphene, nickel, fly ash, and a garnet-based alloy. Stir casting is one of the most useful methods for producing an LM30 with graphene, nickel, fly ash, and garnet-based alloy because it aids in the uniform distribution of the new alloy in the molten metal. The steering speed was 1000 rpm at 300 degrees Celsius for 30 minutes to prepare the graphene, nickel, fly ash and garnet-based alloy samples with varying weight percentages. The moisture in the powder was removed by preheating it. The aluminum alloy LM30 metal was then melted in the crucible for a few minutes at 750 degrees Celsius, and different weight percentages of the alloy were added to generate four different compositions of varying grades. The molten mixture was initially stirred by hand, then by a mechanical stirrer for a few minutes at 1000 rpm to evenly distribute the powder. By milling, the final samples with a diameter of 12 mm and a length of 30 mm were created. For further investigation, the surface of the pins created are cleaned with 150 grade emery paper and acetone.

4 stir casting compositions are
1. Aluminum alloy LM30+1% Graphene +0.8% Nickel
2. Aluminium alloy LM30+1.5% Graphene+0.8% Nickel
3. Aluminum alloy LM30+1% Fly ash+0.8% Garnet
4. Aluminum alloy LM30+1.5% Fly ash +0.8% Garnet

Graphene, nickel, garnet, and fly ash were added to the four aluminum Alloy LM30 compositions to create a new one. For that novel composition, the material was heated in an induction furnace and agitated at 100 rpm before being die-cast into the desired shape. After that, the specimen was put through three mechanical tests: tensile, hardness, and impact strength.

5. Mechanical Test methods:

5.1. Tensile strength:
The tensile test is carried out using the "ASTM E8-2016a" technique. Tensile tests are used to determine the tensile properties of a material, such as its tensile strength. Tensile strength refers to a material's ability to withstand the most tensile stress possible. A suitable specimen must be collected before a tensile test can be performed. This specimen's size and characteristics should meet ASTM standards. Before the test, the cross-sectional area and a pre-determined gauge length can be calculated and indicated.

Figure: 1. Tested sample for Tensile strength

Tensile strength	LM30+1% Gr+0.8Ni	LM30+1.5% Gr+0.8Ni	LM30+1% ash+0.8Gar	LM30+1.5%ash +0.8Gar
yield load(k N)	24.12	18.2	38.12	23.2
yield stress(N/mm^2)	157.25	76.2	149.18	89.691
Elongation %	12.2	12.2	12.4	12.6
Maximum load(k N)	200	200	200	200
MaximumTensile strength(Mpa)	208.13	211.56	217.56	192.35
Specimen Diameter(mm)	12.02	12.01	12.3	12.07
Initial Gauge(mm)	50	50	50	50
Final Guage(mm)	52.3	52	52.4	51.7
Load at peak(kN)	26.1	34.32	53.04	36.052

