MEE2014

Metal Casting Technology

J-COMPONENT PROJECT REVIEW

Title: **Identification of suitable reinforcements to make aluminum metal matrix composite for a piston by stir casting method.**

Declaration

We the undersigned solemnly declare that the project report on the topic DEVELOPMENT OF METAL MATRIX COMPOSITE BY STIR CASTING is based on our own work carried out during the course of our study under the supervision of Dr. Chinmaya Prasad Mohanty, Senior Assistant Professor, School of mechanical engineering VIT. We assert the statements made and the conclusions that are drawn are outcomes of our research work. We further certify that the work contained in the report is original and has been done by us under the general supervision of our supervisor. The work has not been submitted to any other Institution for any other degree/diploma/certificate in this university or any other University of India or abroad. We have followed the guidelines provided by the university in writing the report. Whenever we have used materials (data, theoretical analysis, and text) from other sources, we have given due credit to them in the text of the report and given their details in the references.

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Identification of suitable reinforcements to make aluminum metal matrix composite for a piston by stir casting method.

Abstract

Aluminum metal matrix composites are widely used in automotive industries for manufacturing various parts of an automobile. Usually, composites contain two reinforcements. In this project, four different combinations of reinforcements are proposed with Aluminum as the matrix.

Objectives

To identify suitable reinforcements to make Aluminum-6061 metal matrix composite for a piston by stir casting method.

Introduction

Metal matrix composites(MMCs) are composed of a metallic matrix such as aluminum, magnesium, iron, etc. with a dispersed fiber that could either be metals like gray cast iron reinforced with aluminum alloy or ceramics like SiC. The metallic fiber examples are tungsten, molybdenum, lead, etc. The ceramic reinforcements are oxides, carbides such as cemented carbides, and other carnets. The composite materials are usually composed of two phases with different properties, namely reinforcement, and matrix. The reinforcement material is dispersed in the matrix material and the interface between the two phases is prepared. Aluminum alloy and AlMMCs are widely recognized materials that are used in industries like aerospace, transportation, and automotive machinery. **Stir Casting** is the simplest and cheapest way to make AlMMCs. The solid reinforcement is blended into liquid metal and then allowed to solidify into a suitable mold. The reinforcing material is slowly being added to the melted material.

Challenges faced with composite materials:

1. Many of the constituents of composite materials are expensive and a careful selection needs to be made to control the costs involved.
2. Repairing composites is not an easier task, particularly for doing on-site. Depending upon the composite and specific processing involved in its original manufacture, not all facilities such as hot curing may be readily available on site.

Literature Survey

Fabrication Methods

Stir casting, also known as the vortex technique is the simplest and most commercially used technique. The particulate reinforcements are incorporated into liquid aluminum and the composite is then allowed to solidify. Good wettability between the matrix and reinforcements plays an important role in this process. AMMCs' thermal coefficient of expansion, which can be tailored to zero makes them suitable for avionics applications.[5]

The nano SiCp reinforced Al-MMNCs despite showing good mechanical properties over the unreinforced alloys. The microstructural evaluation showed the uniform distribution of nano SiCp in the metal matrix, as well as strong bonding between the particle and matrix at the interface. The porosity levels obtained in these composites are within acceptable limits. The most common technique used in the production of Al-MMNCs is powder metallurgy. The spark plasma sintering and ultrasonic-assisted casting can be used for high sensitivity parts which is a more expensive process. [26]

In powder Metallurgy, powder compaction & particle size both are the most important parameters. Which will affect the mechanical properties. In stir casting methods, pouring temperature, stirring speed & wetting elements are the most important parameter. Powder Metallurgy & Stir casting methods, both are very important methods for the fabrication of metal matrix composites. But stir casting methods are more commonly used for the fabrication of metal matrix composites due to their economical, Molten metal flow is uniform as well as better distribution of particles. [23]

Fly Ash(FA) is an effective reinforcement for MMCs as it mitigates negative environmental impacts. The friction stir process(FSP) utilizes the frictional heat generated by rubbing the tool with a metallic material to make it plasticized. The material matrix never melts and the composite is produced in the solid-state. Since it does not involve solidification, there is no segregation of FA particles from the matrix due to density gradient, and its distribution is fairly homogeneous. It is an economical process with minimum energy consumption. The FA particles fragment due to the high strain produced. This fragmentation produced debris that instead of agglomerating around larger particles, mixed well in the matrix. This fragmentation does not change the composition of FA particles and is more uniform with copper and magnesium alloy which required higher flow stress to plasticize. A groove was made on the metal and was compacted with FA particles. The grooved top was closed using a pinless tool and then two passes were applied in opposite directions using the tool with a pin. The grains of the composites were extensively refined due to the dynamic recrystallization and pinning effect of FA particles. Microhardness of all the composites increased and FSP was identified to be a suitable process for reinforcing FA particles in metal matrix composites.[1]

