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Weight Optimization of Aluminum Alloys Used in Vehicles

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Abstract

In today's industry, after steels, the most commonly used metals are aluminum and aluminum alloys. Their lightweight, good thermal and electrical conductivity, increased strength properties, and corrosion resistance makes them important materials for engineers and designers. Especially in recent years, energy-saving studies have led to the production of light and economical vehicles that consume less fuel. Consequently, aluminum alloys have become the material of choice for automobiles, buses, trains, and marine vehicles. An optimization study was conducted via the comparison of the aluminum alloys 5052 H32 and 6060 T4 for parts having two different diameters with holes to reduce the mass. Both strength and cost analyses were carried out for the two alloys with different diameters. When the diameters were compared, increasing the size of the diameter, i.e., reducing the mass, did not change the strength relative to the initial state. It was concluded that, if the price and processing costs of the two alloys were kept the same, the selected part would be made of aluminum 5052 H32 with a diameter of 21 mm.

Keywords: *aluminum alloy, vehicle, weight, energy saving*

I. INTRODUCTION

The second most common metal element in the earth's crust is aluminum. Aluminum can be recovered by recycling, remelted, and then used for brand-new products, expending only 5% of the energy required for production from the raw material.

In today's industry, after steels, the most commonly used metals are aluminum and aluminum alloys. Their lightweight, good thermal and electrical conductivity, increased strength properties, and corrosion resistance makes them important materials for engineers and designers. Especially in recent years, energy-saving studies have led to the production of light and economical vehicles that consume less fuel. Consequently, aluminum alloys have become the material of choice for automobiles, buses, trains, and marine vehicles. The distribution of aluminum used by sector is shown in Fig. 1. Aluminum is approximately three times lighter than steel and iron. Every 10% reduction in the total weight of an automobile saves 5-10% in fuel costs [1].

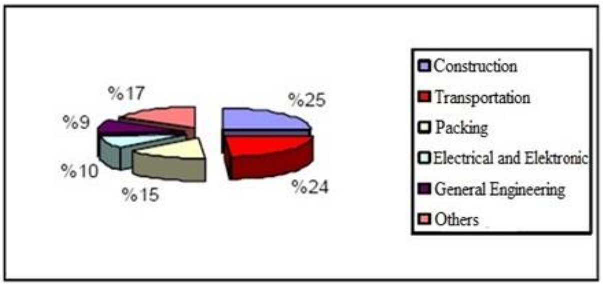

Fig. 1: Distribution of aluminum used by sector [2]

I1. MECHANICAL PROPERTIES OF ALUMINUM ALLOYS

Aluminum and its alloys are used in almost all sectors and industries. Naturally, each application requires different properties, and therefore, it is possible to encounter alloys and aluminum materials that are very different in physical structure. Because of its reusability, aluminum is a versatile and energy-saving metal. These features, combined with its functionality, economy, and easy processability, make it possible at present to produce many products from aluminum and aluminum alloys, with potential for the future. Moreover, from an environmental point of view, its lightweight leads to a reduction in energy consumption in many industrial applications, particularly in transportation. This feature is very important for engineering.

The specific gravity of iron is 7.87 g / cm^3, that of copper 8.93 g / cm^3, and that of zinc 7.14 g / cm^3, whereas the specific gravity of aluminum is 2.69 g / cm^3. This feature has led to the increasing importance of aluminum, primarily in the motor vehicle industry. Vehicles made of lightweight material consume less energy and exhibit higher maneuverability due to their low mass. Lightness, on the other hand, also results in lower CO_2 emissions due to reduced fuel consumption. Aluminum alloys are indispensable materials for the aerospace, aircraft, and shipping industries. In addition, low installation and maintenance costs and high atmospheric corrosion resistance together with its lightweight make aluminum a very attractive material in the construction industry.

Alloying is one possible way to achieve different mechanical strength values and to enable the production of aluminum materials that can meet various needs in many

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different sectors ranging from the automotive industry to the aerospace industry. A comparison of some properties of aluminum with those of other metals is shown in Table 1. Corrosion resistance is high due to the natural oxide film formed on the surface. Therefore, aluminum and its alloys are very important materials for use in the construction, shipping, and chemical industries [3].

Table 1:
Some properties of aluminum compared with those of other metals [4]

Specifications	**Al**	**Cu**	**Fe**	**Zn**	**Mg**
Specific Gravity (g/cm3)	2.71	8.94	7.87	4.1	1.74
Electrical Resistance (Ω·m)	2.66	1.68	9.8	6	4.46
Thermal Conductivity	0.52	0.92	0.19	0.27	0.37
Coefficient of Thermal Expansion (1/°C)	24	16.7	11.9	33	25.7
Melting Temperature (°C)	658	1083	1535	420	651
Combustion Temperature (kcal/kg)	6970	-	1600	1270	6000
Elongation (%)	43	50	48	-	-
Hardness (Brinell)	19	25	70	-	-

The most important properties that give aluminum advantages over other metals in many areas include its lightweight, sufficient strength when alloyed despite its lightness, continuous availability, high corrosion resistance, drivability, formability, malleability, workability, and high thermal and electrical conductivity.

Aluminum, which is three times lighter than iron, can be transformed into an iron-like material by alloying. For example, the use of aluminum in the automotive industry reduces fuel consumption by reducing the weight of the vehicles and increasing the load capacity. Aluminum reacts with oxygen under normal atmospheric conditions to form a natural protective film on its surface. This 635 × 10-9 cm-thick alumina layer protects the aluminum from corrosion. Anodizing, Painting, and lacquering are other applications that increase the protective property of aluminum against corrosive effects.