Table:4. Tensile strength Tested sample values

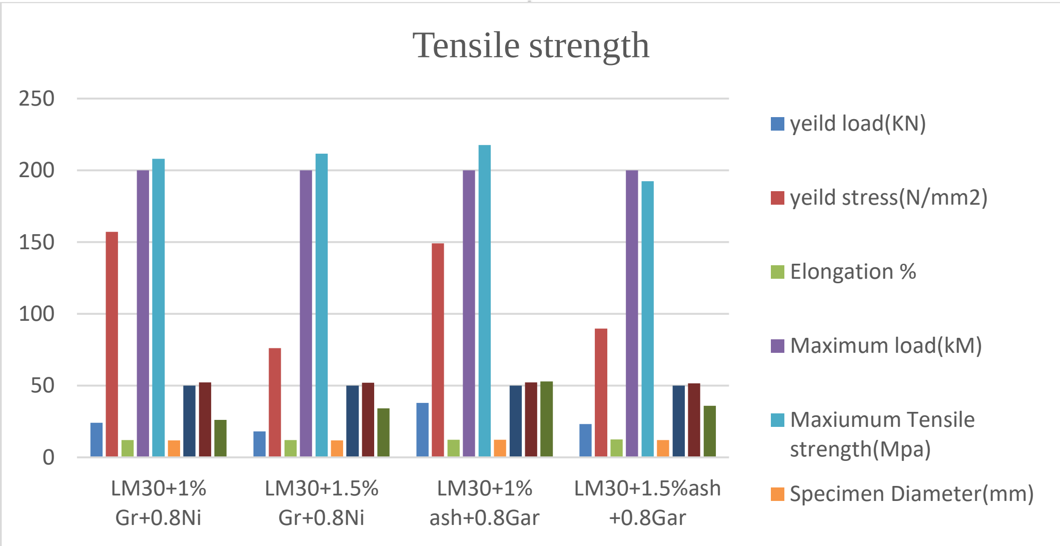

Figure :2.Tensile Strength Tested compositions

1. Tensile toughness when stresses less than the tensile strength are removed, the maximum load that a material can support without fracture when stretched is divided by the original cross-sectional area of the material. When stresses less than the tensile strength are removed, the material returns to its original shape and size, either completely or partially. Tensile strength of four samples (Aluminum alloy LM30+1 percent Graphene +0.8 percent Nickel, Aluminum alloy LM30+1.5 percent Graphene+0.8 percent Nickel, Aluminum alloy LM30+1 percent Fly ash+0.8 percent Garnet, Aluminum alloy LM30+1 percent Fly ash+0.8 percent Garnet, Aluminum alloy LM30+1 percent Fly ash+0.8 percent Garnet as yield strength, Aluminum alloy LM30+1 percent Fly ash+0.8 percent Garnet as yield strength The maximum stress that can be applied along a material's axis before it begins to change shape is known as its yield strength.

2. The fourth sample had the most elongation, whereas the first and second samples had the lowest.
A material with high ductility is more likely to deform (but not break), while a material with low ductility is brittle and will rapidly fracture under a tensile load. When combined with superior tensile strength, a higher % elongation usually suggests a higher-quality material.

3. Maximum load was consistent across all four samples, and ultimate strength is another essential attribute. This is the maximum load that the specimen can withstand during the test. Percent elongation gauges the material's ductility. Before testing, most samples are labeled with a gauge length.

4. The third sample has the highest tensile strength, while the fourth sample has the lowest. The maximum stress a material can endure without breaking when being dragged or stretched is known as tensile strength. In many applications, high-tensile-strength polymers can replace metal, saving weight and money without compromising performance.

5.2 Hardness test:

Brinell hardness testing is carried out using an Optical Brinell Hardness Tester (Model OPFB-3000, FTM) for the generated LM30 aluminum alloy-based composites and unreinforced LM30 aluminum alloy. The hardness test is carried out according to the ASTM E10 standard. The samples are loaded with 500 kg and indented with a 5 mm tungsten ball indenter for 15 seconds. The indentation diameter is directly measured using the built-in optical instrument. The equation is used to compute the Brinell hardness number (BHN) for the samples. Furthermore, each sample's hardness value is assessed at four separate sites, with the average value of hardness considered. The samples were used to determine hardness. The Brinell scale measures the depth of penetration of an indenter loaded on a test piece to determine the indentation hardness of a material. It is one of several hardness definitions used in material science.

Figure 3: Tested sample for Hardness test

Composition	Hardness(HRB)					Average
LM30+1% Gr+0.8Ni	95	102	102	101.6	102.1	100.54
LM30+1.5% Gr+0.8Ni	76.2	85	82	80	81	80.84
LM30+1% ash+0.8Gar	84	83.6	88.3	85.23	84.2	85.066
LM30+1.5%ash +0.8Gar	79	76.44	77.75	77.66	77.4	77.65