The expense in the manufacturing of MMCs using the stir casting process is very low in comparison to other competitive processes, and the cost is expected to decline more for production of high volume. The main issue in this method is to gain satisfactory wetting of the particles through the molten metal in liquid form and to obtain a continuous distribution of the reinforcement particles.[17]

Stir casting parameters

The selection of the stirring parameters over the properties of the stir-casted composite is desired for the current demand of the industries. The position of the impeller is suggested to keep at more than 25–30% of the height of the liquid from the base of the crucible to avoid particle clustering. Further, the optimal value of impeller Blade angle must be at 30 deg to achieve a suitable combination of axial flow and shearing action with lower power consumption. The diameter of the impeller should be in the range of 50–55% of the diameter of the crucible to avoid particle concentration at the center of the base of the crucible. Moreover, the range of stirring speed may vary depending upon the properties of the reinforcements and matrix material, wettability, and chemical properties from 200 to 1000 RPM. [19]

Process parameters-

a) **Stirrer speed-** Stirring is considered an important factor that facilitates the homogeneous distribution of the reinforcement particles in the molten metal.
b) **Stirring period-** The stirring period is considered important, more stirring contributes to consistent particle distribution and less stirring creates particle clustering at certain places.
c) **Pouring temperature-** The Pouring rate should be uniform and the pouring temperature should be sufficiently high.
d) **Wetting elements-** Magnesium can be added to liquid aluminum to enhance wettability because it reduces the surface tension. The presence of magnesium also enhances the strength of the alloy.
e) **Reinforcement preheating-** heat the reinforcement particles at high [19]

A lower stirring time is beneficial as it is economical and also avoids reaction between matrix and reinforcements. Higher casting duration might lead to entrapment of a larger amount of porosity after solidification. 3 samples were tested with different stirring times and temperatures. A sample with 2 minutes of stirring time showed detachment of ceramic particles due to loose connections indicating that a minimum stirring time is required for ceramics to form a strong bond with the matrix. Increasing the temperature from 680 to 850 celsius, resulted in a reduction of mechanical properties. [11]

Aluminum metal matrix composites

Aluminum is simple to handle, lightweight, and has good corrosion resistance, high strength, as well as its economical manufacturing, which is possible through many methods of production. Applications of Aluminum MMCs can be found in the automotive, electronic, aerospace, and aircraft industry, sports, and recreation equipment, electrical transmission, defense applications, marine and rail transport, and construction and building industry. [4] [28]

SiC is one of the most commonly used ceramics owing to its excellent mechanical properties. Addition of solid lubricants such as molybdenum disulfide, Graphite, and hBN decrease the mechanical properties of the base metal. This work dealt with finding the ideal solid lubricant that complements SiC. When compared to Al7075, Al7075 + 5%SiC+5%Gr alloy has improved in Vickers hardness number by 44.3%. The tensile strength of the Al7075 + 5%SiC+5%Gr has increased by 277.6% when compared to Al7075. Al7075 + 5%SiC+5%Gr alloy has improved its compressive strength by 25.8% when compared to Al7075. The specific wear rate of Al7075 + 5%SiC+5%hBN decreased by 92.9%, 36.8% and 88.6% as compared to Al7075, Al7075 + 5%SiC+5%Gr and Al7075 + 5%SiC+5%MoS2 respectively. The effect of graphite reinforcement over Al7075 alloy has a significant increase in static mechanical properties owing to the synergy of SiC and graphite ceramic particles. Stir casting ensured an even distribution of reinforcements.[2]

AA 6061 aluminum alloy was used as matrix material in the fabrication of hybrid composite material in which Al2O3 was used as a primary reinforcement content and Fly-ash as secondary reinforcement content. Results concluded that the addition of Al2O3 and Fly-ash in AA 6061 alloy had improved the tensile strength and hardness of the composite. Tests performed- Tensile strength examination, Hardness, Ductility (percentage elongation). [18]

