White Paper – Current Practices and Emerging Trends in selection of Materials for Automobile and other Engineering Sectors

Technology Cluster Manager

Technology Centre System Program (TCSP)

Office of DC MSME, Ministry of MSME

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List of Abbreviations

IF	Interstitial Free
MS	Mild Steel
BH	Bake Hardened
C Mn	Carbon Manganese
CFRP	Carbon Fibre Reinforced Plastic
GFRP	Glass Fibre Reinforced Plastic
HSLA	High Strength Low Alloy
TRIP	Transformation Induced Plasticity
DP	Dual Phase
MART	Martensitic steel
PHS	Press Hard enable Steel
AHSS	Advanced High Strength Steel
HSS	High Strength Steel
BEV	Battery Electric Vehicle
DBTT	Ductile Brittle Transition Temperature
PCB	Printed Circuit Board
Cu	Copper
Zn	Zinc
Al	Aluminium
Ni	Nickel
Ti	Titanium
PU	Polyurethane
PVC	Poly Vinyl Chloride
LC	Low carbon
MC	Medium carbon
HC	High Carbon
Mg	Magnesium
Pb	Lead
UV	Ultraviolet
HVAC	Heating, Ventilation and Air conditioning
CMOS	Complimentary metal-oxide-semiconductor
H_2S	Hydrogen Sulphide
CO_2	Carbon Dioxide
TC	Technology Centre
MSME	Micro Small Medium Enterprise

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1. Introduction

1.1. Project Background

Technology Centre Systems Programme (TCSP) is a national programme undertaken by the Ministry of Micro, Small and Medium Enterprises with the assistance of the World Bank. The programme seeks to enhance the technological and skill base of MSMEs in certain manufacturing sectors to improve the competitiveness of MSMEs, via upgraded and new Technology Centres (TCs).

The objective of the programme is to enhance the productivity of selected MSME clusters by improving their access to manufacturing technology, establishing a strong focus in providing business & technical advisory services, and improving availability & employability of skilled workforce through TCs[1]. As part of the programme, KPMG has been appointed as the Technology Cluster Manager (TCM) to support TCs and undertake technology and cluster development activities.

The objective of TCM is to increase business opportunities for MSMEs through market linkages, enhance the competitiveness of the cluster business environment, increase the number of MSMEs utilizing the services of TCs, develop a financially self-sustainable business model for cluster related services provided by TCs, identify technologies (Industry 4.0) of the selected sector for TCs, evaluate existing training programs & develop new training programs for rollout at TCs, conduct a gap analysis of TCs, strengthen the capabilities of TCs to provide technical advises to their clients, increase awareness amongst stakeholders on Environmental, Health, and Safety (EHS) requirements[2].

1.2. Abstract of the White Paper

Traditionally steel has been the primary material for various engineering applications due to its abundant availability, comparatively lower energy requirement for production as compared to other metals and hence lower cost and lower greenhouse emission, amenability to enhancement of properties through alloy additions and heat treatment as well as recyclability. Apart from steel other materials used in the industrial scenario are Cast Iron, Aluminium, Copper, Magnesium and their alloys and a wide array of non-metals such as Rubber, Plastic, Ceramics, Glass which have gained prominence over the years.

With the evolution of fibres (natural as well as man-made) as a building material, a revolutionary material development and usage trend is emerging by use of such fibres as a reinforcing material impregnated in a metal matrix or by polymer resin bonding leading to development of composites in various forms, including sandwiches. This developing field has thrown open wide possibilities due to their superior balance of light weight combined with high strength and stiffness.

This paper aims to examine the comparative features of various engineering materials about their associated opportunities and issues, manufacturing processes, usage trends and emerging possibilities.

Scope and opportunities for the MSME sector in India and possible role of the MSME Technology Centres as facilitators for such development have been discussed. Major emphasis has been laid on the Automobile sector, which globally has always been the major driver in the field of material development.

[1] DCMSME website, 25 May 2020
[2] DCMSME website, 25 May 2020

2. Evolution of Engineering materials

Interestingly from the trend of evolution of engineering materials one can see that many of the traditional category of materials which were identified and had found usage in the early ages are coming back (Ref Figure 1) in different forms with improved technology and processing techniques.