Table:5. Tested sample values of Hardness test

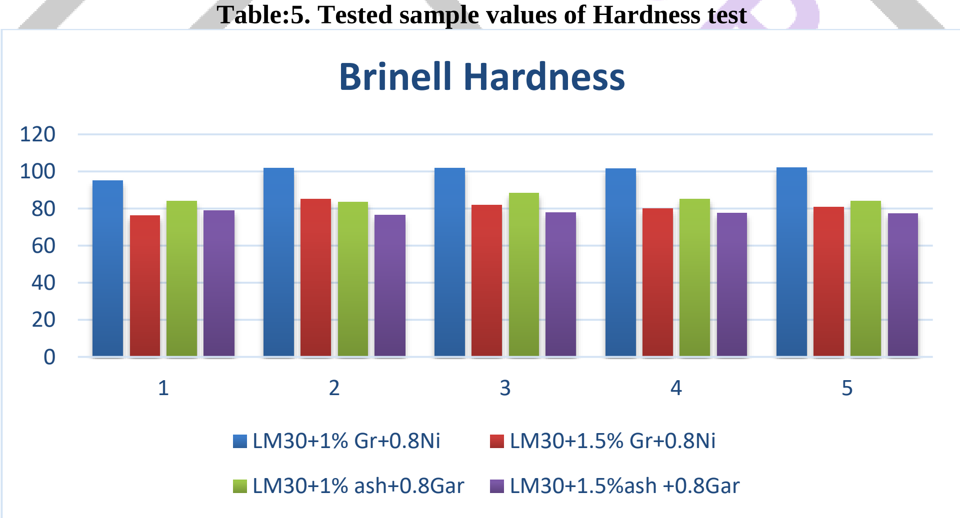

Figure: 5. Tested compositions of Hardness test

The Brinell hardness test is a method for determining the hardness of materials such as metals and alloys. It is preferable to limit the test load to an impression diameter of 2.5mm to 4.75mm. It describes a metal's resistance to persistent indentation deformation. The hardness of a material indicates how resistant it is to being penetrated by a spherical indenter under controlled conditions. The graph above depicts the many types of samples. It was discovered that sample 4 has a high level of BHN. We acquired four readings for each sample since we produced four samples for each setup.

5.3 Method of impact testing:

Impact testing machine the fracture toughness of as-cast and aged as-cast samples were tested using the Charpy Impact test machine. As demonstrated, Charpy Impact specimens were manufactured according to ASTM E23-12c standard. The impact test specimen is struck in the direction by the striking pendulum of the machine with a capacity of 300 J and no additional weights. The amount of energy absorbed throughout the test, as well as the fracture initiation and propagation energies, were all measured. The average values of the energy acquired from the two test specimens were calculated and recorded. Impact strength refers to a substance's

capacity to sustain a quick impact. The impact test was conducted in a Charpy impact testbed, as shown in the illustration. The tests were performed in line with "ASTM D 256" using an impact tester. The impact test specimen was 10mm X 10mm X 55mm thick and measured 10mm X 10mm X 10mm thick. The specimen was placed horizontally in the testbed, as seen in the photograph. The pendulum was lifted from its standard height and made to strike the specimen.
Test procedure: lS 1757, Notch depth: Charpy-V, NOTCH Angle-45◦c.

Composition	Impact1(J/min)	Impact2(J/min)	Average(J/min)
LM30+1% Gr+0.8Ni	22	0	22
LM30+1.5% Gr+0.8Ni	30	0	30
LM30+1% ash+0.8Gar	24	0	24
LM30+1.5%ash +0.8Gar	26	0	26