Because of its excellent electrical conductivity, aluminum is replacing copper, which has been used until recently in the insulated airline and underground power cables, and in additional materials that are the main elements of electrical power transmission and distribution. Another important feature of aluminum is its excellent performance as heat and light reflector. Consequently, aluminum is widely used in lighting components and heat beds. Another area of application is food and pharmaceutical packaging. Even at a thickness of 0.007 mm, aluminum foil is fully impermeable to light, aromas, and gas. Aluminum in its massive form is non-combustible, but when transformed into micro pieces, it burns by releasing large amounts of heat, a feature enabling it to be used as rocket fuel.

Aluminum is nearly 100% recyclable compared to other metals, which is one of the main factors in its importance as the metal of the future. Criteria for the most economical, least polluting, and the lowest energy consumption of limited resources are being applied worldwide, especially in developed countries. Emphasis on these criteria was accelerated by public environmental protection pressures in the 1980s and the oil crises of 1973 and 1979, highlighting the advantages of aluminum compared to alternative materials. Because of its many features, aluminum provides suitable material for these developments in the industrial sector [5].

When production costs are taken into account, fuel-saving gains in importance. Aluminum is an unrivaled material with an excellent strength/weight ratio. Aluminum parts lead to the manufacture of lighter cars. Aluminum provides the same power factor at close to 69% of the weight of steel [5].

III. USING ALUMINUM ALLOYS IN INDUSTRY

Aluminum is used in land vehicles (e.g., body, body panels, inner surface plates, exhaust manifolds, differential box, and wheels), aircraft (e.g., wheels, propellers, rivets, water tanks, oil pipes, and bushings), and watercraft (e.g., sailing masts). Aluminum and aluminum-based alloys are widely used in the aircraft industry due to their high specific strength and high corrosion resistance. Recently, their use in this industry has been significantly increased as a result of the weldability of aluminum alloys. Aluminum was used with Al-Cu-Mg (2xxx) series alloys, well known in the early days for their use in aircraft. After World War II, the development of aircraft for commercial transportation highlighted the use of high-strength alloys in the upper wing surface. At that time, 7178-T6 alloy, containing high proportions of Zn, Mg, and Cu, was used in Boeing-707s. However, a problem arose with the fracture toughness of this high-strength alloy.

When the Boeing-747 aircraft were developed, this problem forced design engineers to use lower-strength 7075-T6 products. Other aircraft design engineers considered the corrosion resistance of the 7075-T6 alloy to be inadequate and tried to increase the corrosion resistance at the expense of the strength of this alloy [6]. The areas where aluminum is used in aircraft are shown in Fig. 2. These include general engine castings, engine oil pumps, cylinder heads, aircraft wing main girders and other connection materials, aircraft exterior, engine pistons, propellers, oil pipes and bushings, control brackets and pulleys, helicopter hubs, hydraulics (in pipes), tools, boxes, and nameplates [7].

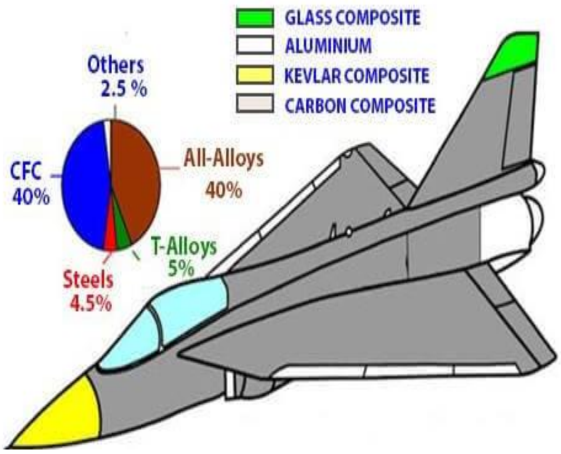


Fig. 2: Use of aluminum in aircraft [8]

A. *Aluminum-Based Parts Used in Cars*

Nowadays, the average automobile contains a wide variety of aluminum parts. These include cylinder heads, gearboxes, and wheels produced by casting, and radiators, bumpers, seat rails, side-impact bars, etc. manufactured by sheet and extrusion methods. The average weight of these parts in a vehicle is around 100 kg. This value corresponds to 10% of the total weight. With every 100 kg weight reduction, 0.6 L less fuel is consumed per 100 km. [1], [9]. Aluminum engine blocks are shown in Fig. 3.

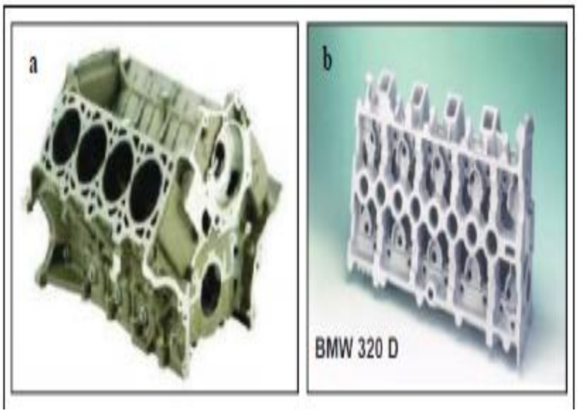


Fig. 3: Aluminum engine blocks for gasoline (a) and diesel (b) vehicles [10]

The use of up to 50 kg of aluminum in an automobile means saving about 100 kg of iron, steel, and copper. It is calculated that an automobile using aluminum consumes 1500 L less fuel during its economic life than an automobile without aluminum. According to a study by Alcoa, cars with aluminum bodywork and chassis consume 25% less fuel than steel cars. Due to the new car investments in our country, it is expected that significant amounts of aluminum will be used in the automobile industry in the coming years, as shown in Fig. 4.

