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Theme:

Materiel selection and manufacturing process optimization for lightweight component

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Thanks

First of all, I thank the God who gave me the strength and

patience to complete my study.

I extend my special gratitude to my dear mother and father.

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I would like to thank **Professor Chiba Elhocine,** *supervisor of this*

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DEDICATION

To the man with a fragrant biography and enlightened thought, he was the primary contributor to my attaining higher education My beloved father, may God prolong his life.

To the one who put me on the path of life, made me steadfast, and nurtured me until I became an adult (My dear mother), may God prolong her life.

To my brothers; Those who had a great influence on me overcoming many obstacles and difficulties.

To all my esteemed teachers who did not hesitate to extend a helping hand to me

Morched Oubbiche

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Abstract:

In order for automakers to meet the new stringent environmental policies and to improve fuel efficiency of their vehicles, they started to change the design of their vehicles to be better aerodynamically, to downside their vehicle sizes, thus they can reduce the engine size as well, and to increase the level of the electrification (partial or full electrification) of their fleet vehicles. Lightweight design is another widely used strategy to improve fuel economy of automobiles. Potential lightweight material needs to be cost effective, has the ability to reduce the weight of the vehicle and can meet the functionality requirements. Thus, we need a systematic material selection process that takes into consideration all design aspects such as cost, performance, and environmental impacts. Eco-material selection provides a systematic method for material selection and takes into account material's mechanical properties, cost, and ability to reduce environmental impacts over product's lifetime.

ملخص:

من أجل أن تفي شركات صناعة السيارات بالسياسات البيئية الجديدة الصارمة ولتحسين كفاءة استهلاك الوقود في مركباتها، بدأت في تغيير تصـــميم مركباتها لتكون أكثر انســـيابية، وتقليل أحجام مركباتها، وبالتالي يمكنها تقليل حجم المحرك أيضًـــا، وزيادة مســـتوى الكهربة (الكهربة الجزئية أو الكاملة) لمركبات أسطولها. يعد التصميم الخفيف استراتيجية أخرى مستخدمة على نطاق واسع لتحسين كفاءة اســـتهلاك الوقود للســـيارات. يجب أن تكون المواد الخفيفة المحتملة فعالة من حيث التكلفة، وأن تكون قادرة على تقليل وزن المركبة، وأن تلبي متطلبات الوظيفة. وبالتالي، نحن بحاجة إلى عملية اختيار مواد منهجية تأخذ في الاعتبار جميع جوانب التصـــميم مثل التكلفة والأداء والآثار البيئية. يقدم اختيار المواد البيئية طريقة منهجية لاختيار المواد ويأخذ في الاعتبار الخصـائص الميكانيكية للمواد، والتكلفة، والقدرة على تقليل الآثار البيئية على مدى دورة حياة المنتج.

Introduction generale:

The automotive sector is one of the most crucial sectors in the worldwide economy and environment because the automotive industry overall continues to face increasing pressures to reduce fuel usage and harmful emissions. As a result, lightweight materials have been one of the main focuses within automotive engineering because they greatly relate to improving both environmental performance and economic performance. Selecting materials, and optimizing processes, to minimize weight but to still meet the performance specifications of strength and durability, is certainly the key to achieving these goals.

Lightweight materials certainly play a very important role in helping improve vehicle economic performance, sustainability, and investment qualities. Weight reduction through the introduction of lightweight materials leads to improvements in vehicle fuel economy improvements on-road and reductions in greenhouse gas emissions. These are really the two of the biggest issues impacting the automotive sector today. To add to these benefits, lightweight materials also enhance vehicle handling, acceleration, and braking characteristics leading to a more enjoyable and ultimately safer experience for vehicle occupants.

The growing demand for these materials is primarily driven by rigorous regulatory requirements and consumer expectations for efficient and environmentally sustainable vehicles. As automotive manufacturers try to comply with these requirements, the development and use of advanced materials including aluminium, magnesium, and advanced composites, are also a priority. These materials provide practical solutions to satisfy performance and sustainability, making them the most plausible option to develop lightweight components that meet both current as well as future markets.

Historical Evolution of Materials in the Automotive Industry

The development of materials for the automobile sector has never stopped evolving with significant advancements and changing priorities. The use of metals, particularly heavy metals like iron and steel was the first priority for a car, but when it came to the needs of a vehicle, the durability and cost of materials ruled supreme. As the demand for improved fuel economy and performance began to grow, car manufacturers started thinking about other materials. In the 20th century, lighter metals like aluminium, showcased an excellent strength to weight ratio, creating a new wave of options for the manufacturing of cars.

The automobile industry has continually responded to technical innovations through time and changing markets through time. The late 20th century and early 21st century saw a movement toward composite materials (carbon fibre-composite, other forms of advanced composite materials) and high-strength steels relating to improved efficiency and performance of vehicles. All of these advancements have opened up new pathways of materials for manufacturers to use in developing vehicles that exhibit lower weight, higher strength, and improved environmental performance.

Scoop of study

Notwithstanding the amount of literature available regarding material selection and improving manufacturing processes, there is a chasm of gap in addressing the optimal weight and mechanical performance operability scenarios holistically and collaboratively. In this study, we seek to fill that gap by proposing a new scientific process that ties together appropriate materials selection that optimized manufacturing process with the best-in-class possible for both efficient and sustainable performance.

I. Chapiter 1:

Generality on lightweight material

1. Introduction:

The global auto manufacturing industry is currently facing challenges in many important aspects of its business, such as energy efficiency, reducing emissions, enhancing safety, and increasing affordability. Automotive lightweighting has come to the forefront as one of several solutions aimed at addressing the above issues. The fundamental goal of lightweighting is to achieve the maximum possible weight reduction—i.e., to reduce the weight of the vehicle as much as possible. To achieve maximum weight reduction requires a system-engineering approach, consisting of an iterative method for optimizing the design, while incorporating material properties and manufacturing capabilities to meet the product requirements, while achieving the minimum mass and/or cost. Advanced high-strength steels, aluminium and magnesium alloys, and carbon-fibre reinforced polymers are vital materials for lightweighting vehicles. This article presents examples of how the relationship between materials science and advanced processing can provide effective lightweighting solutions in automotive engineering.

2. lightweight materials for mechanical components:

In contemporary engineering design, lightweight materials serve a vital function, enabling important enhancements in weight savings, performance, and sustainability. This section reviews the most typically used lightweight materials, focusing on mechanical properties, advantages and disadvantages, and context of common uses. In addition, tables, figures and additional data are provided for clarity.

2.1 Aluminium Alloys:

Cast and wrought (deformed) aluminium alloys may find extensive applications in the automotive area. The cast aluminium alloys may all be classified as 300-series aluminum alloys (Al–Si–Cu or Al–Si–Mg); for instance, 319 for intake manifolds and transmission housings, 383 for engine blocks, 356 for cylinder heads, and A356 for wheels. These alloys have Si as their major alloying element, which increases the fluidity of the alloy during casting. There are many ways to cast these alloys, which include sand cast, die cast, permanent Mold cast, and lost foam or wax cast. After casting, there is the capability to heat treat this type of 300 series cast aluminum alloys to obtain a wide range of strength properties.