Table:6. Tested sample Values of Impact strength

Figure:6.Tested sample of Impact strength

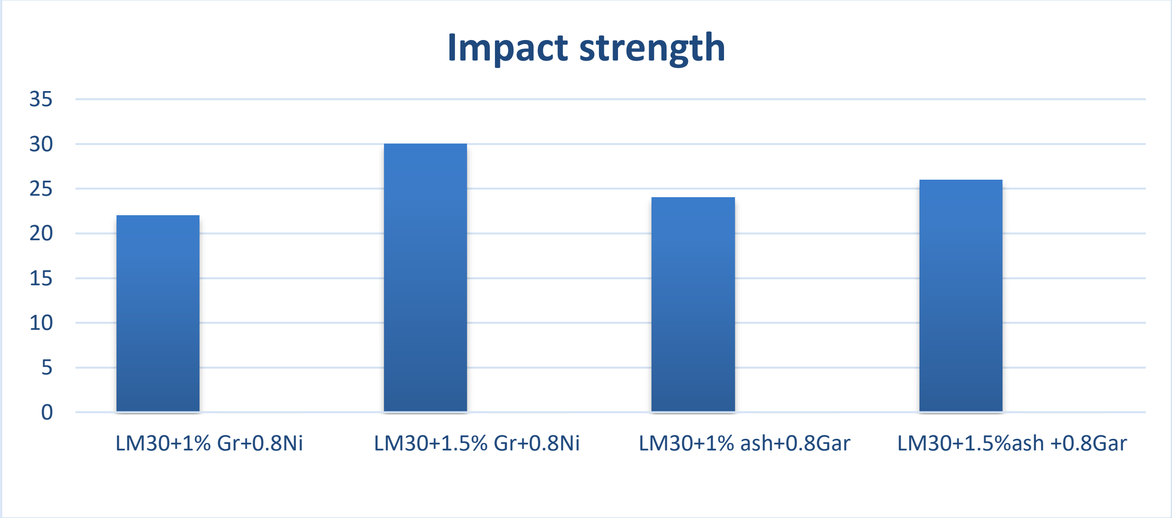

Figure:7. Tested compositions of Impact strength

The material can bear a suddenly applied force and is assessed in terms of energy using the load impact strength test or the Charpy impact test, which both measure the impact energy necessary to fracture a sample. Stresses must be dispersed uniformly throughout the object for a material or object to have a high impact strength. It must also have a big volume, a low modulus of elasticity, and high yield strength of the material. According to the graph, sample 2 has a high impact, while sample 1 has a low influence. 1 It is a measurement of the amount of effort required to fracture a test specimen. When the striker hits the specimen, it absorbs the energy until it yields.

6. Taguchi's method of using the Mini tab is as follows:

Taguchi's design of experiment method was adopted for their experimentation. The Taguchi method of DOE aids in reducing the number of experiments required. Minitab software was used to establish four levels and four factors for experimentation. UTS(MPA), Hardness (HRB)Impact are the factors used (Joules).