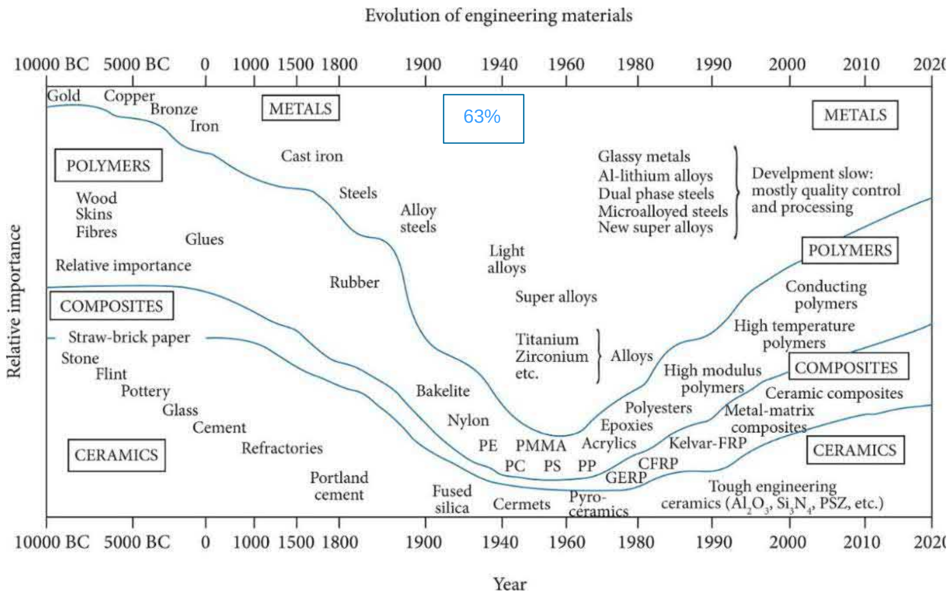

Figure 1: Evolution through ages[3]

While steel continues to be the primary material of choice even in the present day, a wide array of materials has been developed and used over the years. Synchronous with the development in the field of automobiles, usage of non-metals gained prominence in other engineering sectors as well.

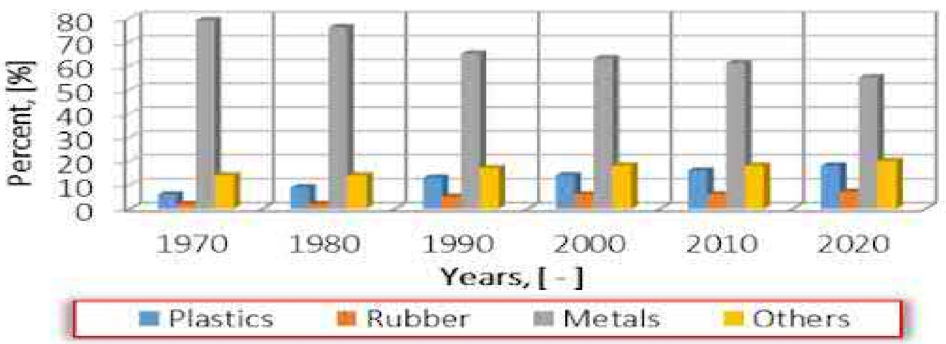

Figure 2: Material usage trend over last five decades[4]

The trends however will reflect a different picture if usage by weight percentage is taken, which will project a continued upward trend in usage of steel. Versatility of steel along with its availability, cost economy and fabricability have helped in its continued usage and growth specially in the heavy engineering sectors. In fact, per capita consumption of steel has become a yardstick of any country's economic prosperity. The current per capita steel usage in India is around 74 kgs as against 300 kgs + in US and 500 kgs + in China.

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[3] CES Information Guide - Materials Science Engineering (washington.edu)

[4] International Journal of Materials Engineering - Scientific & Academic Publishing: Home (sapub.org)

While there has been overall contraction in all the manufacturing sectors as well as in usage due to the unprecedented situation during 2020, the industrial scenario is likely to bounce back in 2021. Growth in the non-metallic sector particularly is likely to pick up pace due to environmental norms and rapid pace of technology development in these areas.

3. The Automobile Scenario

The first commercial automobile introduced in the market in 1908 as model T by Ford Motor company, USA, with all steel construction is now history. Gradually auto industry has seen use of wide variety of materials through rapid development in design and manufacturing over the decades. Broadly different types of material used in automobiles in some major parts are as below.