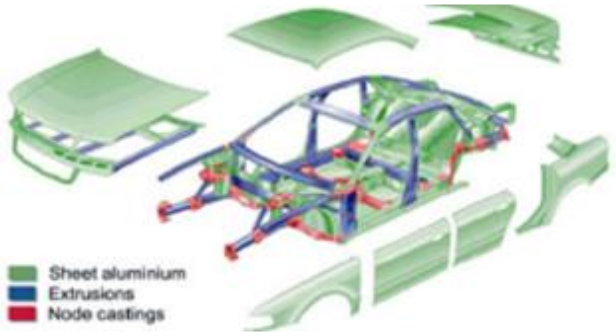


Fig. 4: Aluminum parts of the Audi A8 model [11]

For some parts, aluminum can replace steel of the same thickness. Thus, a weight saving of 65% can be achieved. However, in most aluminum parts replacing steel, the same strength can be achieved by increasing the thickness. The most common ratio in structural applications is 1.5. For example, instead of 0.8 mm-thick steel, 1.2 mm-thick aluminum can be used in a part. In this case, the weight saving would be 50% [12].

B. *Aluminum-Based Parts Used in Marine Vehicles*

Aluminum is used extensively in the production of propellers and structural parts in marine vehicles ranging from cabin cruisers to cruise ships and from the hull compartments of dry cargo ships to the entire upper structure. Cryogenic gas tanks are also made of aluminum and can be used to transport cryogenic gases (at low temperature) by sea [13].

Aluminum alloys are used in the hulls of high-speed military and civilian ships. Sometimes only the superstructures are made of aluminum, which achieves a reduction in tonnage and a lowering of the center of gravity. Aluminum alloys used in shipbuilding are known as marine-type aluminum and are classified, inspected, and documented by classification standards, as for steel materials [13].

IV. CLASSIFICATION OF ALUMINUM ALLOYS

Aluminum alloys on the market are generally divided into two types: forged and cast alloys. Forged alloys are factory products and their final geometric shapes are obtained by mechanical processing, including forging, rolling, drawing, and extrusion. Plates, sheets, rods, pipes, angles and profiles, and wires fall into this group. Parts shaped by solidification in the sand, gravity casting, and compression casting methods, and molten metal shaped in molds of desired form and size are included in the group of bulk products [14].

A. *Aluminum Forging Alloys*

Aluminum forging is the process most widely used around the world for alloys. The symbolic sequence is specified by the American Standards Association (ASA). This symbolization, previously used by the American Aluminum Association, was standardized in 1957 [15].

According to this standard, the first digit of the four-digit numerical sequence indicates the basic alloying element contained in the alloy (e.g., the 1XXX sequence indicates pure - 99.00% - aluminum). The last two digits indicate the 99.00% value after the decimal point and the minimum spacing of the aluminum. In the 1XXX array, the second digit from the left indicates the number of specially controlled impurity elements and can range from 1 to 9. For example, for the 1042 alloy, the alloy is pure aluminum and the gap value is at least 99.42%. The zero in the 1042 alloy indicates that there are no particular controlled elements in the remaining 1.00% - 0.42% = 0.58%.

In sequences from 2XXX to 8XXX, the first number represents the alloy type and the second number represents the changes. In particular, the number of controlled impurities is used as a number between 1 and 9 for the second digit of the symbol sequence. For example, the 5065 alloy represents an Al-Mg alloy with no controlled impurities.

The 9XXX sequence is used only for experimental development. Generally, the 2XXX, 4XXX, 6XXX, and 7XXX series are heat-treatable aluminum alloys. The 3XXX and 5XXX sequences cannot be heat-treated. The strength properties of these alloys are due to the manganese and magnesium in their composition and they may show cold process hardening [16].

B. Aluminum Casting Alloys

The sequence of symbols used for aluminum castings and casting alloys is similar to that of the forging process alloys. In these, a four-digit number is used as an icon. However, this number symbol is reserved from the third digit.

In 1XXX for X, the second and third figures determine the degree of aluminum purity beyond 99.00%. If there is 1X in front of the figures, this indicates that the alloy is in the trial phase. For alloys between 2XXX and 9XXX, X represents the specified alloys. The second and third digits form only one class number. If the last digit is “0”, casting is indicated, whereas “1” is ingot casting and the number “2” is a variation of “0”. For example, the first three digits in the 332.0 aluminum alloy represent an alloy of copper and/or magnesium. The 0 (zero) indicates that it is a cast part. The 32 has no special meaning [13].

V. ALUMINUM MANUFACTURING METHODS

Since the aluminum in the earth's crust is not pure, it is subjected to several processes to obtain metallic aluminum. Aluminum compounds with iron and silicon are found in the crust, along with elements such as oxygen. One of the most important of these structures is bauxite. Bauxite is hydrated aluminum oxide. Pure aluminum oxide is obtained by the Bayer Process.