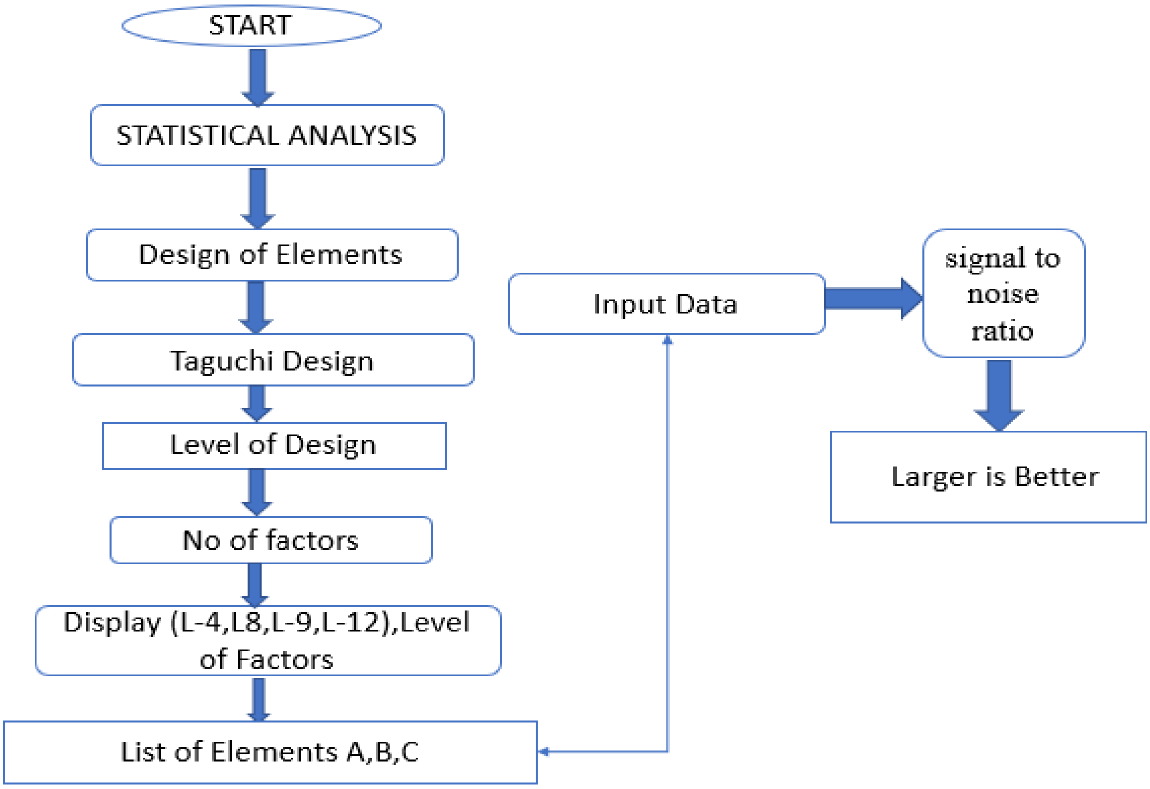

Figure:8. Flow chart of Mini tab software process

7. Results and discussion:

Fly ash	Garnet	AL LM30	UTS(Mpa)	Hardness (HRB)	Impact (J/min)	SNRA1	SNRA2
1%	0.6%	AL LM30	215.4	82	25	32.29080753	-42.5323
1%	0.8%	AL LM30	217.5	85.1	24	31.9943569	-42.6422
1.5%	0.6%	AL LM30	195.2	75	25	32.20879328	-41.698
1.5%	0.8%	AL LM30	192.3	77.6	26	32.53782002	-41.6313