Stir-formed Al alloy 6063 with Al2O3 reinforced composites is superior to base Al alloy 6063 in the comparison of tensile strength, Impact strength as well as Hardness. Dispersion of Al2O3 particles in the aluminum matrix improves the hardness of the matrix material.[20]

Experiments were conducted on the Al7075 to determine the density by weight to volume ratio and by the rule of mixture. The experimental and theoretical densities of the composites were found to be in line with each other. There is an increase in the density of the composites compared to the base matrix. The hardness of the composites was reviewed and in the conclusion, it is discovered that as the reinforcement contents increased in the matrix material, the hardness of the composites also increased. Further, the tests conducted to determine the same indicated the (Vickers and Brinell's hardness) increased hardness with increased reinforcement contents when compared with the base matrix. From the literature, it can be concluded that the ceramic-reinforced Al-7075 MMCs will have better wear resistance than the unreinforced alloys. [24]

The AA 6XXX aluminum alloy series in which silicon and magnesium are the principal alloying elements is gaining particular interest in the aviation and automotive industries. AA 6061 is one of the most popular alloys in the 6XXX series. The research paper consists of studies related to the AA 6061 composites fabricated through the stir-casting method classified according to the reinforcements used and are as follows:

1. AA 6061-SiC composites
2. AA 6061-B_4C composites
3. AA 6061-Al_2O_3 composites
4. AA 6061-TiC composites
5. AA 6061 composites with other reinforcements (other than SiC, B_4C, Al_2O_3, TiC)
6. AA 6061-hybrid composites
7. AA 6061-nanocomposites [21]

The hybrid composite of aluminum matrix, utilizing zirconium dioxide and graphene as strengthening materials is processed by the stir casting method, as it is one of the most economical methods suitable for mass production. Al6061 + 1 wt.% zirconium dioxide + 0.75 wt.% graphene showed 182 MPa yield strength, 250 MPa tensile strength and 7.8% elongation.[3]

As composite properties are dependent on particle type and volume fraction, the current systematic focused on Al_2O_3, B_4C, and SiC. Likewise, parameter recommendation is formulated for these particles. Current MMC research tends to be focused on material property enhancement. However, it is suggested that nanoparticles may have a lower reinforcement content threshold as the presence of a large number of nanoparticles tends to promote agglomeration and induce porosity. In contrast, micro-reinforcement has a higher chance of success at higher volume fractions, allowing both particle incorporation and mechanical properties. [22]

As a more cost-effective, economical, and prominent method for developing and processing metal matrix composite materials, aluminum alloy-based casting composite materials are manufactured by the stir casting process. The resultant properties of the composite material hugely depend on the processing parameters, selection of matrix, and reinforcements. While many experiments were done to study 2,6 and 7xxx aluminum matrix reinforced with SiCp particles in order to achieve high strength properties, No such steps were taken to study about reinforcing aluminum matrix with Al_2O_3 reinforcements. Therefore, this research was conducted to investigate the composite material properties developed by using the 7xxx series of the aluminum matrix that also contains Cu-Zn-Mg reinforced with alpha Al_2O_3 particles using the Stir Casting Process. For experimental purposes, various alloys of aluminum were prepared by taking various proportions of Cu, Mg, Zn, and Al. The developed alloys were purged with N_2 gas for a few seconds. The required quantities of "$Al_2 O_3$ " particles were added in 2.5, 5, 10, and 15% weight percent. The ceramics were then stir-casted at a casting temperature of 750 degrees Celcius.

Various tests were then conducted to study the composite materials with different percentages of Al_2O_3 and the following was concluded:

- The aluminum alloy matrix was successfully developed using Cu, Zn, and Mg metals and reinforced with Al_2O_3 particles
- A 10% Al_2O_3 in aluminum matrix increases the tensile strength to 297 MPa and an elongation of 17%
- Less than 2.7%Cu in the alloy also increases strength and ductility
- The porosity of the aluminum matrix increases with an increase in Al_2O_3 composition [8]

Composites were effectively manufactured by utilizing techniques of stir casting and the SEM displayed reasonably standardized distribution in the Al7075 metal matrix of reinforcement particles. It is demonstrated that the hardness improves with the matrix varying wt% of reinforcing materials. An increase in tensile strength, impact strength, and also stiffness has culminated in the particle inclusion by TiC and SiC. The tensile strength increased when changing the wt% of reinforcement particles in the base alloy. However, further advances in functional properties also culminated in the inclusion of these reinforcement products. As the reinforcement content increases the tensile strength, impact strength, and hardness increase up to 15 wt% of TiC and SiC reinforcement and slightly decrease at 20 wt% SiC and TiC reinforcement. From the investigation, it was concluded that composites containing 15wt% Titanium carbide and 15 wt% SiC reinforcements exhibited better mechanical properties. [25]