The major growth of aluminium use in future automobiles is expected to be in the body structures and body panels, such as front rails, roof rails, hoods, deck lids and fenders. The aluminium alloys that are used for these applications are the 5000-series (al-Mg) alloys, such as aa5754 and aa5182, and the 6000-series (Al-Mg-Si) alloys, such as AA6111 and AA6061. The 5000-series alloys are non-heat treatable, i.e. they cannot be strengthened by heat treatment, whereas the 6000-series alloys are heat treatable, and they are usually strengthened while they are being painted in the paint baking oven. The 5000-series alloys are highly formable, but since stretcher strain marks may appear on their surface as they are strain-hardened during the stamping operation, they are not selected for outer body panels. The 6000-series alloys, used for both inner and outer body panels as well as body structure components, are formed in the relatively soft T4 temper and subsequently age hardened to the T6 temper in the paint baking oven to achieve the final strength. (1)

Design characteristics:

The modulus of aluminium is 70 GPa compared with 207 GPa for steel, which means that, for equal bending stiffness, an aluminium component will be 43.5% thicker than a steel component. As a result, the weight reduction achieved by aluminium will not be in the same proportion as the density ratio between the two materials. A simple weight calculation will show that substituting a steel body panel with an aluminium body panel will result in approximately 50% weight saving. (2)

Formability: The vast majority of the body structure and body panels in both steel and aluminium are manufactured by cold forming operations, such as stamping, roll forming, bending and hemming. in these operations, the two important formability characteristics are the strain hardening exponent (n) and the plastic strain ratio (r). The n-value of aluminium alloys is similar to that of drawing quality (DQ) steels, which means that both exhibit similar uniform elongations during forming; however, aluminium has a much lower post-necking elongation than steel. (2)

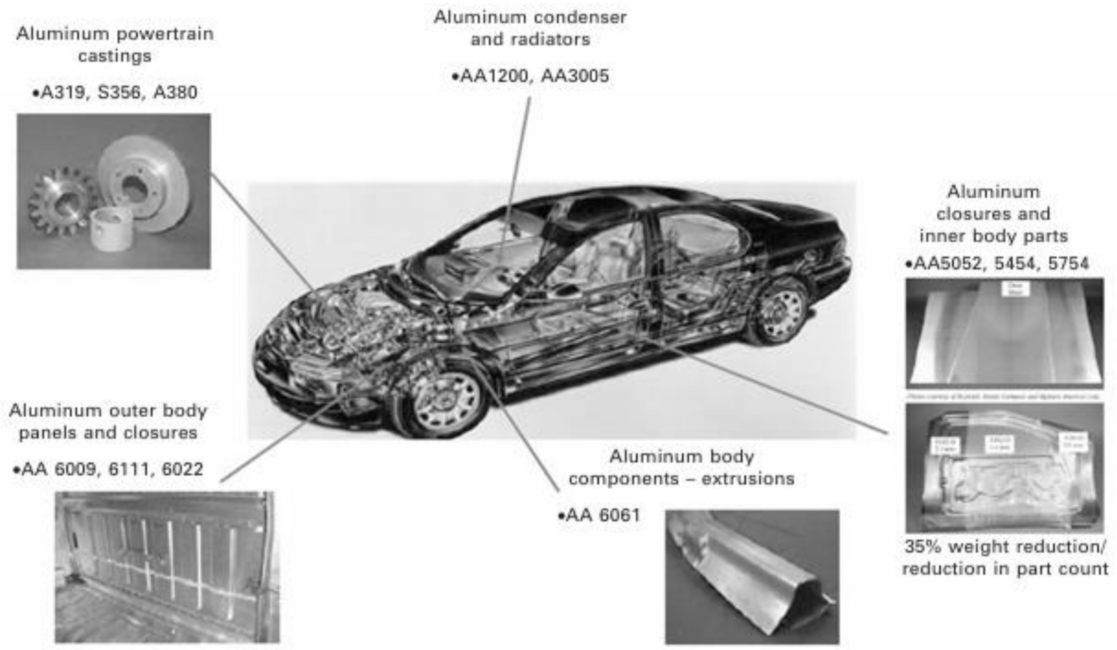

Figure 1: automotive aluminium alloy applications *(1)*

2.2 Magnesium alloys

Magnesium alloys, although not much used in today's automobiles, may experience significant growth in the future for the following reasons:

- lightest structural metal in use (its density is 1.74 g/cm3 compared to 2.7 g/cm3 for aluminium alloys)
- Higher strength-to-density ratio than aluminium alloys
- High damping capacity

The modulus of magnesium alloys is 45 GPa, which is significantly lower than that of steel and aluminium alloys; however, because of their low density, the modulus-to-density ratio of magnesium alloys is the same as that of aluminium alloys. Magnesium alloys have low ductility and poor formability; but many magnesium alloys can be cast in thin sections as low as 2 mm in thickness. The common manufacturing method for making automotive magnesium components is die casting, which allows the opportunity for parts consolidation and cost reduction. (2)

Formability:

Similar to aluminum alloys, magnesium alloys can be classified as being chunk casting alloys or wrought alloys. In regard to the casting alloys, a commonly used magnesium alloy is AZ91, which contains aluminum and zinc as the major alloying elements. Considerable weight savings can be gained by utilizing AZ91 instead of aluminum alloy A380 with non-structural components such as brackets, covers, and housings. In applications for structural components dominated by ductility and in some cases crash protection, AM20, AM50, or AM60 will typically be used when reference is made to an alloy numbered AM-series. The major alloys used in AM-series applications are aluminum and manganese.

Among wrought magnesium alloys, AZ80 is the most commonly used for extruded sections, while AZ31 is most used for sheet applications. Both AZ30 and AZ80 are similar in yield strength to the 5000 and 6000 series aluminum alloys; however, wrought magnesium alloys are more commonly less ductile than aluminum alloys. Wrought magnesium alloys have far lower cold formability than both aluminum alloys and the most common steels.