Table:7.Taguchi method Results of both Fly ash and Garnet

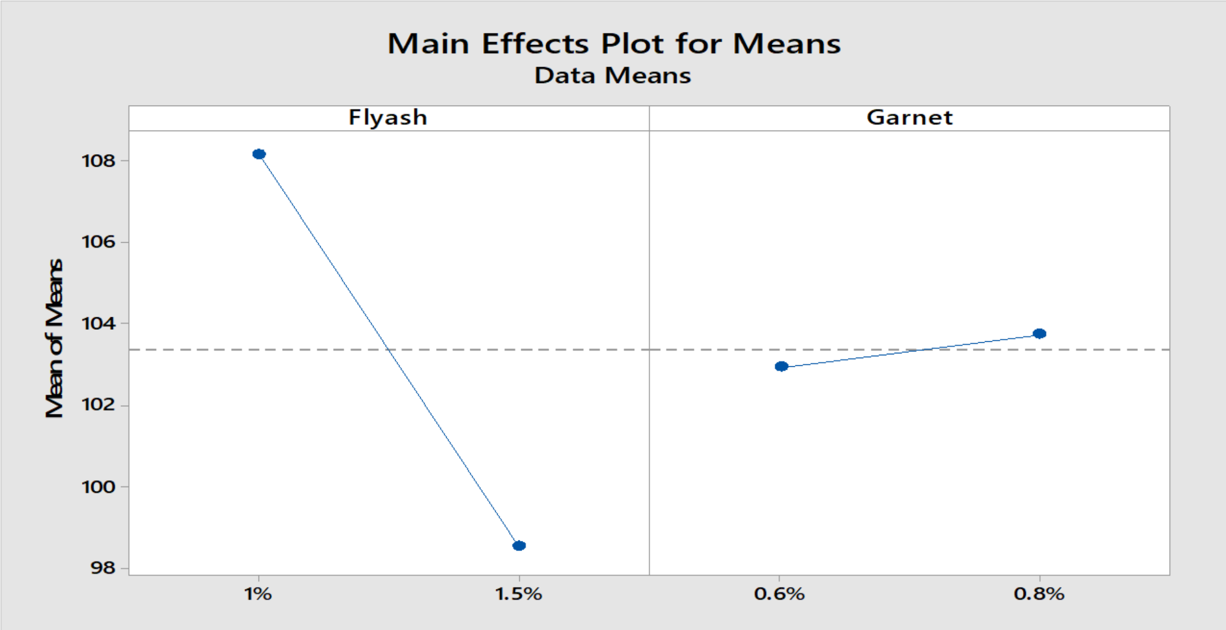

Figure:9. Mean of means results of fly ash and Garnet

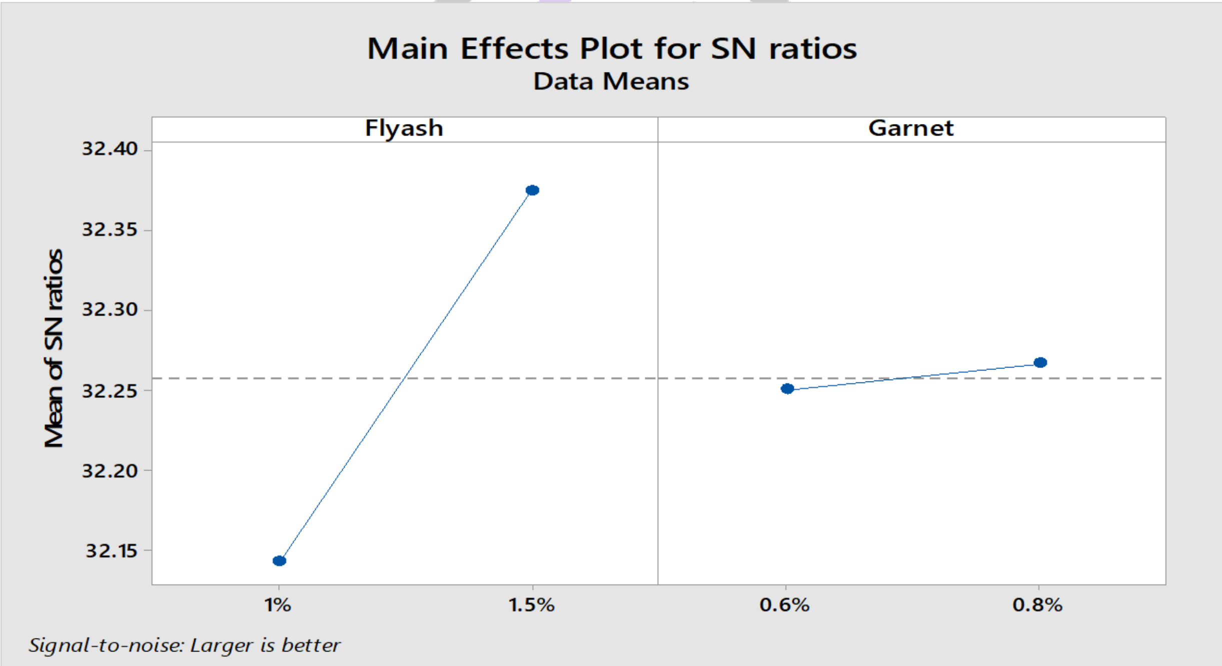

Figure: 10.Mean of SN ratios results of Garnet and fly ash

Response Table for Means Response Table for Signal to Noise Ratios **Larger is better**

Taguchi Array	**L4(2^2)**
Factors:	2
Runs:	4

Level	**Fly ash**	**Garnet**
1	32.14	32.25
2	32.37	32.27
Delta	0.23	0.02
Rank	1	2

Level	**Fly ash**	**Garnet**
1	108.17	102.93
2	98.52	103.75
Delta	9.65	0.82
Rank	1	2

Tables: 8. levels of Fly ash and garnet

Graphene	Nickel	Al Alloy LM30	UTS (Mpa)	Hardness (HRB)	Impact (J/min)	SNRA1	MEAN1	SNRA2	MEAN2
1%	0.6%	Al Alloy LM30	206.4	95	26	32.69334274	109.1333	-42.414	109.1333
1%	0.8%	Al Alloy LM30	208.8	100.2	22	31.36944139	110.3333	-42.5625	110.3333
1.5%	0.6%	Al Alloy LM30	200	82	24	31.96126064	102	-41.9774	102
1.5%	0.8%	Al Alloy LM30	211.5	81	30	33.67920091	107.5	-42.4049	107.5