First, the finely ground and powdered bauxite is reacted to convert the aluminum in the ore to sodium aluminate.

$$\boxed{Al_2O_3 + 2\,NaOH \rightarrow 2\,NaAlO_2 + H_2O}$$

The aluminate solution containing ferrite and silica is slowly cooled with water to precipitate $Al_2(OH)_3$.

$$\boxed{NaAlO2 + 2\,H20 \rightarrow Al(OH)3 + NaOH}$$

The $Al(OH)_3$ is thickened, washed, and calcined at 1100 °C to obtain Al_2O_3. The Al_2O_3 melt is dissolved in a cryolite (Na_3AlF_6) bath and electrolyzed in an electrolytic cell using carbon anodes. The production of Al_2O_3 from Al as carried out by the Hall-Heroult Process is shown in Fig. 5.

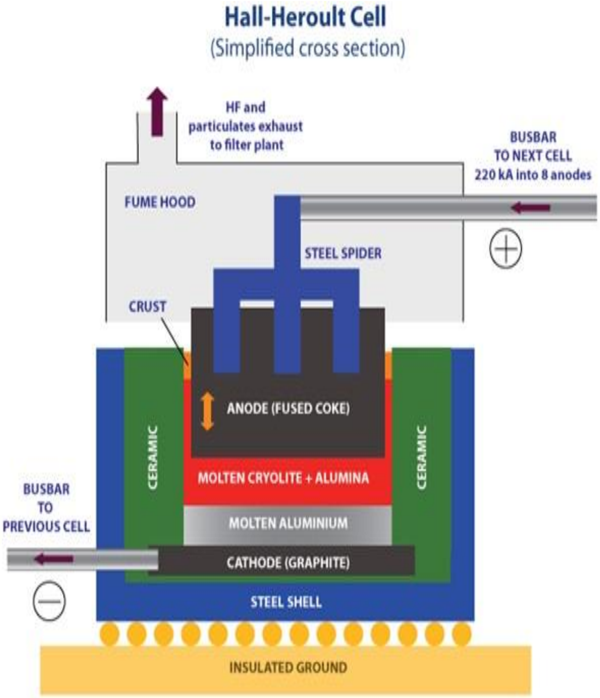


Fig. 5: Schematic view of the Hall-Heroult process [17]

In this process, the electrolysis of the molten aluminum is carried out in a cell with a carbon cathode lining the bottom. Oxygen is collected and released in the anode. The reduced aluminum melt is discharged and subjected to degassing. The resulting aluminum generally contains iron and silicon and is 99.5-99.9% pure [17].

VI. WORKABILITY CRITERIA IN MANUFACTURING

Tool life: This indicates how long a cutting tool can withstand performing on the given workpiece material.
Force and power: Greater forces and power mean lower machinability.

Surface finishing: This indicates surface quality. Better surface quality means better machinability. **Chip removal**: Easier chip removal means better machinability.

A. Aluminum 5052

Aluminum 5052 is an excellent alloy for clean and bright anodizing. Moreover, the corrosion resistance of 5052, which has good weldability, is nearly ideal. It is used in the production of parts and structures in many sectors ranging from the aerospace industry to the food and automotive industries [27].

Aluminum is most extensively used in areas such as road transport, commercial vehicles, buses, fire trucks, railway cars, conveyors, and airport baggage carousels [19].

The second major alloying element of 5052 is magnesium. As the magnesium content increases, hardness and strength increase, but ductility decreases. The addition of Mg up to 5.1% in the solution increases the rate of deformation hardening. It is coldly hardenable for yield strength of up to 270 MPa. It has excellent welding ability, medium strength, and high corrosion resistance against seawater and chemicals. The most important alloy of this series used in the industry is 5052. This alloy contains 2.5% Mg and 0.2% Cr and its tensile strength in the annealed state is 193 MPa [20].

When selecting the aluminum 5052 alloy type, the second figure refers to the cold process. The number 8 represents the hardest temper state available. The H32 indicates it is hardened to 1/4 hard temper and balanced via low-temperature heat treatment. It displays high corrosion resistance, good weldability, high fatigue resistance, and good T4 heat treatment. It is cold forming and suitable for the manufacture of a great variety of parts [21].

B. Determining the Suitability of Machinability Parameters of 6060 Aluminum Alloy

The Mg_2Si intermetallic compounds increase strength by precipitation hardening. The most commonly used alloy is the 6060 alloy, which contains 1.0% magnesium, 0.6% silicon, and 0.3% copper. The tensile strength of the 6060-T4 alloy is 290 MPa. This series is used as a general-purpose structure element in the automotive industry [22].

Artificial aging provides hardness values that cannot be obtained by natural aging and are carried out in a heat treatment furnace at a certain temperature and time. (Example: 60 h for 6060/6063 / AlMgSi0.5 alloy at 180 °C) [23].

C. Step Plate Production Stages

When designing a product for a vehicle (i.e. the step plate for a truck), feasibility analyses are also evaluated in a virtual environment. Prototype products are needed to start the cost-proposal process. After finding the appropriate suppliers, the product, which has passed all the tests and approvals, enters the detailed product feasibility and approval processes again with the manufacturing company, where the production stages are prepared as operations, the necessary machinery and equipment are determined, and a suitable production method is selected. Aluminum sheet material (Fig. 6) is procured depending on the conditions under which the step plate is to be used.