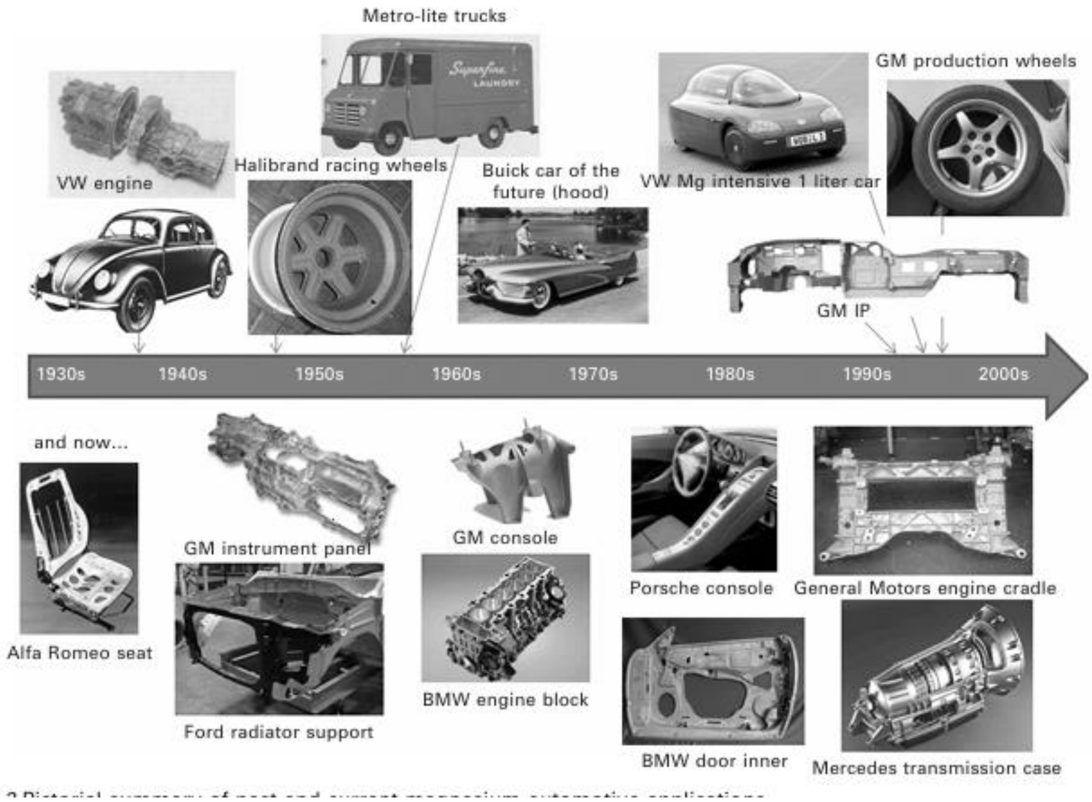

Figure 2: Pictorial summary of past and current magnesium automotive applications *(9)*

2.3 Titanium alloys

The principal advantages of titanium alloys are their low density, high strength to-density ratio and excellent corrosion resistance. They also maintain high strength at elevated temperatures ranging up to 500 °C. The density of titanium is 4.43 g/cm3, which is significantly lower than that of steel. The modulus of titanium is 114 GPa, which is nearly half the modulus of steel. (2)

Mechanical characteristics of titanium alloy cause many problems in cutting process. High-temperature strength and low heat conductivity cause high temperature of the bound Ary surface between the chip and the tool during the process, and highest temperature at the boundary surface reaches 1000 °C in high-speed cutting. High cutting heat stimulates various heat-related phenomena and causes fast tool wear. Diffusion of titanium alloy element reduces hardness of tools, and adhesion due to dissolution causes chipping and early failure of tools. Generally, difficult-to-cut materials have high hardness and tensile strength or low thermal-con ductility and high affinity with tool materials, causing early damage on the tools, and accordingly, they have difficulties in economical cutting and in realizing process precision, and titanium alloy comes under both cases. (3)

2.4 High strength steel

Steel is the most commonly used structural materials in many industry applications, due to good manufacturability and availability, extremely high strength and stiffness in the form of high strength steels, good dimensional properties at high temperatures, as well as the lowest cost among commercial aerospace materials. However, high density and other dis advantages, such as relatively high susceptibility to corrosion and embrittlement, restrict the application of high strength steels in aerospace components and systems. Steels normally account for approximately 5% to 15% of structural weight of commercial airplanes, with the percentage steadily reducing. Despite the limitations, high strength steels are still the choice for safety critical components where extremely high strength and stiffness are required. The major applications for the use of high strength steel in aerospace are gearing, bearings [5a], and undercarriage applications. (4)

3. manufacturing processes for lightweight components:

There are many different manufacturing processes that can be chosen by the manufacturing engineer. Each process has its own capabilities such as particular ranges of surface finish, dimensional accuracy, and geometrical accuracy. Some processes lend themselves better to producing certain shapes or features. Noting these inherent capabilities, there are often alternatives available that can accomplish the same manufacturing objectives. Consequently, it is important to have a general understanding of processes available and detailed knowledge of specific processes.

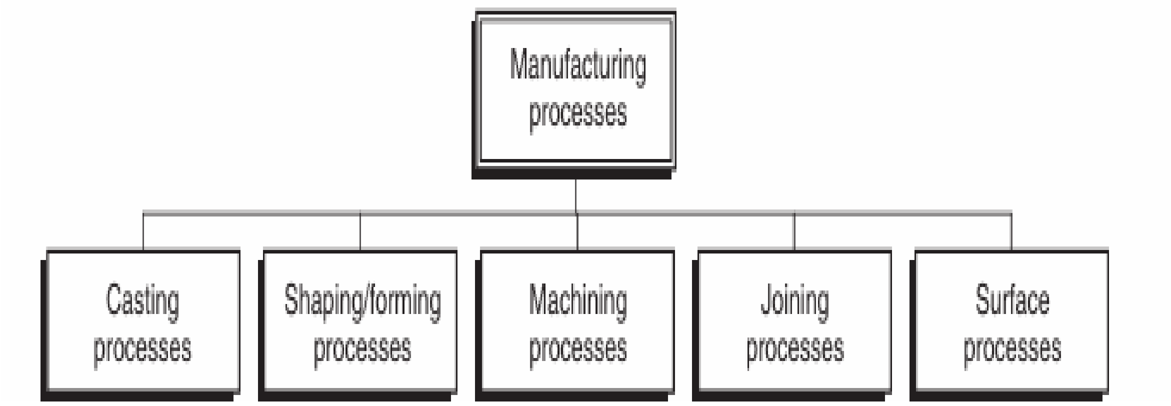

Figure 3General classification of manufacturing processes *(6)*

3.1 CNC Machining:

Machining processes are generally grouped into the removal of material from a workpiece, and could be categorized by several different processes. Machining processes can be grouped into three general subgroups:

- Cutting processes
- Abrasive processes
- Non-traditional machining processes

Most machining processes can be recognized as cutting processes. Cutting processes are used to remove material from a workpiece in the form of chips to create the desired geometry. Cutting processes can be distinguished as to whether the tool (cutting tool) cuts in a linear motion, whether the tool rotates, or if the workpiece rotates. The capabilities to create a wide range of shapes, and the variety of machining processes available to achieve specific levels of accuracy, are two clear reasons of the widespread use of machining processes that we discussed at the beginning of the chapter.