Table:9.Taguchi results of Both Graphene and Nickel

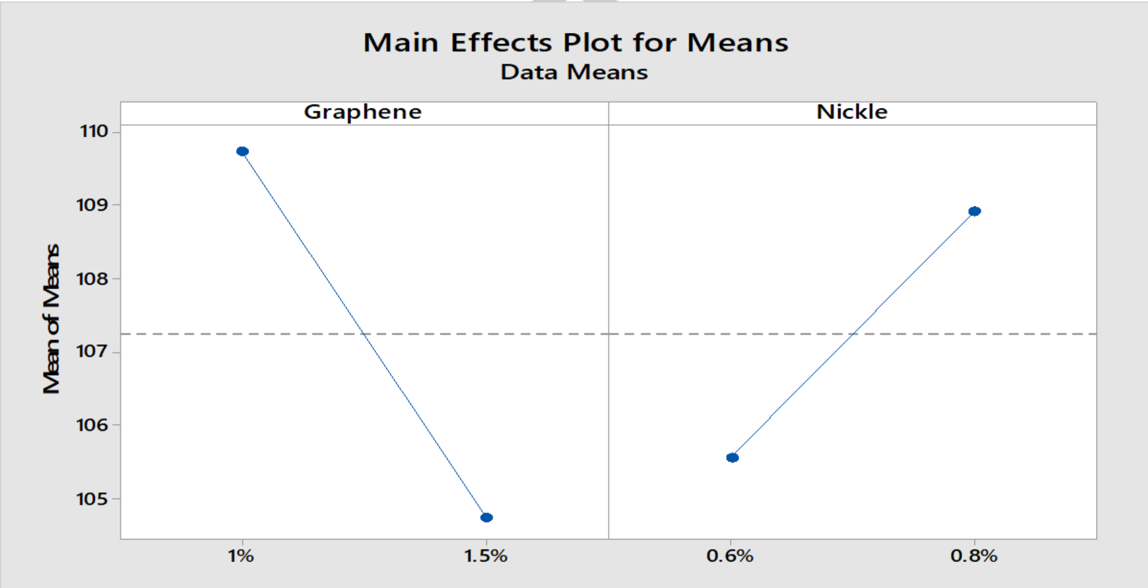

Figure:11.Mean of means of Graphene and Nickle

Response Table for Signal to Noise Ratios, Columns of L4(2^3) array: 1 2

Larger is better

Level	Graphene	Nickel
1	32.03	32.33
2	32.82	32.52
Delta	0.79	0.20
Rank	1	2

Taguchi Array	L4(2^2)
Factors:	2
Runs:	4

Level	Graphene	Nickel
1	109.7	105.6
2	104.8	108.9
Delta	5.0	3.3
Rank	1	2

Tables:10.Levels of Graphene and Nickel

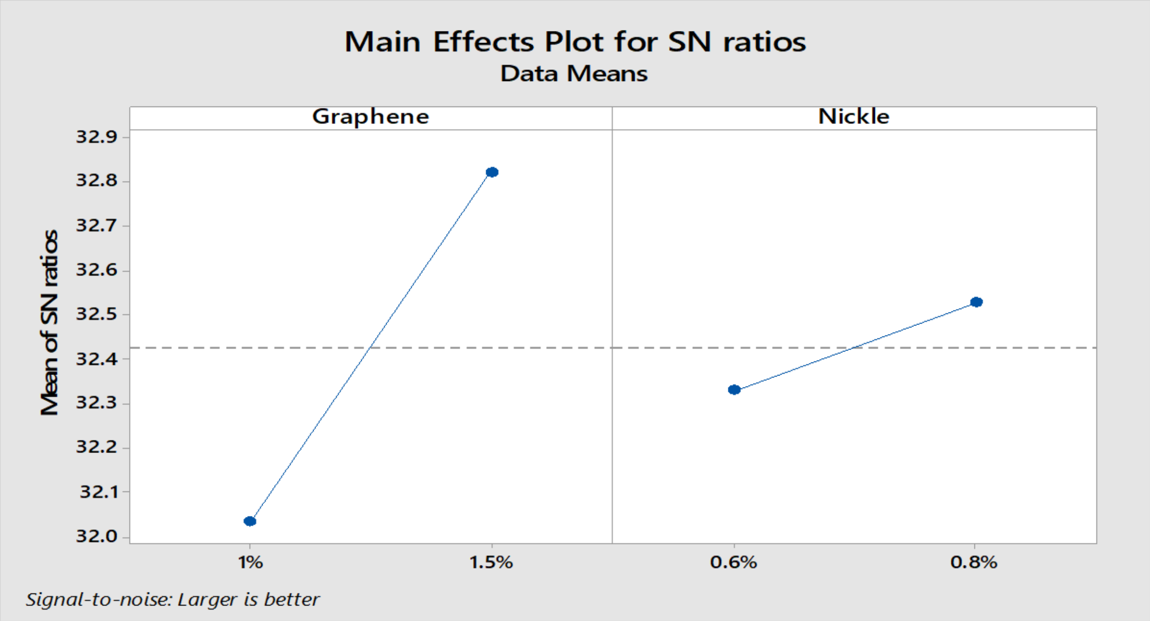

Figure:12. Mean of SN ratio of Graphene and Nickel

Furthermore, the Taguchi approach enables the examination of a wide range of parameters without requiring an excessive number of experiments. Tensile, Impact, and Hardness, for example, are three factors that are tested in a procedure. Graphene, Nickel, Fly ash, and Garnet are the four compositions.