3.1. Metals (Ferrous & Non-Ferrous)

- Steel (Plain carbon, Alloyed, Micro alloyed, Specially treated and Stainless)
    - Body panels, chassis frame, doors, decklid, wheel rims (in commercial vehicles), support beams, Exhaust pipes and mufflers
- Cast Iron (Grey and Nodular)
    - Engine block, brake drums, wheel hub, brackets (in commercial vehicles)
- Aluminium alloys
    - Pressure Die casted covers and other miscellaneous parts, engine piston, bumper structure, alloy wheels
- Copper alloys
    - Electronic and electrical parts e.g. wire harness, starter motor, alternator, charging points, safety system
- Magnesium alloys
    - Limited usage in body, structures and machine parts in some passenger car models
- Titanium
    - Titanium along with Niobium and Vanadium singly or in combination are also used as micro alloying element in micro alloyed steels.
- Lead
    - Vehicle batteries, balancing weights in wheel

3.2. Non-Metals

- Plastic (various categories in Thermoplastic and Thermosets)
    - Dashboard, door handles, bumper fascia, air vents, pipes, sunroof
- Rubber (Natural and Synthetic)
    - Tyres, engine mounts, hoses, seals, o rings, wiper blades
- Glass (laminated and toughened)
    - Windshield, rear view mirrors, side and rear windows, camera lenses
- Composites (Fibre glass, Metal matrix)
    - Engine hood, Bumper, Fender, Lids and many other structural parts

Requirements on Automotive Industry	Reaction of Automotive Industry	Significance of Materials Engineering
--Conservation of Resources --Care of Environment	--Consumption Reduction --Weight Reduction	--Light Weight materials with Higher Efficiency --Material lifecycle with lower carbon footprint
	--Emission reduction from vehicles and production processes	--Non-Toxic Materials --Low emission processes
	Closed material cycles	--Recyclable Materials: Metals and Plastics --Renewable organic materials
		Low-price materials
Price Reduction	Cost effective development and production	Cost effective processes

Table 1: Highlights the strategic initiatives for material development

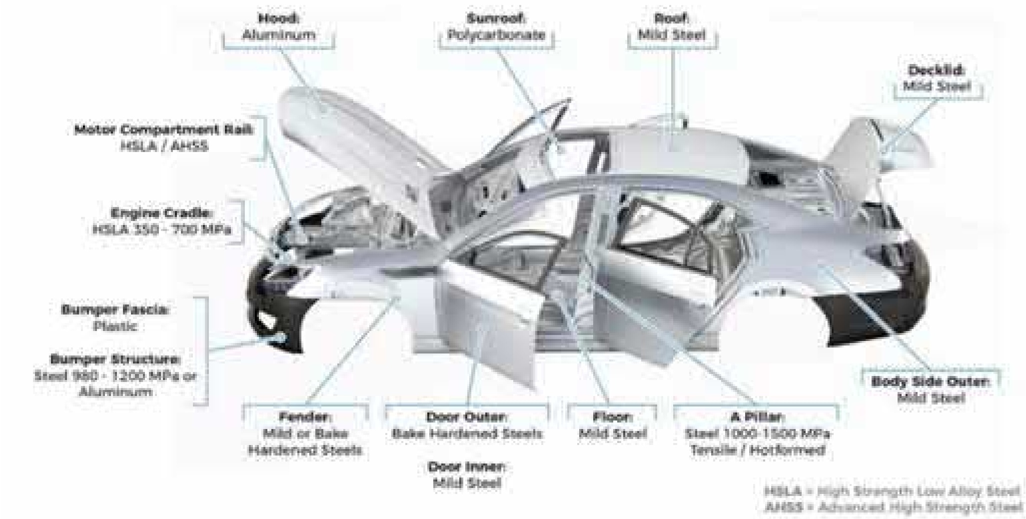

Figure 3: Examples of material usage in structural parts of a typical car body[5]

[5] Future Automotive Manufacturing Process & Materials | Mentor Works

4. Development Trends in Steel

After the birth of the first automobile in 1886 as Benz Patent- Motorwagen introduced by Karl Benz, the first commercial car model T was manufactured by Ford Motor company, USA in 1908 with all steel body which is long forgotten.

Over the decades a large variety of alternate materials have been developed with cost effective processes which are now used extensively in automobiles. Intensive research and development programs are continuing among motor manufacturing companies globally to stay ahead in the race.

However, despite challenges posed by alternate materials, steel continues to be the primary material of choice even to this day so much so that current usage by weight is still more than 60% and in passenger cars and more than 70% in commercial vehicles.