3.2 Additive Manufacturing:

Additive Manufacturing, commonly known as 3D printing, is a method of creating objects by layering material in a precise pattern according to a CAD model. It is an incredibly powerful technique in today's manufacturing sector. Recently the additive manufacturing capabilities have advance in ways that while lowering cost, enhancing performance, and solidifying quality of the processes. Additive Manufacturing has a number of aliases, including additive fabrication, additive processes, layered manufacturing, fast prototyping, solid freeform fabrication (SFF) and rapid manufacturing. More and more industries are using 3D printing for mass customization and open-source models, with industries such as agriculture, medicine, transportation, and aerospace being just a few examples. Additive Manufacturing is and has full design variability and capabilities with the capabilities of multiple material types to create complex shapes inexpensively and efficiently.

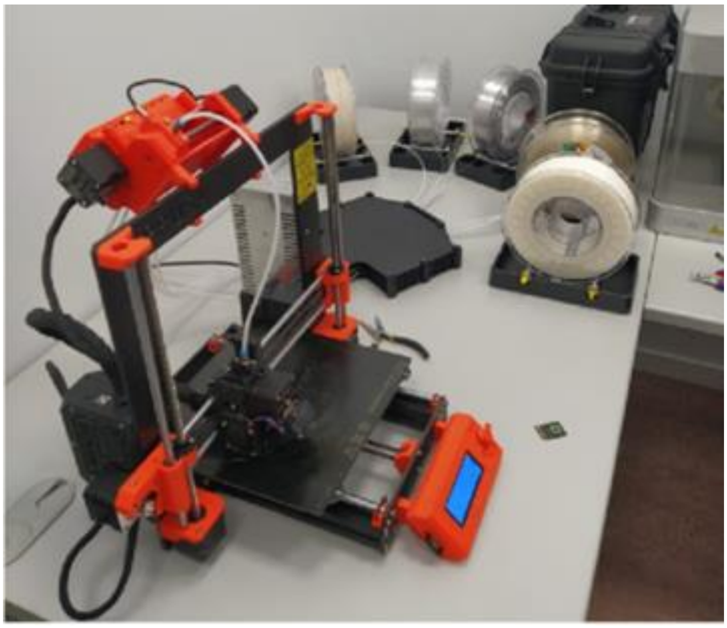

Figure 4: Multifilament printer Prusa i3 MK3S & MK3S + MMUS *(10)*

Additive manufacturing (AM) is a versatile method of production, and fibre-reinforced additive manufacturing (FRAM) takes those advantages one step further by incorporating the strengths of composite materials. The human labour involved in traditional composite manufacturing, such as Mold preparation, is eliminated, allowing for the simultaneous fabrication of critically shaped parts. AM makes rapid production of unique components with minimum human involvement feasible (5)

3.3 Casting:

There are a variety of casting methods, and as such, virtually any shape or size of part or product can be created by casting. Casting is one of the quickest ways to convert raw materials to finished parts and the selection of appropriate casting process can also help to reduce secondary processing. As with all manufacturing processes, achieving the best results at the lowest cost depends upon the designer's knowledge of the processes and their ability to design for the most appropriate process.

General classification of casting processes

Most casting processes involve the use of molten material (typically metal). This molten material is poured into a cavity in a mold which has the exact shape of the final part. The molten material then cools (with heat typically being removed through the mold) and solidifies in this shape. This may sound like a fairly straightforward process, but casting is primarily complicated by the complex metallurgical behaviour of molten metals. Casting processes can be separated into two main areas:

- Expendable mold processes
- Permanent mold processes

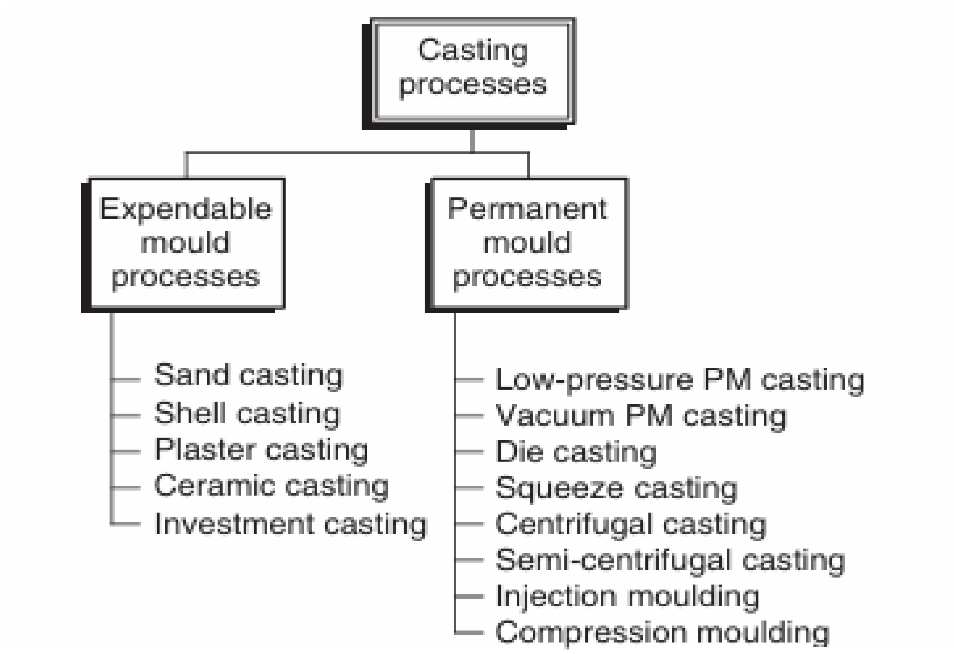

Figure 5: General classification of casting processes *(6)*

3.4 Forming processes:

While forming and shaping are technically different, they will be discussed together because they have many more similarities than differences. In the forming process, a solid piece of material (usually a billet) is altered by means of force to create the target shape. For shaping, the configuration usually involves melding a molten material (similar to casting). Forming can create complex shapes, but it is not as geometrically flexible as casting, although forming can promote good microstructures in the material which increase its mechanical properties.