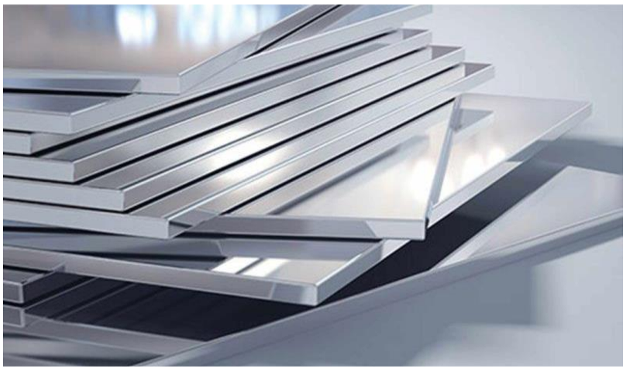


Fig. 6: Aluminum sheet [21]

The manufacturer starts the first stage of production with the supplied sheet. The dimensions of the selected sheet material can be standard or custom-made, according to the order quantity. All supplied materials must have quality certifications. The quality control team tests the supplied materials to confirm that they meet engineering requirements.

Operations are determined based on the amount to be produced. In addition to production quantity, material savings and production times are the most important parameters to be considered. After determining the operations required, molds, machinery, and so on, preparations are made for the production of the vehicle part.

VII. ALUMINUM EXPERIMENTAL DESIGN

The step plate of a truck was selected as the part for the experimental study and analyses. The original version of the selected part was drawn using CATIA. The aluminum step plate for a MAN truck is shown in Figs. 7 and 8. The finite element modeling and analysis were carried out using D-FORM 3D software [24, 25].

Fig. 7: Aluminum MAN truck step plate [26]

The aluminum alloys 5052 H32 and 6060 T4 were chosen as the materials. The dimensions of the part were taken and drawn as realistic values: width, 341 mm; length, 142 mm; height, 21 mm; sheet thickness, 2.5 mm.

A comparison was made between the parts made of the two aluminum alloys by applying two different diameters for each alloy: 17 mm in diameter for Object 1 and 21 mm for Object 2

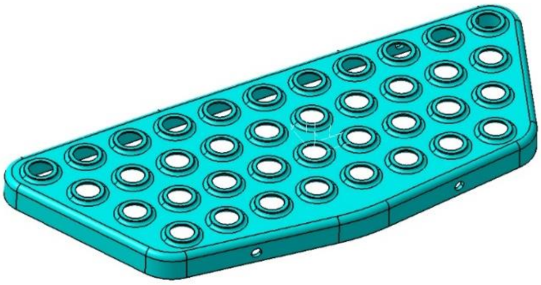


Fig. 8: CATIA drawing of aluminum MAN truck step plate

Force was applied at selected points to the objects of different diameters and different alloys. To ensure fairness, 14 points were selected from the center of each object, representing the points of the footprint of a person weighing 90 kg (g = 9.81 cm / s^2, 882.9 kN), as shown in Fig. 9.

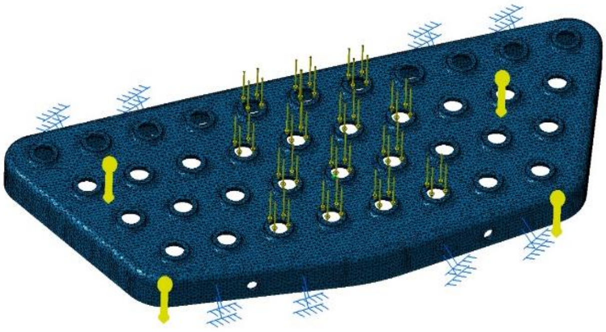


Fig. 9: Force structure of the aluminum part

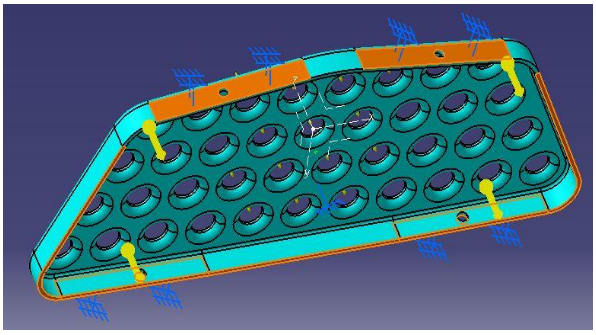
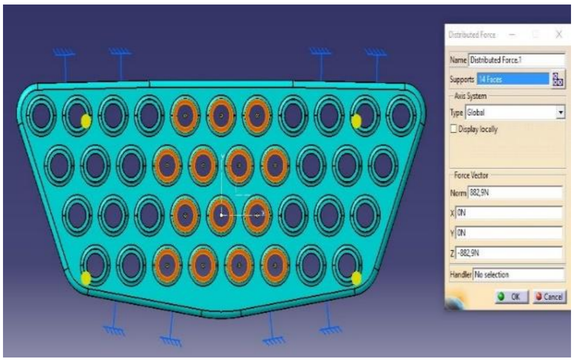