Wear resistance and self-healing

In this composite Al-6103, 98% pure alloy was used as a matrix material. Alumina and SiC which is 99% pure in powder form and grain size is 200 meshes were added as reinforcement to the metal.8 wt% SiC and 1 wt% of Al_2O_3 reinforced AMCs show maximum hardness. The wear rate of composites increases with an increase in load. At higher load, wear rates of composites were higher due to the higher coefficient of friction. At higher reinforcement content wear rate is less because ceramic particles provide a lubricating film on the counter surface which lowers the coefficient of friction. Hence, lowers the wear rate of composite. [12]

When SiC content fixed is as 1 wt% and TiC content varied as (1, 1.5, 2, and 2.5 wt%), it is found that an increase in the reinforcement content of SiC-TiC particles increased the hardness because of their hard nature and decreased the density of composites due to volatile nature of ceramic particles. Improvement in wear resistance is also seen at higher reinforcement content because ceramic particles provide a lubricating film on the counter surface which reduces the coefficient of friction.[13]

Introducing self-healing properties intrinsically in metals is a challenging task. Generally, the healing of crack is achieved by the oxidation of metal under heat which fills the crack. In this case, though, the mechanical and thermal stability of the formed oxide plays a major role. But simultaneous decomposition and oxidation of Ti3SiC2 caused by frictional heat, shear stress, and severe deformation, can achieve healing of stress cracking. The repetitive fretting wear leads to a modest amount of 'flowability' of Ti3SiC2 toward the crack, facilitating crack recovery. [15]

Automotive Industry

- Metal Matrix Composites (MMC) are widely used in automotive applications because of their high strength-to-weight ratio, high stiffness-to-weight ratio, and excellent resistance to wear and corrosion.
- The composites can be strengthened by reinforcing particles, fibers, and whiskers.
- The metal matrix composites can be prepared using two or three reinforcements which offer better mechanical properties when compared to single reinforced composites. In addition, coating fibers or particles can be used as well to provide a better interface bonding between the matrix and the reinforcement.

Today's automotive industry is pushed to achieve as much fuel efficiency as they can and meet strict emission norms while providing the end consumer with quality and amenities that result in increased weight. This makes them have to work on using Metal Matrix Composites (MMC) for structural and other major parts of the vehicle like chassis, engine blocks, pistons, etc. These MMCs can be tailored to be lightweight with various other attributes like high strength, stiffness, hardness and wear resistance, etc. Doing so aids in not only reducing weight but also can improve reliability and efficiency. [6]

Al-MMCs behave differently from Al matrix under extreme processing and operating conditions. From experimentation, it is noticed that the Al-MMCs at 640°C for 1 hour and at a pressure of 13MPa exhibit high strength and ductility in comparison to other matrices. Similarly, AL-MMCs at 640°C for 2-3 hours at 13MPa exhibit the lowest yield strength and are brittle in nature compared to the monolithic Al matrix. A comparison between the stiffness of the base material and that of the substituted material shows that k_{base} material = 4 % while $k_{composite}$= 2.8 %. For example, the roof panel is one of the heaviest panels in the car body. In a passenger car, the steel roof panel weighs about 11kgs on average and it will be 78 % lighter using Al-MMCs reinforced by continuous steel fibers with V_f= 0 35. [7]