The major advantages of steel and its alloys are –

- High strength and Stiffness contributing to crash resistance
- High fatigue strength enabling usage under dynamic loading
- Possibility of alloying with other elements and heat treatment giving rise to wide range of properties
- Suitability for multiple downstream processing techniques for part manufacturing
- Ease of fabrication and forming
- Aesthetics and corrosion protection through surface treatment
- Comparatively lower energy requirement for extraction from ore as compared to some other competing metals and thus resulting in cost economy as well as lower life cycle environmental impact
- Recyclability
- Abundant availability of Iron ores from which Iron is extracted

4.1. Future Readiness

Two important developments and research trends in steel worth mentioning are-

4.1.1. Micro alloyed forging quality steels

By way of micro alloying with Vanadium can develop strength properties equivalent to heat treated (quenched and tempered) steel thus eliminating the need for energy intensive heat treatment, which apart from lowering throughput cost have helped to reduce carbon footprint as well. Such steels have now totally replaced hardened and tempered variety for crank shafts and some other engine components. However, challenge remains to adopt such steels for chassis frames which can experience extreme temperature drops down to (-) 50 deg C in cold regions. Sudden drop in Notch Toughness (Impact strength) in first and second generation micro alloyed steels with lowering temperature becomes a deterrent. Researches are on for a suitable grade of third generation micro alloyed steel to address the issue of DBTT (Ductile Brittle Transition Temperature).

4.1.2. High Strength Steel (HSS) in flat products

Developed and used over the years. However, to achieve a superior strength-ductility balance, current trends of development are aiming towards **AHSS (Advanced High Strength Steel)**. Relationship of various steel grades based on their strength (ultimate tensile strength and percentage elongation (measure of ductility) has been depicted in Figure 4.

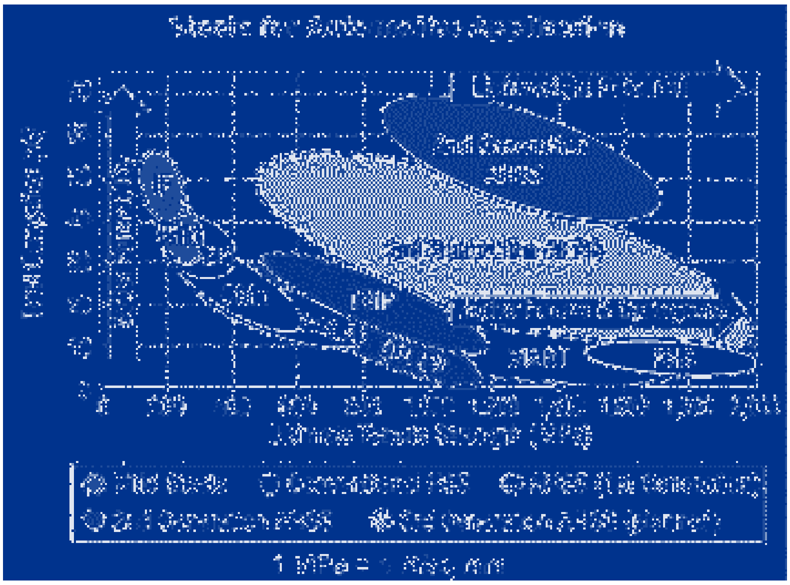

Figure 4: AHSS vs other grades of steel[6]

AHSS has been the buzzword in steel industry for nearly two decades now. However, with the growth of automotive industry and increased focus on statutory norms of lower emission and passenger safety, this class of material is getting increasing importance for development and usage in modern day automobiles.

With global warming and climate change, there are ever tightening regulations to lower automobile emissions, which can be achieved by increasing fuel efficiency. Lighter weight of a vehicle can help to achieve lower fuel consumption and therefore lower emission. Usage of higher strength steel helps to bring down the vehicle weight through use of thinner gauge steel in structural parts.

The other important factor is the passenger safety. AHSS exhibits excellent strength and stiffness resulting in improved crash resistance, which makes this class of material a preferred choice.

In modern automobiles there is increasing pressure on designers to incorporate various safety gadgets and additional safety features which tend to increase the weight of the vehicle. AHSS with possibility of thin gauging and light weighting help to counterbalance such weight increases.

Within the broad category of AHSS, one has the option to choose a suitable strength toughness (e.g. % elongation) balance depending on the part geometry and manufacturing process for the same.