Fig. 10: Support structure of the aluminum body



Distributed Force

Name: Distributed Force.1

Supports: 14 Faces

Axis System

Type: Global

☐ Display locally

Force Vector

Norm: 882,9N

X: 0N

Y: 0N

Z: -882,9N

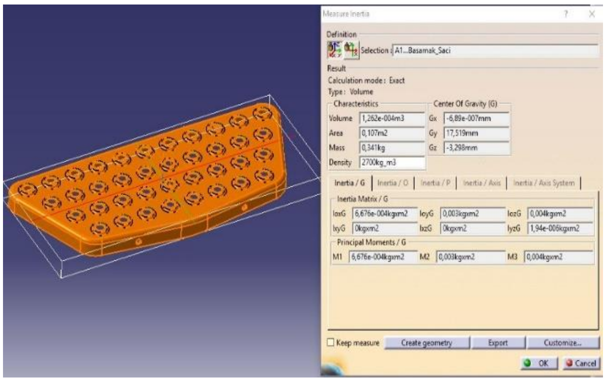
Handler: No selection

Fig. 11: Aluminum part top view of force points

Assuming that it was fixed at these points, the force was applied and the screws were tightened. The support points of the body are illustrated in Fig. 10, and the top view of the 14 selected force points and the connection points of the screws are shown in Fig. 11

A. *Aluminum 6060 T4 Alloy Design Specifications*

For the aluminum 6060 T4 alloy, the values of mass and moment of inertia of the parts having the diameters of 17 mm and 21 mm are shown in Figs. 12 and 13.



Measure Inertia

Definition

Selection : A1...Basamak_Saci

Result

Calculation mode : Exact

Type : Volume

Characteristics

Volume: 1,262e-004m3

Area: 0,107m2

Mass: 0,341kg

Density: 2700kg_m3

Center Of Gravity (G)

Gx: -6,89e-007mm

Gy: 17,519mm

Gz: -3,298mm

Inertia / G

Inertia Matrix / G

IoxG: 6,676e-004kgxm2

IoyG: 0,003kgxm2

IozG: 0,004kgxm2

IxyG: 0kgxm2

IxzG: 0kgxm2

IyzG: 1,94e-006kgxm2

Principal Moments / G

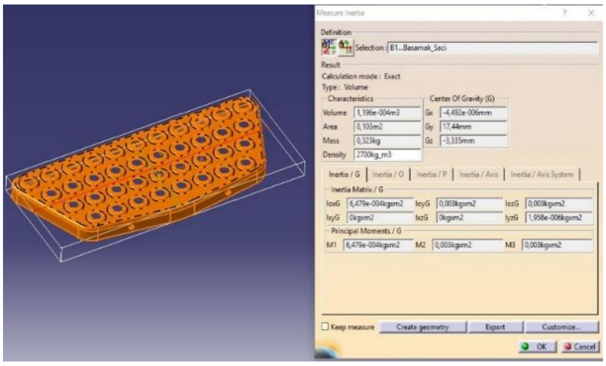
M1: 6,676e-004kgxm2

M2: 0,003kgxm2

M3: 0,004kgxm2

☐ Keep measure

Fig. 12: Specifications for aluminum 6060 T4 ø17 mm



Measure Inertia

Definition

Selection : B1...Basamak_Saci

Result

Calculation mode : Exact

Type : Volume

Characteristics

Volume: 1,196e-004m3

Area: 0,103m2

Mass: 0,323kg

Density: 2700kg_m3

Center Of Gravity (G)

Gx: -4,492e-006mm

Gy: 17,44mm

Gz: -3,335mm

Inertia / G

Inertia Matrix / G

IoxG: 6,479e-004kgxm2

IoyG: 0,003kgxm2

IozG: 0,003kgxm2

IxyG: 0kgxm2

IxzG: 0kgxm2

IyzG: 1,958e-006kgxm2

Principal Moments / G

M1: 6,479e-004kgxm2

M2: 0,003kgxm2

M3: 0,003kgxm2

☐ Keep measure

Fig. 13: Specifications for aluminum 6060 T4 ø21 mm

For the diameter of 17 mm, the mass was 0.341 kg and for the diameter of 21 mm, the mass was 0.332 kg. For the two parts, the mass decreased as the diameter grew, with a mass variation of 0.018 kg, i.e., 18 g, as shown in Figs. 14 and 15.