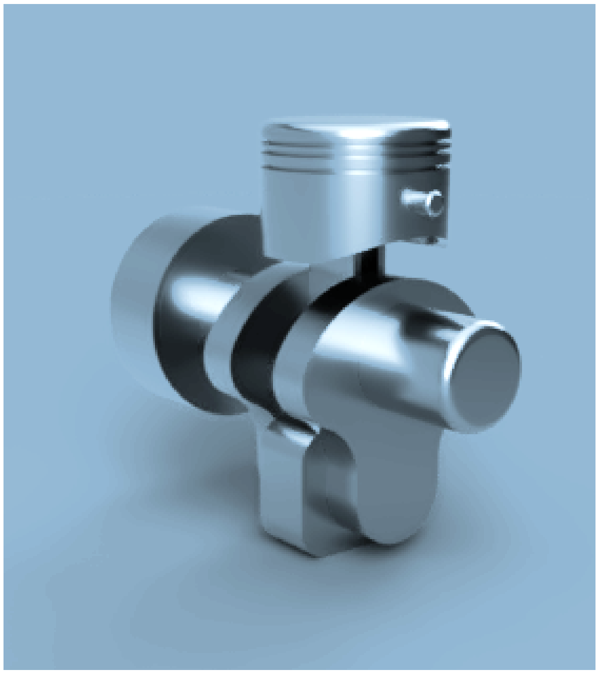
MMCs are preferred to be used in the automotive industry these days over other materials due to their lightweight, high impact strength, and high fatigue life. Components based on MMCs can result in a better auto component rather than those made with traditional materials. For the past few years, the demand for fuel efficiency and electrification has increased leading to a need for lightweight and high-strength parts in the auto industry. These reasons are why the research and development of MMCs have been of importance. Homogeneity is one of the most important properties of MMCs required for good performing components and this is achieved by modifying traditional casting methods such as **stir casting,** squeeze casting, etc. [9]

There are a number of properties that make Al alloys a good fit for automotive applications. But they exhibit poor resistance to galling and seizure. Reinforcing aluminum helps overcome these downfalls. Aluminum MMCs reinforced with SiC, Al2O3, and graphite particles by dispersion using different methods show a considerable decrease in wear due to friction, making them lightweight and more efficient. They also can withstand high mechanical and thermal loads. [10]

Metal Matrix composites can be used in automobile applications that require high fuel efficiency, safety, recyclability, and low emissions. These materials can be engineered to match the current and future requirements of the auto industry. The driving forces such as cost, durability and quality, safety, fuel economy, emissions, styling, performance, ride, handling, comfort, and recyclability put significant importance on ensuring that the technologies meet the requirements and are cost-efficient at the same time.[14]

Aluminum composites have several desirable properties for auto part manufacturers, however, at the same time, the machining and production of such composites tend to be on the expensive side of the spectrum. [27]

System Model



A piston was modeled for the purpose of Simulation and study of the test results. The software Fusion 360 was used for both the modeling and simulation.

Methodology

GENERAL PROPERTIES OF AL-ALLOYS

Alloy	Density (Kg/mm^3)	Young's Modulus (Gpa)	Poisson's Ratio	Yield Strength	UTS (Mpa)	Thermal Conductivity (W/mm C)	Coefficient of thermal expansion (/C)	Heat (J/ Kg C)
5052 (2.5% Mg, 0.25%Cr)	$2.68*10^{-6}$	70.3	0.33	193	228	0.138	$2.38*10^{-5}$	880
6061 (0.6% Si, 1.0%Mg, 0.2%Cr, and 0.28% Cu)	$2.7*10^{-6}$	68.9	0.33	275	310	0.167	$2.36*10^{-5}$	897
7075 (5.6% Zn, 2.5%Mg, 0.23%Cr, and 1.6% Cu)	$2.81*10^{-6}$	71.7	0.33	145	276	0.173	$2.34*10^{-5}$	960

Preparations :

Enter the simulation module by clicking on the icon in the top left of the toolbar. In the window that pops up after pressing Simulation select Static Stress.

In the browser on the left side, we can expand one of the entries (the one with the component icon) and check/uncheck which bodies/components you want to include.

Then we select what material the different bodies will be simulated as (aka. study material) by pressing the Material button

Structural Constraints:

Any simulation needs at least one constraint.

The fixed constraint is the most basic type of constraint where we select one or more face, edge or vertex that should stick in place no matter what. You can also select which axes it should be locked along.

Loading:

After the constraint(s) is/are in place we apply the load. There are several types of static load we can simulate (pressure, moment, etc.)

Force can be applied to either a single or multiple faces, edges or vertices. The magnitude must be specified (in Newtons).

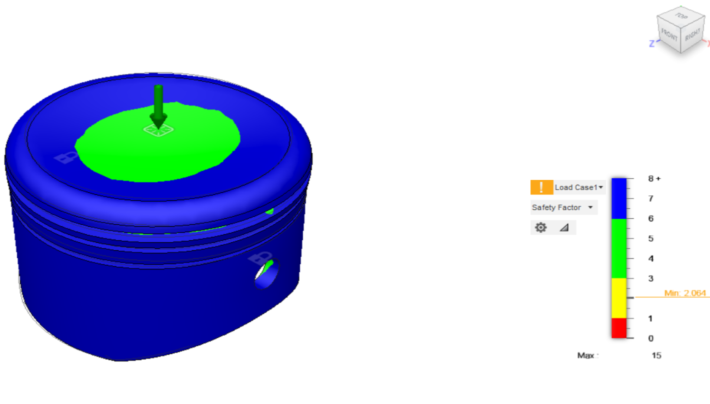
Solution:

The simulation can be done by clicking on the solve traffic light icon when it turns green.