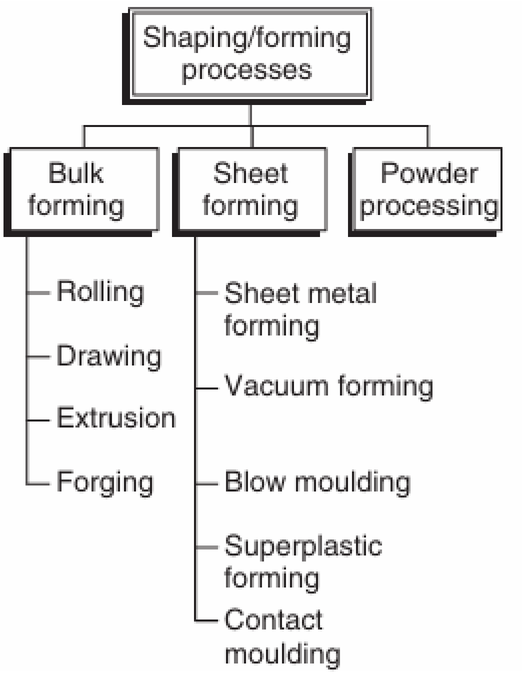

Figure 6 : General classification of shaping/forming *(6)*

General characteristics of forming and shaping processes:

The selection of an appropriate forming and/or shaping process will depend on a number of factors that include the material, size, weight and complexity of the geometry, labour equipment and tooling costs, tolerances and surface finish required, strength and quantity and production rate required and the overall quality requirements. (6)

4. Materiel Selected criteria:

Choosing the right materials is one of the main parameters impacting the design and production of lightweight parts. This section discusses the important criteria for choosing materials, with particular emphasis on balancing mechanical performance, cost and ease of manufacture.

4.1 Mechanical Strength:

Mechanical strength is one of the most important properties when selecting materials for lightweight components. This property reflects the ability of a material to withstand applied external forces, whether tension, compression, or shear stresses, without deformation or fracture.

Engineers use mechanical strength properties, such as tensile strength, elastic modulus, and flexural strength, as criteria for decision-making. For instance, in both recreational vehicle and aircraft applications, designs must be able to withstand dynamic stresses along with potentially extreme environmental exposure such as rods and extreme temperature pressure.

If adequate mechanical strength is not provided by a material, then component failure probability increases significantly when a component is subject to end-use conditions providing potential major monetary and/or human impact. Thus, it is crucial to select materials capable of high strength that can adhere to application requirements.

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4.2 Fatigue Resistance:

Fatigue resistance is the quality of a material to withstand repeated or dynamic loads for long periods without failure or damage. In real life, many components will be subject to cyclical or dynamic loads which can lead to fatigue failure, from engine vibrations in cars to air pressure in aircraft.

Fatigue resistance is typically measured with cyclic loading tests, applying the same load cycle to a material until it fails. The result shows how many cycles the material is able to undergo before breaking. Materials with high fatigue resistance have longer lives and allow for reduced use of maintenance.

In dynamic applications, like automobiles and aircrafts, fatigue resistance also becomes more important. If the material being used does not withstand cyclic loads under different uses, you may have very sudden and serious component failures.

4.3 Manufacturability:

Manufacturability is defined as the ease which a material can be manipulated and processed using available industrial processes. Different materials have different abilities to be formed, cut, or cast. These differences affect production costs and timelines for manufacturability.

Many times, materials that are strong and lightweight, for example a composite can be hard to manufacture, and may require specialized techniques such as CNC Machining or Additive Manufacturing. Further, products made of composites, such as Carbon Fiber, has exacting and complex manufacturing processes, which tends to make them expensive.

However, there are materials such as aluminium and ABS plastic which can be shaped into form or manufactured with relative ease through processes profiles such as casting or thermoforming. Choosing a material that turns out to be difficult to manufacture often leads to increased costs and loss of productivity. Therefore, and so, a trade-off must be struck between mechanical performance and manufacturability.

4.4 Cost:

Cost will always be a parameter in material choice, especially for mass production. The cost involves; raw material cost, manufacturing cost, and the cost to essentially own the end product.

Some materials, for example titanium and carbon Fiber, may offer outstanding mechanical performance but are prohibitively expensive, and therefore not sometimes a sustainable material choice for some applications. By contrast materials like aluminium and ABS plastic are inexpensive.

The life cycle cost must also be considered covering production, cost of operation and cost of maintenance. In some cases, a more expensive material may be cheaper over the long term, as possibly the materials durability and therefore longevity may offset its cost.

It is vital for the project's sustainability, to achieve the right trade-off between cost and performance. Using too expensive material could mean the final product is too expensive to compete in the market.

4.5 Sustainability:

Sustainability has become an essential aspect of product design in today's world. Sustainability considers how eco-friendly a material is, including recyclability, carbon emissions during production, and consumption of natural resources.

For example, aluminium is 100% recyclable and is designed to be continually recycled. This is considered "more sustainable" compared to materials that have no recycling option or use significant energy in production. There are also other materials or emerging trends that use bio-based polymers (corn or sugarcane) that can have a lower environmental impact.

Exploring the environmental impact of materials when manufactured and at the end of their lifecycle for disposal should also be considered. Companies are now finding they are responsible and obligated to reduce their carbon footprint and use eco-friendly materials due to the rise in environmental awareness. If a company uses non-sustainable materials, it could result in legal action and potentially tarnish their reputation with consumers.

5. Optimization techniques in manufacturing:

Optimization methods are an important part of developing productive manufacturing processes for lightweight parts. These methods are used to improve performance, reduce cost, and improve efficiency. This section traces the most commonly used optimization methods in manufacturing and their potential use for improving products.

5.1 Finite Element Analysis (FEA):

Finite Element Analysis (FEA) is a computational method for analysing and modelling a component's and materials' behaviour under different environmental conditions. FEA works by divining the component into smaller elements (finite elements) and analyses the stresses, deformation; and the forces acting on those elements.

FEA can support maximizing the design of a component before a manufacturer produces it by limiting how many physical prototypes, reducing cost. FEA can be used to analyse the response in dynamic, thermal, or environmental stresses to failure. FEA is common in the lightweight structure design of components in the automotive and aerospace industries. FEA supports the relation of the amount of composite material needed to achieve an optimal weight while retaining strength.

5.2 Multi-Criteria Decision-Making (MCDM):

Multi-Criteria Decision-Making is an approach for comparing alternatives that involve multiple criteria for evaluation, such as cost, performance, sustainability, etc. The most widely used methods are,

1. AHP (Analytic Hierarchy Process): This involves the ranking of options based on a prioritized list of criteria.

2. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution): This is used to select the option most similar to the ideal solution.

This method allows engineers to select materials or design processes and still achieve a degree of balance between criteria in their selection. The method allows engineers to select materials to manufacture lightweight components and was applied to optimize a manufacturers process to reduce cost whilst maintaining quality.

6. Conclusion:

As further development of improvements in fuel economy efficiency and reduction of environmental impact continued to fuel demand in recent decades from global vehicle manufacturers to revolutionize weight-saving in vehicular design, the additional challenge of cost-control and easy recovery further complicates materials selection and structural design. Therefore, swapping traditional automotive materials like steel and cast iron for advanced lightweight materials has been shown to be a capable approach resulting in considerable weight savings for newly developed vehicles utility with lightweight materials. Subsequently, this review presented a full overview of available and impending lightweight materials for automotive purviews, which can be grouped into lightweight alloys (i.e. aluminium, magnesium and titanium alloys), high-strength steels.

