Available online at www.ijapie.org

INTERNATIONAL JOURNAL OF ADVANCED PRODUCTION AND INDUSTRIAL ENGINEERING

IJAPIE-2021-07-352, Vol 6 (3), 18-26

https://doi.org/10.35121/ijapie202107353

IJAPIE
Connecting Science & Technology with Management.
Crossref
A Journal for all Products & Processes.

An analysis of smart materials for auto parts manufacturing for reduced weight and cost of automobile

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ABSTRACT: Auto manufacturers are using smart materials to produce conventional automobile parts for reducing manufacturing cost, weight and to fit within the engineer's criteria. In the present research, the focus is made on major systems, parts, and support, which are crucial for any vehicle. An in-depth explanation of the part with advantages and disadvantages of the alternatives material is provided. A thorough analysis is made for material selection for making a particular system according to our requirement. Components that were analyzed in the study are body panels, car interiors, engine, and its components, exhaust system, brakes calipers, and their subparts. The study will help in understanding the part requirement with a broader perspective while researching a material best suited for the vehicle's needs and specifications.

Keywords: Engines, Steel, Iron, Aluminum, Piston, Body panel,

I. INTRODUCTION

Material selection for upcoming cars has now renewed its importance for making cost-effective smart designs that can be mass-produced and also meet the engineer's standards. It now plays a crucial role to get an edge over other manufacturers in the game. The automotive industry uses many parts such as pistons, crankshaft, camshaft, spark plug-in engines. It uses asbestos in the clutch, chassis, brakes, tires, suspension, etc. In the present study, we have compared different materials used for manufacturing parts/components in the automotive industry. According to one of the studies materials consumed by the automotive industry is one of the largest in the world [1]. With a diverse range of materials that are available today, the frequently used materials today are steel, cast iron, aluminium, polymers, different alloys, and composites. They are used because of strength or their ability to make a structure lighter. Most of these are still produced by conventional techniques which require a relook.

At present time we are mainly focusing on improving the performance of the vehicles. While creating a vehicle it is important to reduce its mass, with maintained basic characteristics [2]. This would require a strong but lightweight material for its manufacturing. From the primitive times, Iron and its alloy i.e steel have been the first preference among material for making automotive parts, and with the introduction of alloy steel, some parts have started moving towards this material. The main reason for starting producing automotive parts in steel was to reduce the total weight of the vehicle that will in turn boost, both the fuel economy and the speed to weight ratio. It had been that way only until we started using material that was previously only used for making aircrafts in the early 1900s, that was aluminium. Aluminium being more light in weight provided greater scope to reduce the curb weight of the vehicle, and by mixing it with other materials, aluminium alloy also showed

more structural strength than other counterparts and steel too. Both steel and aluminium alloys are used in making body panels and other engine block parts.

With expansion of new combinations of materials, which helped in the increased durability and reliability of the parts of vehicles This has led to further increase in analysis in material sciences. The development is seen in the automotive industry too as more and more lighter, better, safer materials are developed. Increasing standard of safety and quality which has helped in the innovation of new materials has helped in cutting the cost of the vehicle. It has bee witness that ongoing battle between the manufacturers to make more advance components has helped competition which further led to improved quality of the existing part [3–5].

Proving the above statement credibility industry is working on plastic / its mixtures for component manufacturing. It was first used as a polybag, it was the ford engineer's that first used plastic in the making of a car, for the production of 1982 ford sierra bumper. Nowadays most of the manufacturers use plastic for making body panels or the interior of the car. Almost 10% of vehicle weight account for plastic. A high use of polyolefins (i.e. polypropylene and polyethylene) has been seen in bumpers, fuel tanks, battery trays etc.

The last major type of material that is used in a vehicle is the polymer composites. Composites are used since when the steel is used. We can see polymers in the interior of the car as well as the chassis of the car where we use liquid polymer in the small cavities to provide extra strength to that part and overall increasing the stability of the design. Other parts where we see use of composites are the body panels where we are currently using RRIM instead of thermoplastic that helps in satisfying the structural requirements of it too etc.

In the present study a comparison of different materials on the basis of their properties and the place they are used is made. Best suitable material for manufacturing a part based on material properties and component usage is proposed.

II. LITERATURE REVIEW

The different automobile components that are reviewed are engine, car interiors, body panel, exhaust system, brakes and rims.