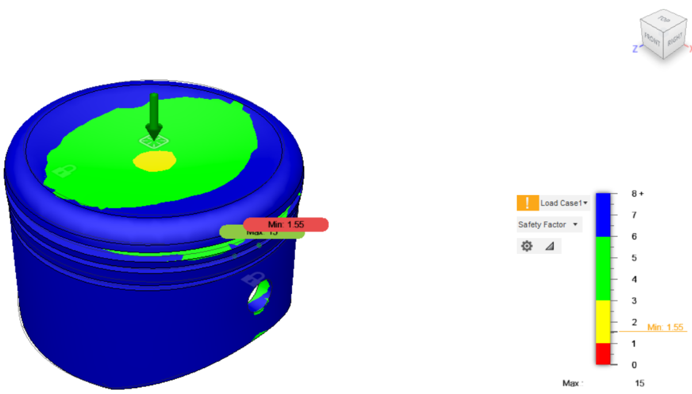
After a successful solution, we examined the following results:

Safety Factor – also called Factor of Safety (FoS). For typical numbers, see this page.

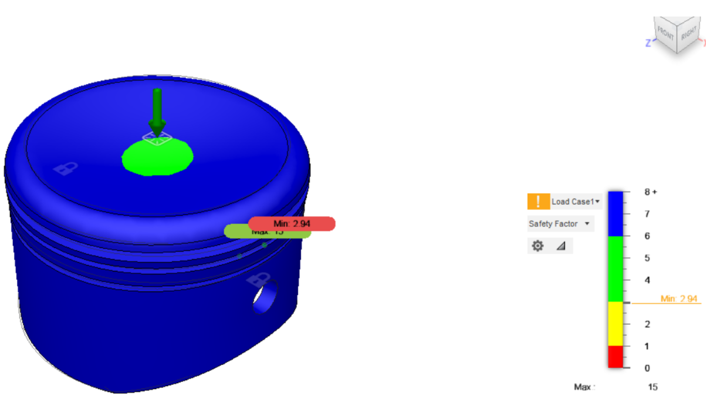
Al-5052



Al-7075



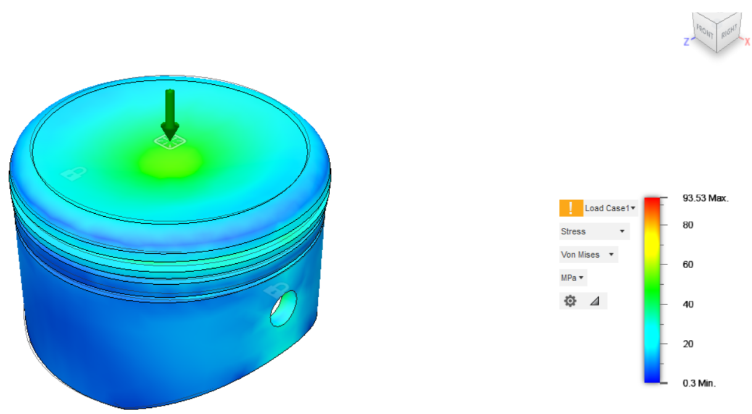
Al-6061



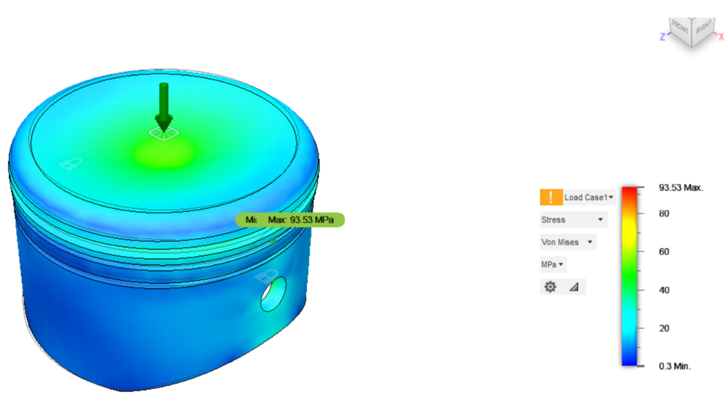
Alloy		5052	6061	7075
Safety factor	MAX	15	15	15
	MIN	2.064	2.94	1.55

Stress – is a quantity of how much pressure a particle exerts on a neighboring particle.