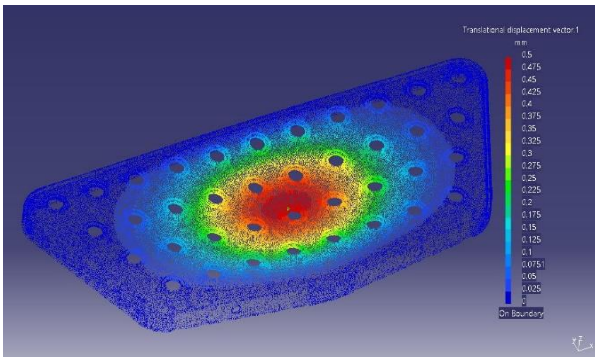


Fig. 14: Displacement of the body for aluminum 6060 T4 ø17 mm

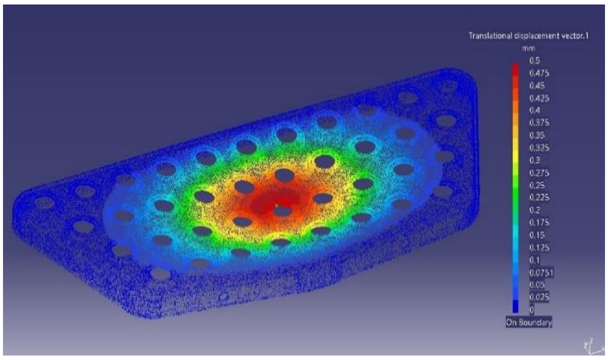


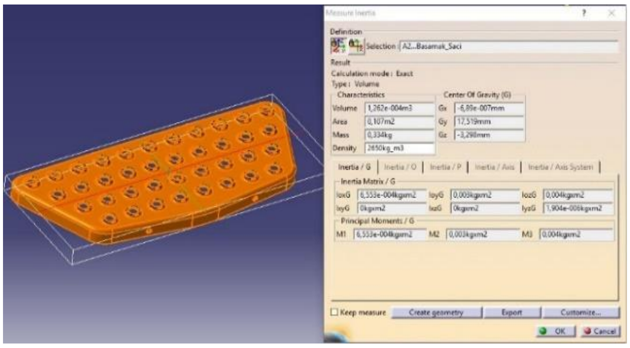
Fig. 15: Displacement of the body for aluminum 6060 T4 ø21 mm

B. Displacement Analysis

The scale on the right side of the figures shows the amount of displacement. The amount of displacement increased from bottom to top. The maximum displacement of the body appears to be the midpoint of the region where pressure was applied. The maximum displacement for the diameter of 17 mm was 0.5 mm, as was that for the diameter of 21 mm. Accordingly, there was no difference between the amounts of displacement for the two diameters. We reduced the mass in the diameter analysis to ensure that the strength remained constant.

C. Aluminum 5052 H32 Alloy Design Specifications

For the aluminum 5052 H32 alloy, the values of mass and inertia of the parts having a diameter of 17 mm and a diameter of 21 mm are shown in Figs. 16 and 17.



Selection : A2...Basamak_Saci

Result

Calculation mode : Exact

Type : Volume

Characteristics

Volume 1,262e-004m3

Area 0,107m2

Mass 0,334kg

Density 2650kg_m3

Center Of Gravity (G)

Gx -6,89e-007mm

Gy 17,519mm

Gz -3,298mm

Inertia Matrix / G

IoxG 6,553e-004kgxm2 IoyG 0,003kgxm2 IozG 0,004kgxm2

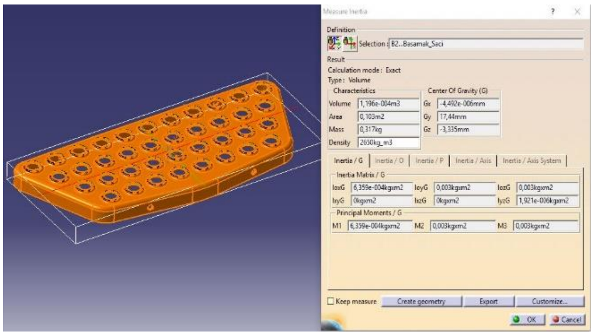
IxyG 0kgxm2 IxzG 0kgxm2 IyzG 1,904e-006kgxm2

Principal Moments / G

M1 6,553e-004kgxm2 M2 0,003kgxm2 M3 0,004kgxm2

☐ Keep measure

Fig. 16: Specifications for aluminum 5052 H32 ø17 mm



Selection : B2...Basamak_Saci

Result

Calculation mode : Exact

Type : Volume

Characteristics

Volume 1,196e-004m3

Area 0,103m2

Mass 0,317kg

Density 2650kg_m3

Center Of Gravity (G)

Gx -4,492e-006mm

Gy 17,44mm

Gz -3,335mm

Inertia Matrix / G

IoxG 6,359e-004kgxm2 IoyG 0,003kgxm2 IozG 0,003kgxm2

IxyG 0kgxm2 IxzG 0kgxm2 IyzG 1,921e-006kgxm2

Principal Moments / G

M1 6,359e-004kgxm2 M2 0,003kgxm2 M3 0,003kgxm2

☐ Keep measure

Fig. 17: Specifications for aluminum 5052 H32 ø21 mm

For the diameter of 17 mm, the mass was 0.333 kg and for the diameter of 21 mm, the mass was 0.317 kg. For the two parts, the mass decreased as the diameter grew, with a mass variation of 0.017 kg, i.e., 17 g.

D. Design Analysis of Aluminum 5052 H16 Alloy

A design analysis was performed on the parts having different diameters. Displacements of the body for the 5052 H16 alloy are shown in Figs. 18 and 19.