1. **Engine**

For road transport vehicles are required and internal combustion engines is the main system that propels the vehicle. Serrano [6] referred that it will be impossible to replace engine in vehicles. Even now this statement is true, even though a lot of research is going on electric and hybrid vehicles. Engine is the heart of any automobile and it's the place extreme conditions are found. The parts inside engine moves in thousands of rpm and temperatures are high. Only a few materials can withstand these conditions with proper working. A comparative chart is prepared based on part usage and material used and is placed in table 1.

Table 1 Comparative chart

Engine components	About these components	Material used in manufacturing of these components	Alternative material available for the manufacturing of these components
Crankshaft	Rotating shaft Material Proposed Forged steel superior performance than cast iron	Forged steel Advantages: Forged steel crankshaft are stronger and possess superior fatigue resistances Disadvantages: They are more costly to produce lower quality manufacturing processes	Cast iron Advantages : Cast Iron crankshaft offer lightweight design and cost efficient production Disadvantages: It has many series of defects like segregation, sand holes

Camshaft	IC Engines uses this part i.e camshaft for proper functioning of motor and ignition system. [7].	Camshaft are made of chilled cast iron Advantage :It has high wear resistances	The other material is steel. Advantages: Steel camshafts handle more mechanical loads than cast iron
Piston	Piston is a reciprocating component. It is used in pumps, compressors, hydraulic and pneumatic cylinders. They are also used in similar other mechanisms [8].	Pistons are commonly made of a cast aluminum alloy Advantages: They have high thermal conductivity Disadvantages: Abnormal wear of cylinder bores.	Other piston material is cast iron Advantages: They are heavier hence produce more torque Disadvantage: It has less thermal conductivity compared to aluminium
Valves	Valves keep a check on the fluid flow by varing gap opening in passage ways.	The inlet valves uses materials like chrome while the exhaust valves uses metals like nickel alloy,	The other alternatives are: For inlet valves: nickel, or alloy steel For outlet valves metallic element, or cobalt-chromium alloys.
Engine Block and Cylinder head	An engine block contains the cylinders, and different components. Engine cylinder head is fixed with engine block	Engine head and cylinder are made of aluminium alloy Advantages: They are lighter in weight Disadvantages: Less stiff as compared to steels thus working is affected at higher loads.	Other alternative is cast iron Advantages: Cast iron is much more durable. Disadvantages: Cast Iron is heavier and does not conduct heat as well as Aluminium

2. Interior of cars

A. Seat

Seats form the majority of the interior of the car and are a very important component as a good comfortable seat will allow passengers to relax. Materials used for seats are [9].

i. Nylon fabric: Seats are mostly made of this material. Durability and affordability are the main positive points that favour its usage.
ii. Leather: It is expensive but market supports this material because of its feel, comfort, elegance, aesthetics, and softness.
iii. Faux vinyl fabric: This material possesses high quality, it is elegant having low cost. It is comfortable as compared with leather with low cost. It can be easily cleaned and maintained.

So considering all the factors, leather is the best material. But if cost is the issue then the best alternative is faux vinyl fabric that will give you a primary look and also can be cleaned [10].

B. Seat belt

A seat belt is used for safety for the occupants in a vehicle. Once in use they keep occupants fixed to their seats on impact and thus preventing them from hitting with any car interior during impact [11]. Seat belts are long strips which are made from nylon / Polyester filament yarns. These yarns have high tensile strength that is need during impact. The seat belts that are used in cars are of three-point type. These have a single continuous length of webbing [12]. They are called three-point because of its structure which helps in absorbing / spreading energy of the moving body during collision over the other body parts such as chest, pelvis and shoulders. Nylon filament / polyester filament yarn is woven to produce the webbing pattern in the seat belt. As per the research made it is concluded that polyester has better stiffness then nylon and also has lower extensibility. It also produces a strong webbing pattern than nylon and also easy to clean [13].

C. Steering wheel

The steering wheel controls the steering system and the direction of the vehicle travel. It constitutes of a linkage system that connects with the front wheels of the vehicle. Moulded, pigmented vinyl resins / RIM pigmented urethane are basic materials that are used to make steering wheel. Now a day's plastic has also

emerged as a new material for steering columns. Simultaneous usage of in-mould thermoplastic and metal are used for different steering components. Vinyl resin, Teflon leather are some other materials used for this component [14].