Conclusion:

By lowering component weight and thus enhancing engine performance, aluminum (LM-based) has unique mechanical and corrosion resistance qualities. As a result, LM Series alloys are utilized in automobiles. These LM-based aluminum alloys are unusual due to their tensile, hardness, and impact properties. They can be made in a variety of ways, including stir casting, liquid metallurgy, and die casting, with each approach improving the required qualities based on the requirements and applications. According to the above-mentioned findings, LM-based aluminum alloys are encouraged in the continuous development of MMC technology for automobile engine applications, including engine blocks and selective cylinder area strengthening. In this study effect of the condition of Graphene, Nickel, Garnet, and fly ash of LM alloy was investigated, and the Taguchi method was also analyzed, and from the results obtained above following conclusions can be made. From among four samples of all mechanical test methods and Taguchi methods we conclude that

1. Tensile strength is as high for the third sample and fourth sample as the lowest.
2. Sample 4 is an as high level of BHN, low-level BHN is sample 1 from the Brinell hardness test.
3. Sample 2 has high impact strength while sampling 1 has low influence.

References:

[1] A. J. Clegg, Elsevier, 1977, pp. 367-376, "Wear of A Hypereutectic Aluminum-Silicon Alloy."
[2] S. Das, "Microstructure and Wear of Cast (Al-Si Alloy)-Graphite Composites," Wear, vol. 2, no. 2, pp. 173-189, 1989. [3] Sandeep Sharma, Ceramics International, Elsevier, 2017. "Effect of Particle Size on Dry Sliding Wear Behavior of Sillimanite Reinforced Aluminum Matrix Composites."
[4] Sourav Das, "Analysis of Aluminum Alloy Brake Drum for Automobile Application," International Journal of Scientific and Technology Research, Vol. 2, Issue 11, November 2013.
[5] Hani Aziz Ameen, "Effect of Loads, Sliding Speeds, and Times on the Wear Rate for Different Materials," AJSIR, vol. 2, no. 2, pp. 99-106, doi:10.5251/ajsir.2011.2.99.106.
[6]. Aluminum and Aluminum Alloy Corrosion, ASM International, J.R. Davis, Ed., 1999
[7]Abdul Saheb, Newal Muhammad Dawood, Newal Muhammad Dawood, Newal Muhammad Dawood, Newal Muhammad Dawood, Newal Muhammad Da Materials Dunia Engineering Collage, Babylon University Al matrix with SIC particle reinforcement
[8] Aluminum and Aluminum Alloys, in J.R. Davis, Ed., ASM International, 1998, Metals Handbook Desk Edition, 2nd ed., p 417–505.
[9]. Institute of Technology Taillight, Institute of Technology, Uncontrolled Copy, (c) BS Yashpal c.s. Jawalkar, Suman Kant manager's Journal on Material Science, Vol. 3 l No. 3 l October - December 2015.
[10]. Review on the use of Aluminum Alloys in Aircraft Components, Yashpal c.s. Jawalkar, Suman Kant manager's Journal on Material Science, Vol. 3 l No. 3 l October - December 2015.
[11] T. Miyajima and Y. Iwai, "Effects of reinforcements on sliding wear behavior of aluminum matrix composites," Wear 255, 606–616 (2003).
[12]Mortensen A, Wong T. Metal Trans A; Vol 21 A: pp 2257–63. [12]. Mortensen A, Wong T. Metal Trans A; Vol 21 A: pp 2257–63.

[13] Y.M. Pan, M.E. Fine, and H.S. Chang, "Wear mechanism of aluminum-based metal matrix composite under rolling and sliding contraction in the technology of composite materials," P.K. Rohatgi, P.J.B. Ian, and C.S. Yune (Eds.), ASM International, 1990, pp. 93–101.
[14] S.V. Prasad and P.K. Rohatgi, "Tribological properties of Al alloy particle composite," J. Metall. 39, 22 (1987).
[15] L. Cecchini, C. Bosi, A. Casagrande, and G.L. Garagnani, Wear 251 (2001) 1377–1385, "Effect of heat treatment and recycling on the tribological behavior of an AlSiMg–SiCp composite."