II. Chapter 2:

multi-objective optimization of materiel selected

1. Introduction:

Real-life decision-making frequently requires that a compromise be reached between conflicting objectives. The compromises required to strike a balance between wealth and quality of life, between the performance and the cost of a car, or between health and the pleasure of eating rich foods, are familiar ones. Similar conflicts arise in the choice of materials. The objective in choosing a material is to optimize a number of metrics of performance in the product in which it is used. Common among these metrics are cost, mass, volume, power-to-weight ratio, and energy density, but there are many more. Conflict arises because the choice that optimizes one metric will not, in general, do the same for the others; then the best choice is a compromise, optimizing none but pushing all as close to their optima as their interdependence allows. This paper is concerned with multi-objective optimization of material choice. It draws on established methods for multi objective optimization and for material selection illustrating how the first can be applied to the second. The methods are equally applicable to material selection and to material design. (7)

2. Previous study:

In this chapter, we took an example of previous study

that will apply a hybrid evaluation approach (G-TOPSIS) that combines Gray relationship analysis and the technique for order preference by similarity to ideal solution (TOPSIS) to evaluate lightweight material alternatives and obtain an ideal material. A study of 17 types of lightweight materials was conducted to verify the hierarchical structure and the multi-criteria decision-making (MCDM) method.

From this study:

As shown in Section 1, many quantitative and qualitative criteria should be taken into consideration in the process of material selection. For different eld of engineering application, the emphasis points and evaluation indicators should also be distinct. In automotive manufacturing eld, mechanical and technical properties are commonly considered in the hierarchical structure of evaluation indicators. However, other properties, e.g., durability, also need to be included as indispensable criteria for automobile applications. Therefore, we formulate a systematic hierarchical structure that considers mechanical, durability, societal and technical properties for the lightweight material selection. (8)

Factor/attribute level	Symbol
Density (g/cm^3)	F_1
Modulus of elasticity (GPa)	F_2
Yield strength (MPa)	F_3
Tensile strength (MPa)	F_4
Recycle fraction (%)	F_5
Corrosion resistance	F_6
Thermal performance	F_7
Wear resistance	F_8
Health and Wellness (NVH)	F_9
Crashworthiness	F_{10}
Forming	F_{11}
Joining	F_{12}
Painting	F_{13}

Figure 7:symbol of factor / attribute level *(8)*

Material alternatives	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}
Low strength steels	7.85	205	200	260	85%	5	9	9	5	7	8	9	9
High strength steels	7.85	205	470	535	85%	5	9	9	5	7	8	9	9
Advanced high strength steels	7.85	200	860	1150	85%	6	10	8	4	9	5	7	9
Ultra-high strength steels	7.85	205	970	1250	85%	5	9	9	4	8	5	7	9
Stainless steels	7.85	205	310	620	85%	5	9	9	5	8	6	8	9
Aluminum alloy 7×××series	2.80	72	385	460	95%	7	8	6	9	4	8	5	9
Aluminum alloy 6×××series	2.80	70	260	310	95%	7	8	6	9	4	8	5	8
Aluminum alloy 5×××series	2.80	69.5	170	220	95%	7	8	6	9	4	8	5	8
Aluminum extrusion profiles	2.70	70	160	215	95%	7	8	6	9	4	8	5	8
Cast aluminum	2.70	73	210	290	95%	7	9	6	9	4	7	6	8
Magnesium alloy	1.79	45	130	237	90%	3	8	6	8	3	5	4	7
Ti alloy	4.50	108	1100	1200	90%	9	9	6	6	8	4	5	7
Thermoplasticsting plastics (PP)	0.90	1.60	35	35	20%	9	5	6	3	6	9	7	9
Thermosetting plastics (UP)	1.20	3.16	51.3	65	5%	9	5	5	3	6	9	7	9
Carbon fiber/epoxy Composites	1.61	115	1100	1400	5%	9	6	7	3	9	8	7	8
S-glass fiber/epoxy Composites	1.83	23.8	354.5	448.8	5%	9	6	7	3	6	8	7	8
Epoxy-glass fiber(sheet molding compound)	7.85	205	200	260	85%	5	9	9	5	7	8	9	9

Figure 8: The decision matrix for lightweight material alternatives. *(8)*

Four decisionmakers, including two experts who specialize in automobile design and two senior engineers from a reputable automobile manufacture enterprise, we reinter viewed to obtain the initial data and related information through questionnaire surveys. This investigation was conducted in October 08 in 2017. The decision matrix for lightweight material alternatives to each criterion in the hierarchical structure for optimal lightweight material selection is formulated as shown in Table2. (8)

3. Materiel and process database:

In this research, we will take 14 materials for study with their properties from the previous studied and apply the multi-objective optimization method to find optimal Pareto solutions for the best materials we need based on the criteria we have set from the outset.

Material	Density (Kg/m³)	Tensile Strength (MPa)	Forming
Low strength steel	7850	260	8
High strength steel	7850	535	8
Advanced high strength steel	7850	1150	5
Ultra-high strength steels	7850	1250	5
Stainless steels	7850	620	6
Al alloy 7*** series	2800	460	8
Al alloy 6*** series	2800	310	8
Al alloy 5*** series	2800	220	8
Al extrusion profiles	2700	215	8
Cast Aluminium	2700	290	7
Magnesium alloy	1790	237	5
Titanium alloy	4500	1200	4
Thermoplastic sting plastics (PP)	900	35	9
Thermosetting plastics (UP)	1200	65	9

4. Defining the problem and Mathematical modelling:

4.1 The problem:

The overall goal is to determine the best combination of materials, manufacturing processes, and thickness to balance multiple objectives using mathematical optimization tools.

4.2 Mathematical modelling:

x(1): Material type (Integer: 1–14)

x(2): Thickness (m) (0.05 – 0.05 m)

4.3 Converting to equations:

Weight = Density × Volume × Thickness.

Strength = Material Strength / Thickness.

- Component size is constant (100 cm^2).
- Thickness is the only variable (between 0.5–5 mm).

4.4 Applying the Weighted Sum Method:

Transforming Multiple Objectives into a Single Objective Function:

$$F_{total} = w_1 \cdot (\text{Weight}) + w_2 \cdot (-\text{Strength}) + w_3 \cdot (-\text{formability})$$

Weights used:

W1 = 0.3 (Weight)

W2 = 0.4 (Strength)

W3 = 0.3 (formability)

5. Modelling in MATLAB:

In order to reach Pareto solutions and optimal solutions for the material selection and manufacturing process using MATLAB and through multi-objective optimization (MOO), we use the genetic algorithm and weight sum method.