3. Body Panel

Body panels are the outer thin sheet of metal, composite, plastic etc. It's also the sheet that first comes in contact in case of collision so it needs to be shock absorbent and also designed for aerodynamic performance. It is attached to the frame or chassis of the car to form the structure of the car [15]. Parts like a bumper, fenders, doors, roof, cowl panel and valance panel etc forms the complete body panel of any automobile.

For the manufacturing of body panels for a long time the best material has been high grade Steel. This is due to the fact that steel has high ductility and malleability which helps it to not break. It can be easily turn into sheets and also reduce the weight of the car as they are lighter in weight and cheap too [16].

Innovators used alumina in place of steel sheets for making the cars body panel and got impressive results as it improves cars power to weight ratio being lighter than steel and also have higher strength and stiffness.

The newest finding in the field of materials for body panels is the carbon fibre composite. That gives you increased velocity and less drag due to the fact that carbon fibre is too light, it can reduce the weight of the component by up to 30-40%.. It is costly and also can shatter when exposed to high pressure situations [17].

So keeping that in mind the best material for making body panels is steel only. It provides good strength, can be easy to repair and is cheap. If more power to weight ratio is required than aluminium will be the best alternative.

4. Exhaust system

An exhaust system guides the exhaust gases from engine combustion chamber to external environment. This is done through exhaust pipes. Based on the system design the gases has to pass through [18]:

- Engine Components: cylinder head and exhaust manifold
- Energy Saving Device: turbocharger
- Pollution control device: i.e catalytic converter. .
- Noise Reduction system: muffler / silencer.

Table 2 shows characteristics that are required for the exhaust system. Woking temperature variation are shown in the Figure 1.

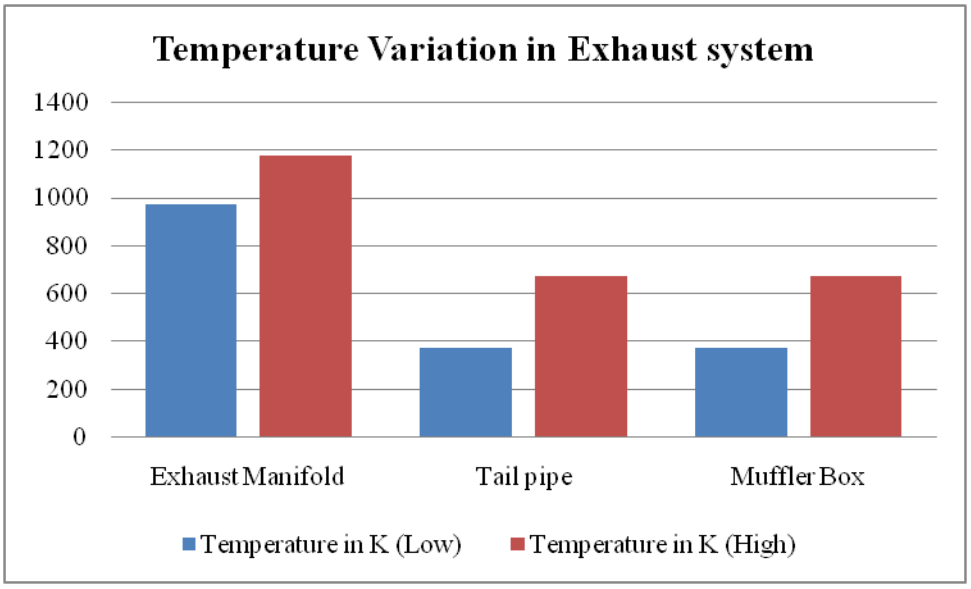

Figure 1 Temperature variation in exhaust system

Table 2 Necessary characteristics for the exhaust system [19]

Component	Exhaust Manifold	Tail pipe	Muffler Box
Working temperature	973.15 - 1173.15K	373.15- 673.15K	373.15 - 673.15K
Characteristic, properties required	Can bear high temperature. High thermal fatigue life. Should be oxidation resistant	Must be oxidation and corrosion resistant	Must be corrosion and oxidation resistant

A. Manifold

Exhaust Manifold collects the exhaust gases from the multiple cylinders into one exhaust pipe. The starting points is the exhaust valve (which are inside the engine) while the end point is the inlet of the catalytic converter [20]. Because of the presence of high temperature exhaust gases the temperature in this section is quiet high. The material having high thermal expansion coefficient, can withstand high temperature, strength, and corrosion resistant is used to manufacture this system [21]. The whole exhaust system uses the same material because of the hard / tough conditions.