While Aluminium is lighter, it cannot match AHSS in strength, stiffness and fatigue resistance. Therefore, while other competing materials are gradually replacing steel in automobiles, AHSS and HSS remain the primary materials of choice for critical structural parts. Currently all car manufacturers use such class of steels. Vehicle weight can be reduced by 20-30% by use of such steels as compared to conventional steel. This would mean reduction of curb

[6] Steels for Automotive Applications – IspatGuru

weight of a typical five-passenger family car by 170 to 250 kgs and save about 3 to 4 tonnes of greenhouse gases over the car's lifespan.

The advantages of AHSS are now being made use of in other engineering applications and critical structural as well, apart from automobiles. Some examples are ship building, aerospace, energy and infrastructure.

4.2. Future Mobility

The future mobility of wheels is with Electric Vehicles (EV). With stringent emission norms and depleting reserves of fossil fuel, we can expect a continuing surge of electric vehicles globally.

Apart from usage of AHSS in some critical structural parts, the other major usage of steel is in the transformers and generators apart from the stators and rotors in the motor. Electrical steel, which is manufactured to contain specific magnetic properties, is an important material of construction for such sub-assemblies.

Such steels have a critical influence on the efficiency of the motor, minimising core energy losses and thus boosting the vehicle's range. While charging stations appear to be a major constraint for the roll out of the EVs, a unique concept of trickle charging from the road surface itself is getting developed, with steel belts on the wheels and steel electrodes under the road surface in the designated charging lanes.

4.3. Distribution of Steel usage in different industrial sectors

[7]Steel is the primary material in building and infrastructure, railroad transportation, ship building, machine tools and other engineering sectors, which are constantly growing in keeping with the country's economic progress. Various types of steel in commercial (mild and other plain carbon) as well as special grades (alloyed and heat treated) are manufactured in bulk keeping in pace with the ever-growing demand.

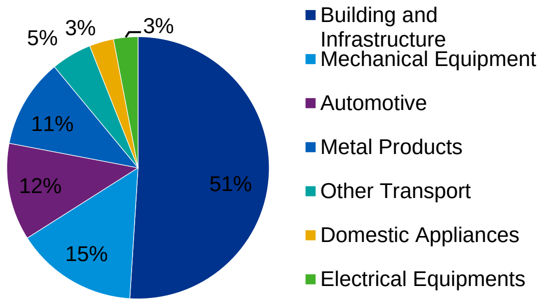

Figure 5: Engineering Sector wise global steel usage

[7] Global steel usage by sector 2018 | Statista

5. Aluminium and its alloys

5.1. Usage and development trends in automobile

Next to steel, Aluminium is the second most important metallic material in terms of number of parts in automobiles. According to the recent Ducker Worldwide research, the content of mild and high strength steel (HSS) in vehicles will gradually decrease in future, while the contents of aluminium and AHSS will increase between 2017 and 2025 (aluminium from 11% to 16% and AHSS from 7% to around 10%). The content of mild and HSS steel will decrease, by half, to around 20% in vehicles by 2025.

Apart from a few critical areas, such as roof rail, longitudinal front and upper, relevant for safety of passenger cabin, it is now possible to make an entire body-in-white from aluminium, resulting in significant weight reduction and performance enhancement.

Some car models have adopted aluminium alloy chassis frames such as - Aluminium alloy wheels are preferred in passenger cars because of their light weight and higher heat dissipation characteristic as compared to steel wheels. The increase in the usage of aluminium will be aided by improved alloying and heat treatment techniques.

In the Electric Vehicle (EV) sector, one of the global leading producers Tesla, have two aluminium intensive models (Tesla Model S and Tesla Model X). Some of the other leading manufacturers who have gone for aluminium intensive models are Jaguar and Chinese-based EV manufacturer Nio, who have recently launched aluminium alloys for structural components for different models.

However, Tesla after their two aluminium intensive models as above, has now launched its smallest and cheapest model as Tesla Model 3, which is a steel intensive vehicle.

Thus, the tussle between steel and aluminium continues in the automobile industry with each trying to gain ground through new technological developments. Aluminium alloys are likely to reach 16% of curb weight in passenger cars by 2025 from the present 9% approximately.

While the advantage of aluminium is lower weight, corrosion resistance, high formability and recyclability among others, the following points need to be addressed by auto designers –

- While the density of aluminium is approximately one third that of steel, the elastic modulus of aluminium on the other hand is also one third of steel. Hence because of lower stiffness and strength of aluminium as compared to steel, a structural section made of aluminium must be made proportionately thicker for similar load bearing capacity.

- Fatigue strength of aluminium is not comparable to that of steel and hence is not suitable for parts subjected to dynamic loading.