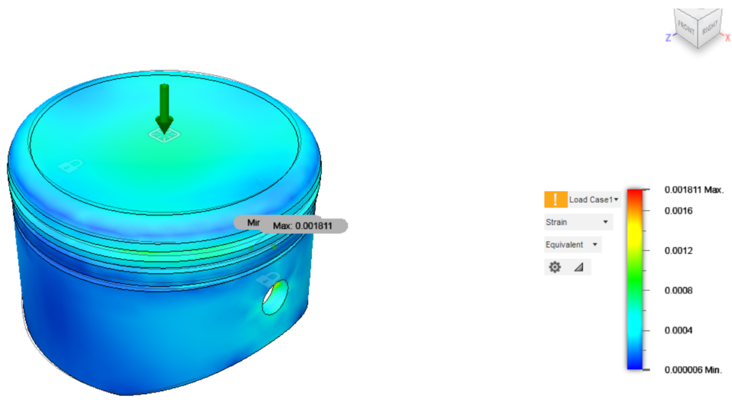
Al-5052



Al-7075



Al-6061

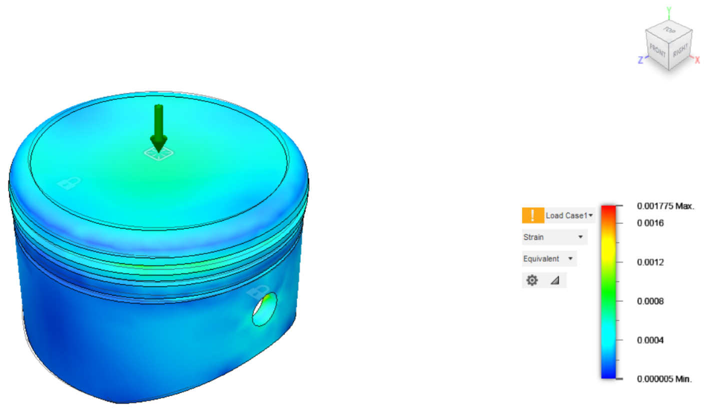


Alloy		5052	6061	7075
Stress (MPa)	MAX	93.53	93.53	93.53
	MIN	0.2994	0.2994	0.2994

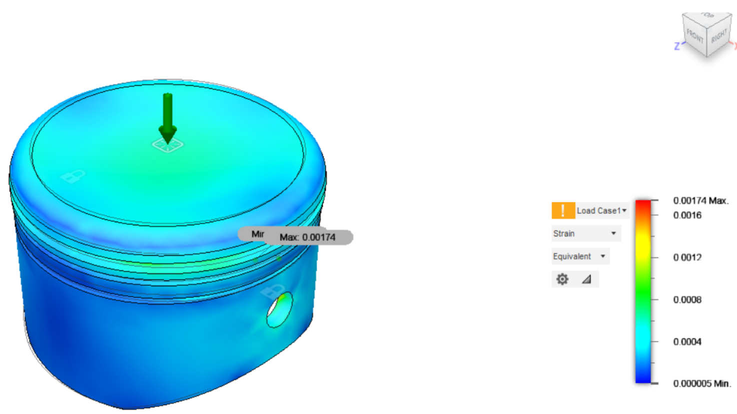
Displacement – how much the body has deformed relative to its original state.

Strain – a measure of deformation in the material as a result of stress. Visually often quite similar to stress.

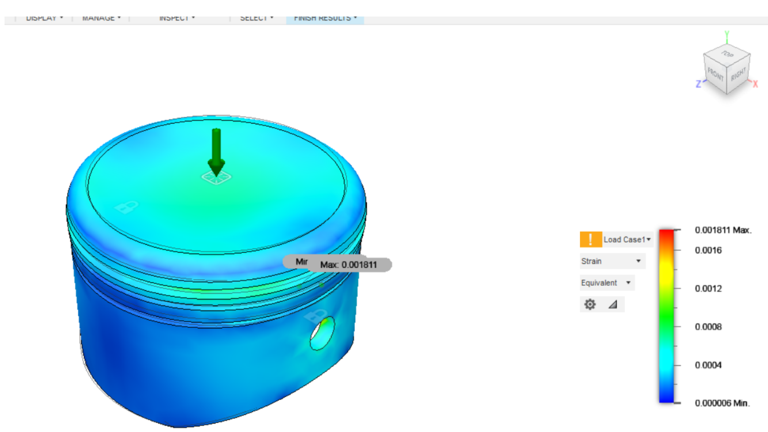
Al-5052



Al-7075



Al-6061



Alloy		5052	6061	7075
Strain	MAX	1.775×10^{-3}	1.811×10^{-3}	1.74×10^{-3}
	MIN	5.4×10^{-6}	5.51×10^{-6}	5.299×10^{-6}