There are majorly two types of material used for production of manifolds; they are cast iron or stainless steel. The grade of materials used for cast iron manifolds in the industry are FCD500-SM1, FCD500-7A and FCD550-SM1 etc. and stainless steel grades like SUS 429LM, SUS441L etc. These materials are having high melting point and temperature resistant properties. High thermal resistance thus helps the system to withstand cracking [22]. We require light weight material and smooth passage for the application of the exhaust system for reducing the overall weight and easy flow of the exhaust fumes. Advantage of stainless steel is it's easy to weld. Table 3 is a comparative table where in properties of both the materials are compared. The same is explained with the help of figure 2.

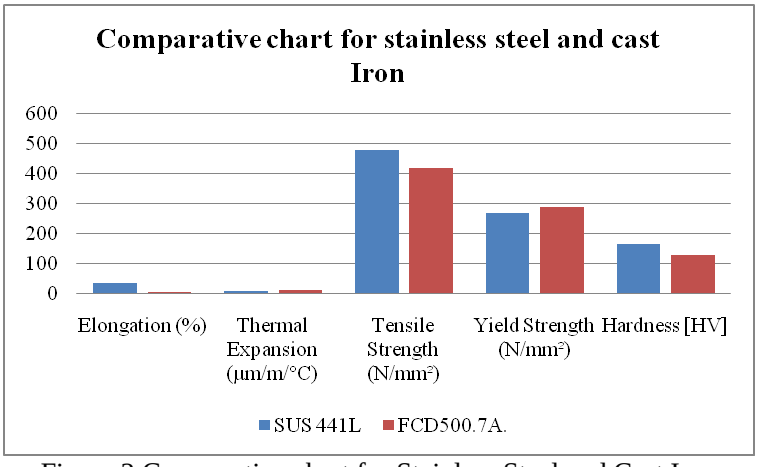

Figure 2 Comparative chart for Stainless Steel and Cast Iron

Table 3 Comparison between stainless steel and cast iron [22].

Material	SUS 441L	FCD500-7A
Elongation (%)	38	5-7
Thermal Expansion (µm/m/°C)	10.4when T=(950°C)	14.4 when T=(20-425°C)
Tensile Strength (N/mm²)	480	420
Yield Strength (N/mm²)	270	290
Hardness [HV]	166	130

Since two alternatives are present the more suitable option will be stainless steel SUS441L as compared to more common cast iron.

B. Catalytic Converter and muffler Assembly

The converter assembly is an exhaust emission control device that is responsible for reduction of the toxic gases and the pollutants that are produced during the combustion inside the engine. The gases pass through the catalytic converter and the harmful gases are shielded or reacted to make them less dangerous [23]. The muffler is responsible to reduce the vibrations or any kind of noise. The materials used for both of them should provide good thermal properties, corrosion resistance and strength.

Muffler assembly is responsible for noise, vibration and harshness reduction. The muffler assembly consists of endplates, baffle plates, perforated and non-perforated pipes, absorption material (glass wool) and shell [24]. The materials used for these components are mostly stainless steel (it can be of different grades) such as SUH 409L, SUS 436LM, SUS 439L, SUS 436L, SA1D etc. and as we described earlier that properties needed in the exhaust system are mostly same so grades of cast iron does the job. The superior material would definitely be stainless steel.

5. Brakes and Rims

The wheel hub connected with the axle has a brake disc. On the brake disc stationary callipers are mounted. Calipers have brake pads that come in contact with rotating disc, The braking relies on the friction between brake pads and discs. The kinetic energy of the high-speed rotating wheels is converted into a large amount of heat / thermal energy by the application of brakes. Since large heat energy generated has to be dissipated creates requirement on the material having heat dissipation and thermal conductivity of the brake discs.

A. Brake Disc Analysis

An automotive brake disc also known as rotor is a mechanical part in the brake system that helps in stopping or slowing the speed of the vehicle when it is moving at a certain rpm. Brake disc material can withstand the extreme load at different speed and braking style. It should be able to bear variable temperature, and pressure. As we know rotor has to stop the vehicle so it needs to be made of substance that can bear the high temperature levels generated due to friction and also wear slowly too [3]. Materials that are suited for these criteria are cast iron and alloys of titanium and aluminium. [25]

Following materials are used for the manufacturing of brake disk

1. Gray Cast iron (GCI)
2. Titanium alloy (Ti-6Al-4v)
3. SiC (20 %) reinforced with aluminium copper alloy (AMC 2)

A comparative chart of properties of material is prepared and is shown as Table 4.