- High cost due to large energy requirement for extraction of aluminium from ore (bauxite) by electrolysis. Energy required for manufacturing aluminium is around 145 MJ per Kg as against approximately 35 MJ per Kg for steel. Thus, manufacture of aluminium leaves a much higher carbon footprint (more than four times) than manufacture of steel. The total life cycle emission of aluminium on environment (from raw material extraction to end of life recycling and disposal) expressed as Kg/CO2 also falls far short of steel. This aspect can more than counterbalance the advantage of lower emissions achieved by using a lighter metal in automobiles.

5.2. Aluminium Usage in Aircraft

Aluminium has traditionally been the ideal material of choice for aircraft manufacture because of its lightweight and strength (in alloyed, heat treated, and precipitation hardened forms). This allows the aircraft to carry more weight and become more fuel efficient. Furthermore, aluminium's high resistance to corrosion adds to the safety features of the aircraft. However, new generation of Titanium alloys and carbon fibres are gradually replacing aluminium in the fuselage and wing parts.

5.3. Aluminium in General Engineering Industry

In the general engineering sectors the usage of aluminium is mainly in structural, air conditioning, solar panels, power lines, packaging etc.

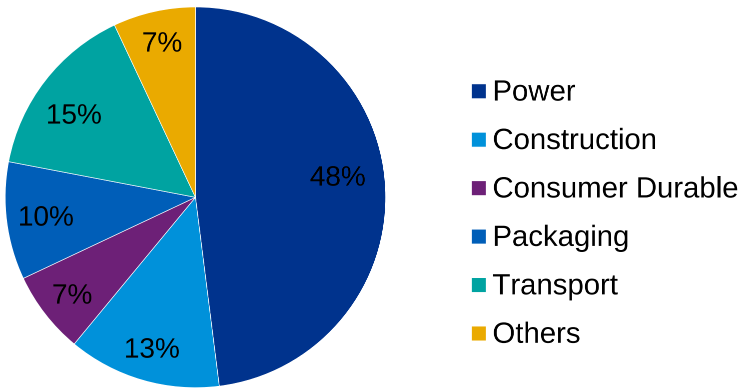

Figure 6: Sector wise Aluminium usage in India[8]

While aluminium continues to be the most expensive among the bulk building materials due to the high embedded energy from the ore extraction process, part of the high cost of raw material gets offset by low cost, high volume output downstream manufacturing processes such as pressure die casting and extrusion.

6. Polymeric Materials

Many materials found in nature are polymers. In fact, the basic molecular structure of all plant and animal life is similar to that of a synthetic polymer. Natural polymers include such materials as Protein, silk, shellac, bitumen, rubber, cellulose and jute. However, the majority of polymers or plastics used for engineering design are synthetic and often they are specifically formulated or "designed" by chemists or chemical engineers to serve a specific purpose.

6.1. Plastic types and usage

Apart from packaging, building and construction, the major consumer of polymers is the automotive industry. Polypropylene, Polyurethane, Polyamides and PVC are the major grades of polymers used in present day automobiles.

[8] The Aluminium Industry in India | Consult MCG

In early days of car manufacturing in the 1950s, there had hardly been any use of plastic. In the current scenario the typical automobile has more than 120 kilograms of plastic. Plastics are preferred mainly because of their light weight apart from total freedom from corrosion.

It has been estimated that every 10 percent drop in vehicle weight means 5 to 7 percent decrease in fuel usage.

Plastic is easily mouldable into intricate parts. Developments in Injection moulding have further helped in producing critical and intricate plastic parts in high volumes. Plastic parts can be made aesthetically appealing by various surface treatment techniques such as painting and electroplating.

Out of the various types of plastics used in cars the major ones are –

6.1.1. Polypropylene (PP)

Polypropylene is a thermoplastic polymer. It is partially crystalline and non-polar. Its properties are somewhat similar to Polyethylene but is marginally harder and more heat resistant. Because of these properties and high chemical resistance, Polypropylene is a preferred plastic material for automobiles and is used in bumpers, cable insulation, carpet fibres etc.

6.1.2. Polyurethane (PU)

Polyurethane exists in various forms. While majority of PU grades are thermosetting plastics (which do not soften when heated), thermoplastic polymers (TPU) are also available. PU can take on hard as well as soft forms. It has excellent abrasion resistance, heat resistance, toughness, and flexibility. It has very high weather, radiation, and solvent resistance.