Novelty

Sample No.	Combinations	Comments	
Sample 1	**Al_2O_3+SiC+Graphene** Al2O3 = 5 wt% SiC = 5 wt% Graphene = 0.75 wt%	Alumina is for strength, hardness and density	SiC and graphene are lubricating agents for wear resistance
Sample 2	**ZrO_2+SiC+TiC** ZrO_2 = 3 wt% SiC = 5 wt% TiC = 5 wt%	ZrO_2 for enhancing tensile and hardness properties.	SiC+TiC will enhance compression strength, act as lubricating agents
Sample 3	**Al_2O_3+TiC+Graphene** Al_2O_3 = 5 wt% TiC = 5 wt% Graphene = 0.75 wt%	Alumina is for strength, hardness and density	TiC will enhance compression strength.
Sample 4	**Al_2O_3+ZrO_2+Ti_3SiC_2** Al_2O_3 = 5 wt% ZrO_2 = 5 wt% Ti_3SiC_2 = 0.5 wt%	Alumina is for strength, hardness and density	ZrO_2 for enhancing tensile and hardness properties.

Performance Analysis

Properties desired in a piston

The piston works in an exceptionally cruel and troublesome dynamic, warm, and mechanical condition. It is stacked by cyclic mechanical pressure, frequencies of 100 Hz with the goal that the weakness is essential.

The cylinder should likewise guarantee a tight fit inside the chamber, to withstand the most extreme weight of burning. Cylinder ought to have great Weakness quality, brilliant wear opposition, and coefficient of warm extension (CTE). Because of the low CTE of AMC, freedom between the chamber divider and the cylinder can be decreased, which results in less clamor and less wear of counter surfaces.

It is additionally critical that the leader of the cylinder can withstand a temperature of about 3000˚C. Because of warm inclinations and warm cycles, high warm and warm conductivity is required to diminish the general temperature and warmth waves.

Aluminum-silicon (Al-Si) combination is most generally utilized as a network material. Silicon is an imperative part of the structure since it prompts a decrease in CTE. It would be exceptionally useful that the CTE of the barrels and the cylinders are near one another to accomplish better control of the clearances between the chamber divider and the cylinder. The defining moment in the utilization of aluminum MMC speaks to the generation of fortified aluminum cylinders in the Toyota diesel motor.

Piston manufacturers that use AMMCs

1. Duralacan
2. Martin Marietta
3. Lanxide [30]

Pistons fail mainly because of thermal stresses and mechanical stresses. Thermal conductivity and the factor of safety play a vital role in selecting the material for pistons. Hemispherical piston with Al 6061 alloy material has a high factor of safety for a given loading condition. [31]

Results and discussions

- Aluminum 6061 were found to be most suitable for the matrix of composites to be used for manufacturing pistons from the comparative study of stress, strain, and safety factor simulations of aluminum alloys.
- Alumina, silicon carbide, and graphene were chosen to be one of the combinations of reinforcements for their ability to provide strength, hardness, and density and also act as lubricating agents for wear resistance.
- The combination of zirconium dioxide, titanium carbide, and silicon carbide in the right proportions will enhance the tensile, hardness, and compression strength and will also act as lubricating agents.
- Alumina, titanium carbide, and graphene, together will enhance compression strength along with providing hardness, strength, and density.
- Alumina, zirconium dioxide, and titanium silicon carbide in the aluminum matrix will enhance tensile and hardness properties along with providing strength, hardness, and density.

Conclusions and Future work

Aluminum metal matrix composites have many advantages compared to alloys and pure metals in terms of saving fuel, increasing the longevity of the parts, and economical manufacturing. Hence, more research and advancements are expected in this topic.

Future work on this project will include mapping a procedure for manufacturing these composites and doing tests on them to find the best one of these four suggested metal matrix composites.

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