Table 4 :- Properties of the selected material for brake disc.[26-28]

Properties / Materials	1	2	3	4	5
	Friction coefficient (μ)	Specific heat constant, Cp (KJ/Kg.K)	Specific Gravity (Mg/m^3)	Compressive Strength (mPa)	Wear rate ($x10^{-6} mm^3/N/m$)
AMC 2	0.44	0.92	2.8	761	2.91
GCI	0.41	0.46	7.2	1293	2.36
Ti-6Al-4V	0.34	0.58	4.42	1070	246.3

Scaled value chart is prepared to find out the performance index of the material for selection for best suitable material and is shown in table 5

Table 5 Scaling for calculating performance index [25].

Scaled Properties						
Materials	1	2	3	4	5	Performance index (γ)
AMC 2	100	94	96	59	81	88.6
Ti-6Al-4V	77	59	61	82	0.96	49.5
GCI	93	47	38	99	100	81.0

Performance index indicates how well work is meeting its defined goal, here of making a brake disk. it shows the technical ability of the substance not keeping in mind the cost of the product. Hence it can be concluded that AMC 2 is the best suitable material for the manufacturing of brake discs because of properties like low density and high thermal conductivity. Also it reduces the weight almost by 50% as compared to that with gray cast iron. Cast iron is still the most widely used material for brake discs because of its easy availability and dependability. AMC 2 is still new for mass production and is mainly tested in the labs.

B. Brake pads

The brake pad is connected to the hub with the help of callipers that hold them in one position. Its function is to slow the vehicle by pressing against the rotor that transforms the motion or kinetic energy into heat energy that is taken away by the rotor and released in the atmosphere [29].

Suitable material should be able to withstand the high temperature [30] wears less. In India the organic based brake pad material used is asbestos. Its properties include long life, good heat resistance and less cost. In developed nations it is not used because of the presence of asbestos dust. It is very harmful for health and also has tendency to lose grip when overheated. So considering the health related issue the best material can be ceramic brake pad. Ceramic is the newest material for brake pads it is expensive but have a long life. It works well in overheat condition and are less noisy. Only drawback is they take time to warm up. Less costly alternative includes semi metallic brake pad [31].

C. Wheel Rim

A wheel rim can be defined as an outer edge or part of the wheel that helps in holding the tire. It is a circular design that forms the outer structure of the wheel. The inside edge of the tire is mounted on this outer structure. They must be strong enough to hold the total weight of the vehicle and should be light enough to lower the weight below the suspension or unsprung weight to be as minimum as possible [32].

Nowadays the most common material for the production of rims is aluminium because it full fills all requirements as mentioned above. The types used commonly are aluminium 6061 & aluminium 6066

When same specification of both the materials of rims and considered and after simulate the different properties identified are compared in table 6.

Table 6:- Comparison of aluminium 6061 and 6066 in solid works [33]

Test Performed	Aluminium 6061	Aluminium 6066
Total Deformation	Deformation seen is 0.66057 mm	Deformation seen is 0.061716mm
Stress Distribution	Distribution seen is 23.24 N/mm³	Distribution seen is 23.193N/mm³
Strain Distribution	Distribution seen is 0.00031	Distribution seen is 0.00029

The experiment carried in the CAD and CAE program indicates that aluminium 6066 and 6061 have gone through same stress, when similar conditions were applied [34]. Results were satisfactory. So it basically ends up on their availability in abundance. That's why the researcher has chosen aluminium 6061 as it is available in large quantities and also cheaper than the other alternative.

III. CONCLUSION

Through this review paper, analysis of different materials used for auto parts is made. Materials that are used in manufacturing of the components are metal, alloy, composite, or a fibre. Based on analysis suggestions were made for selection of materials for different parts based on their points of usage different stresses faced by the component while in use. Review made gives scope for replacement of existing material with new smart materials developed. Most automobile industries use material that meets the requirement of Auto Industry production standards. As the market is going more towards budget-friendly products like daily use cars, industry is also taking care by the use of metal and fibres that behaves in a similar way like steel, polyester, leather, etc.

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