In automobiles PU is used in tyres, suspension bushings and seating. Domestic usage are PU foams in mattresses, refrigerator sealings etc.

6.1.3. Polyvinyl Chloride (PVC)

PVC is one of the most used thermoplastic polymers. It is available in rigid (un-plasticized) as well as in flexible form. The rigid form finds usage in piping, furniture, packaging bottles etc. In the flexible form (made with plasticizers such as phthalates) it is used in electrical cable insulation, flooring and inflatable products. PU is an excellent flame retardant and has good thermal stability.

In automobiles PU finds extensive usage in in electrical cable sheathing, instrument panels and door parts. Parts using PU can be formed by various processes such as injection moulding, blow moulding, extrusion etc.

6.1.4. Acrylonitrile Butadiene Styrene (ABS)

ABS is a thermoplastic which is made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. ABS have excellent toughness and impact resistance. It is resistant to acids as well as alkali.

ABS can be produced in different grades and properties by altering the proportion of the constituents, which can make it suitable for making parts either by extrusion or injection moulding. In automobiles this polymer finds usage in dashboards and wheel covers.

6.1.5. Nylon 6/6

Nylon 6 (single monomer) and 6/6 (twin monomers) both are synthetic polyamides under the thermoplastic category. Polyamide is characterized by its rigidity, durability, wear resistance and high melting temperature (214°C).

However, it has limitations of water absorption and poor resistance to strong acids. It is a versatile plastic and have replaced metals in various applications.

Nylon parts are made by extrusion as well as injection moulding processes. Glass reinforced Nylon 6/6 with improved impact strength is used in parts meant for reduction of NVH (Noise, Vibration and Harshness) in automobiles, apart from usage in small gear parts.

This grade of plastic is also used in carpets, fibres for textiles as also in waterproof coatings.

6.1.6. Polystyrene (PS)

PS is a synthetic thermoplastic which is naturally transparent but can be artificially coloured. It is available as a solid hard material as well as a rigid foam. It has good electrical and chemical resistance but poor UV resistance.

PS parts can be made by injection moulding or vacuum forming. PS is used in automobiles in instrument panels, door panels, knobs etc. Other usage of PS is in packaging, optical discs (CDs, DVDs) etc. PS foams are used as insulators.

6.1.7. Polyethylene (PE)

PE is the most used thermoplastic polymer. The most common forms are LDPE (Low Density Polyethylene) and HDPE (high Density Polyethylene). LDPE is a semi rigid translucent polymer. It has excellent electrical insulation properties with low water absorption. However, it is highly flammable and has poor UV resistance. It is generally used in water bottles, dispensing bags etc.

HDPE apart from excellent insulation and low water absorption characteristics has higher tensile strength and reasonably high impact resilience making it suitable for water tanks, drums, jerry cans etc.

PE parts can be processed by various processing techniques such as injection moulding and others. Glass reinforced Polyethylene are used in car bodies and for insulating purposes.

6.1.8. Polyoxymethylene (POM)

POM also known as Acetal (or Delrin as another variation), is a thermoplastic with excellent rigidity, yield strength and high dimensional stability and low friction characteristics along with superb chemical and fuel resistance. In automobiles POM is used in bumpers, cable insulation, carpet fibres, interior and exterior trims, small gears and fuel system parts.

6.1.9. Polycarbonate (PC)

PC is a type of thermoplastic polymer with high hardness, rigidity and durability. PC has high weather, heat resistance and flame-retardant properties. It has high impact resistance but low scratch resistance. Hence a hard coating is applied for parts which requires scratch resistance for example automotive head lamps, sunroofs etc. PC can be laminated to make bullet proof glass.

This plastic is widely used in lenses, LCD, TV screens, roofing sheets etc. Parts from PC can be formed by injection moulding and other techniques.

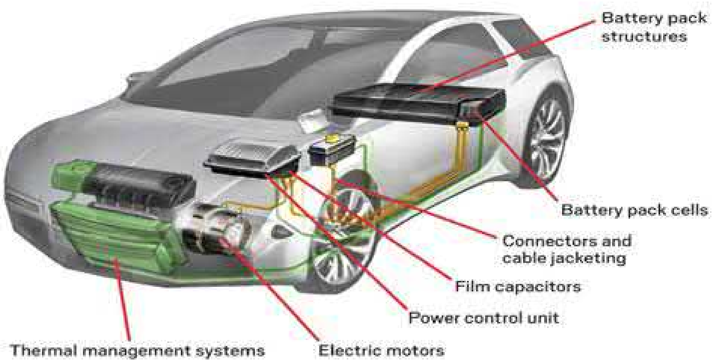

Figure 7: Schematic of plastic usage development trends in Electric Vehicles[9]

6.2. Plastics in general engineering applications

Large variety of plastics are used in general engineering for cosumer durables, agitators, anti corrosive liners, bushes, buffer pads, chain guides, exhaust ducts, gaskets, seals, pump components, tanks, bearings, conveyor mechanisms, valve bodies and many others.