- Definition of materials and their properties in MATLAB

```matlab
% === تعريف المواد ===
materials = {
    'Low strength steel', 'High strength steel', 'Advanced high strength steel', ...
    'Ultra-high strength steels', 'Stainless steels', 'Al alloy 7*** series', ...
    'Al alloy 6*** series', 'Al alloy 5*** series', 'Al extrusion profiles', ...
    'Cast Aluminium', 'Magnesium alloy', 'Titanium alloy', 'Thermoplastic plastics (PP)', ...
    'Thermosetting plastics (UP)'};

% === خصائص المواد ===
density = [7850, 7850, 7850, 7850, 7850, 2800, 2800, 2800, 2700, 2700, 1790, 4500, 900, 1200];
tensile_strength = [260, 535, 1150, 1250, 620, 460, 310, 220, 215, 290, 237, 1200, 35, 65];
formability = [8, 8, 5, 5, 6, 8, 8, 8, 8, 7, 5, 4, 9, 9];
```

Figure 9: materiel and property

- Multi-objective function application

```matlab
% === دالة الهدف متعددة الأهداف ===
objectiveFunction = @(x) myMultiObjectiveFunction(x, materials, density, tensile_strength, formability);

% === حدود المتغيرات ===
lb = [1, 0.5]; % x(1): نوع المادة (1 إلى 14), x(2): السمك (mm)
ub = [14, 5];

nvars = 2;

% === خيارات gamultiobj ===
options_ga = optimoptions('gamultiobj',...
    'PopulationSize', 100,...
    'MaxGenerations', 200,...
    'PlotFcn', @gaplotpareto);

% === تشغيل التحسين متعدد الأهداف ===
[x_pareto, fval_pareto] = gamultiobj(objectiveFunction, nvars, [], [], [], [], lb, ub, options_ga);
```

Figure 10: multi-objective function

```matlab
%% ==================== الدوال المساعدة ====================
function F = myMultiObjectiveFunction(x, materials, density, tensile_strength, formability)
    material_idx = round(x(1));
    thickness = x(2); % mm

    rho = density(material_idx); % kg/m³ → g/cm³
    strength = tensile_strength(material_idx);
    form = formability(material_idx);

    volume = 100 * thickness; % cm³
    weight = (rho / 1000) * volume; % الوزن بالجرام

    F = [weight, -strength, -form]; % "-" لتحويل الهدف إلى تقليل
end
```

Figure 12: Auxiliary functions

- Function to place solutions for the best materials in a table

```matlab
% === تحويل النتائج إلى جدول ===
resultsTable = cell(size(x_pareto, 1), 5);
for i = 1:size(x_pareto, 1)
    material_idx = round(x_pareto(i,1));
    thickness = x_pareto(i,2);

    resultsTable(i, 1) = {materials{material_idx}};
    resultsTable(i, 2) = {thickness};
    resultsTable(i, 3) = {fval_pareto(i,1)};
    resultsTable(i, 4) = {-fval_pareto(i,2)};
    resultsTable(i, 5) = {-fval_pareto(i,3)};
end
```

Figure 11: function of solution table

- Graph Extraction Function

```matlab
figure;
scatter(fval_pareto(:,1), -fval_pareto(:,2), 'filled');
xlabel('الوزن (g)');
ylabel('مقاومة الشد (MPa)');
title('الوزن vs مقاومة الشد (Pareto Front)');
grid on;

figure;
scatter(fval_pareto(:,1), -fval_pareto(:,3), 'filled');
xlabel('الوزن (g)');
ylabel('قابلية التشكيل');
title('الوزن vs قابلية التشكيل (Pareto Front)');
grid on;
```

Figure 13: figure function

- Weight sum method pours Parejo solution:

```
% === تعيين أوزان للأهداف ===
weights = [0.3, 0.4, 0.3];

% === توحيد القيم (Normalization) ===
min_vals = min(fval_pareto);
max_vals = max(fval_pareto);

norm_fvals = zeros(size(fval_pareto));
for i = 1:3...

% === حساب الهدف المركب ===
combined_scores = weights * norm_fvals';

% === العثور على أفضل حل باستخدام WSM ===
[~, best_idx] = min(combined_scores);
best_solution = T_unique(best_idx, :);

% === عرض الحل الأمثل باستخدام WSM ===
disp(' ');
disp('✅ الحل الأمثل باستخدام Weighted Sum Method:');
disp(best_solution);
```

Figure 14; WSM function

6. Conclusion:

Choosing the best lightweight material, considering many factors, is a difficult and limiting issue for automotive applications. This chapter defines the mechanical and technical properties and requirements that will assist in selecting the best lightweight materiel. A weight-sum method and genetic algorithm via MATLAB are used to rank lightweight material options, to find the best alternative. The authors conducted a case study with four lightweight material types to facilitate multi-criteria decision making. In addition, this research has significant guiding importance on lightweight material design and performance enhancement in automobiles.

III. Chapter 3:

results and discussion

1. Introduction:

Lightweight design has received a growing amount of interest in the automotive industry due to energy savings and emissions reductions, but the decision-making process must consider all aspects of materials and structures, manufacturing, recyclability, and economics. This chapter looks at a multi-objective optimization method and the results of Pareto's work for the best materials and processes.

2. Main Optimization Results:

Show optimal solutions Table showing: material, , thickness, weight, strength, formability, and the perfect solution by using weight sum method.

Command Window

Optimization terminated: average change in the spread of Pareto solutions less than options.FunctionTolerance.

الحلول المثلى بعد إزالة التكرار:

Material	Thickness_mm	Weight_g	Strength_MPa	Formability_Index
{'Thermoplastic plastics (PP)' }	0.50005	45.004	35	9
{'Thermosetting plastics (UP)' }	0.50025	60.03	65	9
{'Magnesium alloy' }	0.50002	89.504	237	5
{'Al extrusion profiles' }	0.50002	135.01	215	8
{'Cast Aluminium' }	0.50004	135.01	290	7
{'Al alloy 6*** series' }	0.50002	140.01	310	8
{'Al alloy 7*** series' }	0.50004	140.01	460	8
{'Titanium alloy' }	0.50004	225.02	1200	4
{'Stainless steels' }	0.50003	392.52	620	6
{'Advanced high strength steel'}	0.50004	392.53	1150	5
{'Ultra-high strength steels' }	0.50005	392.54	1250	5
{'High strength steel' }	0.50013	392.6	535	8

✓ الحل الأمثل باستخدام Weighted Sum Method:

Material	Thickness_mm	Weight_g	Strength_MPa	Formability_Index
{'Ultra-high strength steels'}	0.50005	392.54	1250	5

Figure 15: Parejo solution

3. Pareto Front Solutions:

This chart shows Parejo's weight vs. strength and weight vs formability results for the best materials.