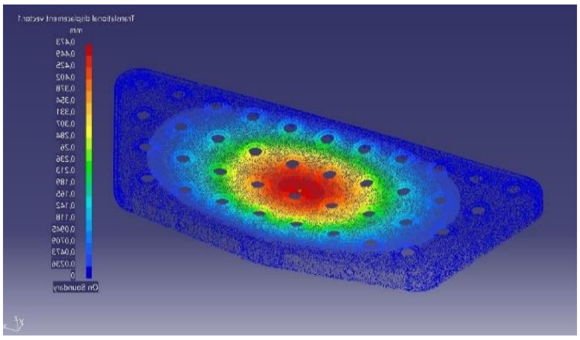


Fig. 18: Displacement of the body for aluminum 5052 H32 ø17 mm

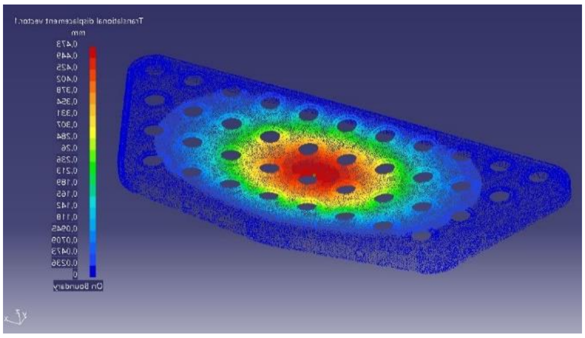


Fig. 19: Displacement of the body for aluminum 5052 H32 ø21 mm

The scale on the left side of the figures shows the amount of displacement. The amount of displacement increased from bottom to top. The Von Mises experimental graphical models for aluminum 6060 T4 are shown in Figs. 20 and 21. In the aluminum 6060 T4 alloy, the forces applied to the stress points varied in millimeters. The maximum displacement for the 17-mm diameter was 0.473 mm, whereas that for the 21-mm diameter was 0.473 mm. In this regard, there was no difference between the amounts of displacement for the two diameters. In the diameter analysis, the mass was reduced to ensure that the strength remained constant. The Von Mises experimental graphical models for aluminum 5052 H32 are shown in Figs. 22 and 23.

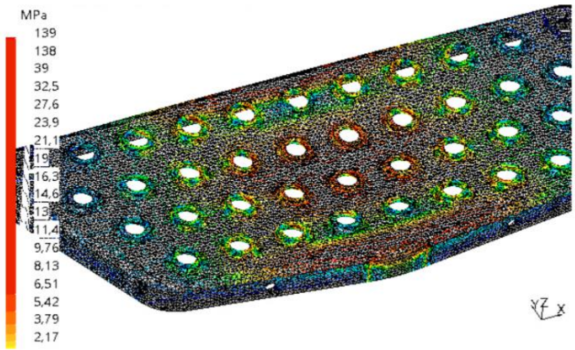


Fig. 20: Von Mises experimental graphical model for 17 mm-diameter aluminum 6060 T4

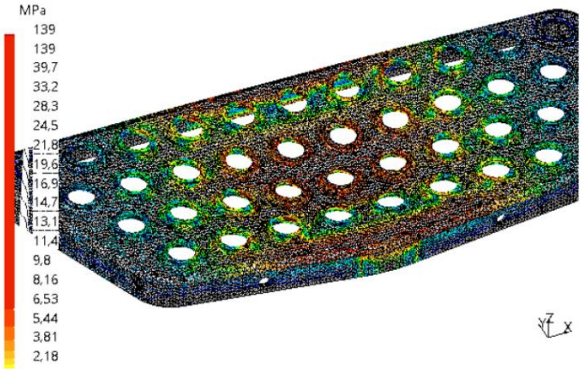


Fig. 21: Von Mises experimental graphical model for 21-mm diameter aluminum 6060 T4

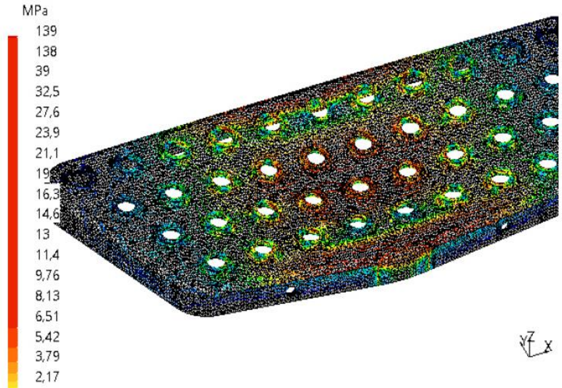


Fig. 22: Von Mises experimental graphical model for 17 mm-diameter aluminum 5052 H32

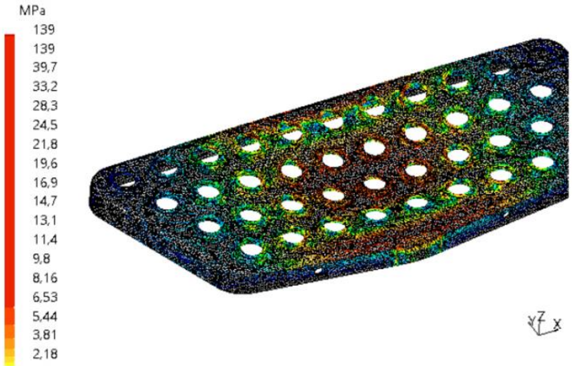


Fig. 23: Von Mises experimental graphical model for 21-mm diameter aluminum 5052 H32

VIII. CONCLUSION

For this optimization study, a comparison was made of aluminum alloys 5052 H32 and 6060 T4 in parts having two different diameters, with holes to reduce the mass. Both strength and cost analyses were conducted for the two alloys and the different diameters. When the diameters were compared, increasing the size of the diameter, i.e., reducing the mass, did not change the strength compared to the initial state. Two different alloy types in accordance for use with this step plate were examined. When the diameter in the aluminum 6060 T4 alloy part was increased, the mass was reduced from 0.341 kg to 0.323 kg. In the aluminum 5052 H32 alloy part, the mass was reduced from 0.334 kg to 0.317 kg when the diameter was increased. Since it was accepted that the strength did not change, we decided to use the larger diameter. The displacement of the aluminum 6060 T4 was 0.5 mm, and that of the aluminum 5052 H32 was 0.473 mm. This difference was insignificant. The final evaluation was made and consequently, considering the optimization data, the graphical models and values, and the Von Mises criteria, it was concluded that, if the price and processing costs of the two alloys were kept the same, the selected part would be made of aluminum 5052 H32 with the diameter of 21 mm.

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