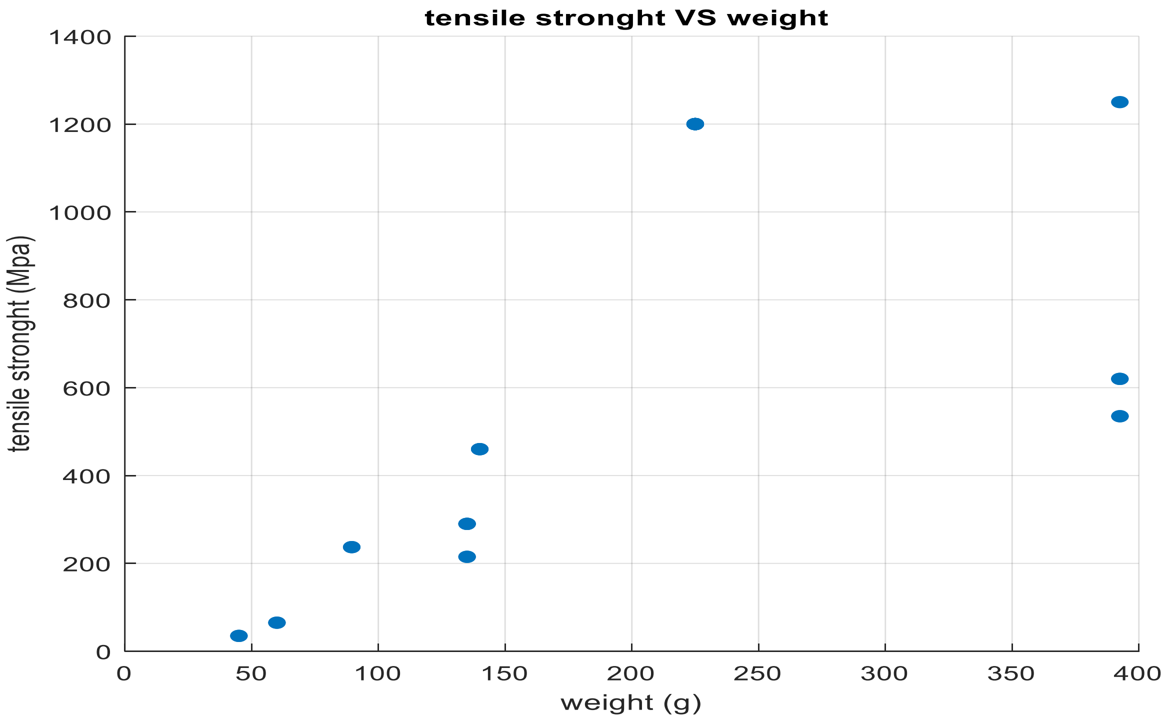

Figure 17: weight vs strength

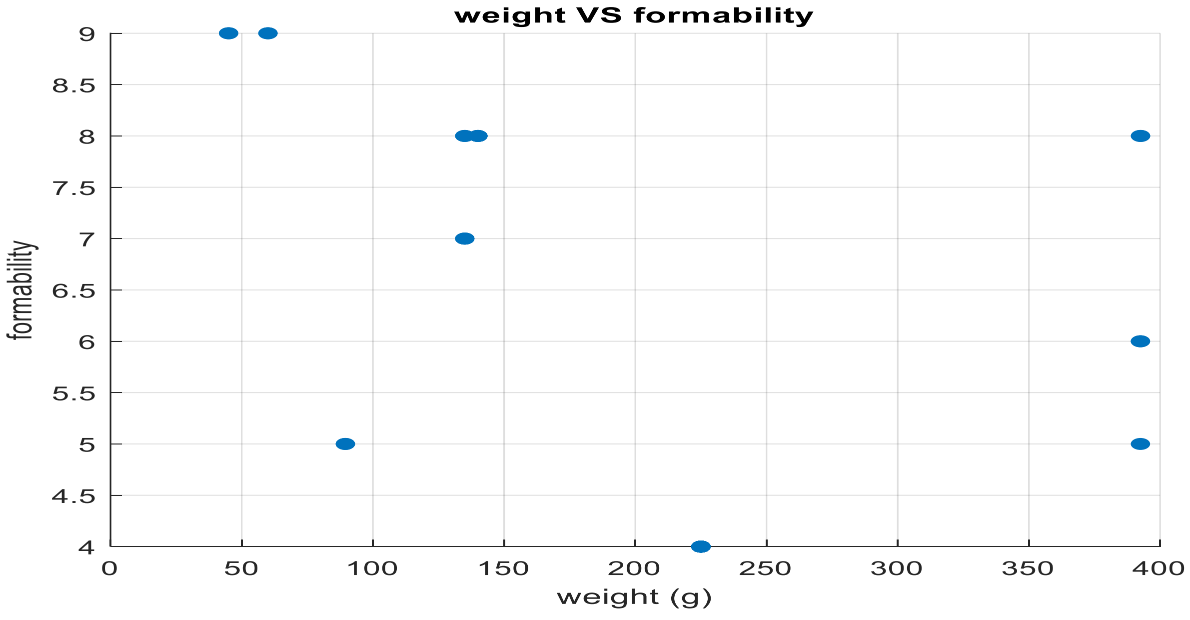

Figure 16: weight vs formability

4. Result Comparison:

The application of the Weighted Sum Method (WSM) in the MATLAB program enabled identification of the best material based on the three primary criteria of weight, tensile strength, and formability. Results suggested Ultra High Strength Steel was the best material (based on the weights applied), while the reference study relying on the TOPSIS and GRA (Grey Relational Analysis) method indicated Advanced High Strength Steel is the best material.

Differences in the method of value normalization and weighting can be significant to the material chosen. The findings highlighted the need to select the appropriate method for the nature of the problem and criteria used as neither is the single correct method; each method offers a different viewpoint on what is 'best.'

5. Conclusion

This study's goal was to help users optimize materials for lightweight components with the Weighted Sum Method in MATLAB. I had analysed (14 total materials , low-strength steels, high-strength steels, advanced high-strength steels, ultra-high-strength steels, stainless steels, aluminum alloy 7*** series, aluminum alloy 6*** series, aluminum alloy 5*** series, aluminum extrusion profiles, cast aluminum, magnesium alloy, Ti alloy, thermoplastics (PP), thermosetting plastics (UP)) The results showed that the Weighted Sum Method will resolve conflicting foci such as weighing concern on minimizing weight vs weighing concern on maximizing strength, however it also presented limitations such as fixed-volume assumption and it didn't have real-life manufacturing considerations. Future research considers, experimental testing or using more advanced techniques like NSGA-II to help the user do more optimal design.

conclusion generale:

This memorandum focused on advancing material selection for lightweight components. The goal was to achieve a balance between three main objectives: weight reduction, increasing mechanical strength and formability. The research was structured in chapters based on methodology to ensure the rigor of the results obtained. The background context for the relevance of lightweight components in modern industries such as automotive and aerospace was defined, and the main research objectives were indicated: to develop a methodology for integrated material selection using MATLAB. A review of some of the most prevalent lightweight materials and their properties and manufacturing processes was conducted. The emphasis of initial study was on multi-objective optimization, and by using the Weighted Sum Method obtained optimal Pareto solutions that illustrate the balance between the objectives. In the end, we hope to pursue this study, improve it and broaden its scope.

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