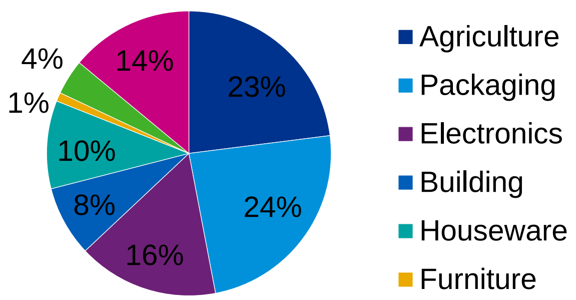

Figure 8: Sector wise Plastic Usage[10]

[9] Plastics makers plot the future of the car (acs.org)
[10] Plenary 2 - Plastics - Mohanty (unido.org)

7. Composites

This class of materials appears to be the fastest growing in terms of research, development and application. Composites are combination of two or more constituent materials with different physical or chemical properties. When combined, they produce a material with characteristics different from their original properties. When combined, the resulting material is stronger than those individual materials by themselves.

The two main components within a composite are the matrix and fibre. The matrix is the base material while the fibre provides reinforcement. Figure 9 depicts a schematic of composite construction. Based on the matrix material the composites are named as Polymeric composites (e.g FRP), Metal matrix composites (MMC), Ceramic composite, Carbon-Carbon fibre composite etc. Figure 10 highlights general types of fibre shapes used in composites. Major fibre – matrix combinations are shown in Table 2.

Figure 9: Schematic composition of composite[11]

Figure 10: Fibre Shapes[12]

S No	Matrix type	Fibre	Matrices
1	Polymer	E-glass, S-glass, Aramid (Kevlar), Boron, Carbon (Graphite)	Epoxy, Polyamide, Polyester, Thermoplastics, Polysulphone
2	Metal	Alumina, Borosil, Boron, Carbon (Graphite), Silicon Carbide	Aluminium, Copper, Magnesium, Titanium
3	Ceramic	Alumina, Silicon Carbide, Silicon Nitride	Alumina, Glass Ceramic, Silicon Carbide, Silicon Nitride
4	Carbon	Carbon	Carbon

Table 2: Major Composite Combinations

[11] What are Composites? - Romeo RIM
[12] Various types of reinforcement in composites: a) particles, b) short... | Download Scientific Diagram (researchgate.net)

7.1. Why Composites

- Reduction in weight
- Freedom from corrosion
- High specific strength and specific stiffness ratio as compared to most metallic materials
- Excellent energy absorbing capability by mass, hence safer in impact situation
- Low thermal conductivity
- No machining or fabrication requirement
- Flexibility in design with part consolidation

Usage of non-metallic materials like plastics and composites are gradually replacing metallic materials in automobiles and other engineering industries. Below figure shows a car model with parts which have adopted large variety of plastics and polymeric composites in the parts shown in Figure 12.

Figure 11: Car parts with plastic and composites[13]

Among the various composites developed, CFRP (carbon fibres reinforced plastic) have gained prominence in various structural applications including automobiles and aircraft. CFRP materials weigh only one fifth of steel under equal strength conditions compared to steel. Density of CFRP is lower than GFRP (glass fibres reinforced plastic). Carbon fibres reinforced plastic (CFRP) is extensively used in high-end racings cars. Carbon fibres is lighter and stronger compared to the aluminum structures, and therefore faster and safer.

Current development trends in aircraft manufacturing are use of CFRP in structural parts of Airbus 380 and Boeing 787 Dreamliner. Use of approx. 35 metric tons of CFRP in each of these models accounting to approximately 50% of the structural parts have helped to reduce aircraft weight by 15 to 20%. Comparative strength properties of composites and other competing materials have been shown in Figure 12.

[13] www.rbex.ro/en/Business-opportunities/Large-Asian-manufacturer-of-plastic-injected-components-for-the-automotive-industry-is-looking-to-buy-or-partner-with-a-Romanian-based-producer

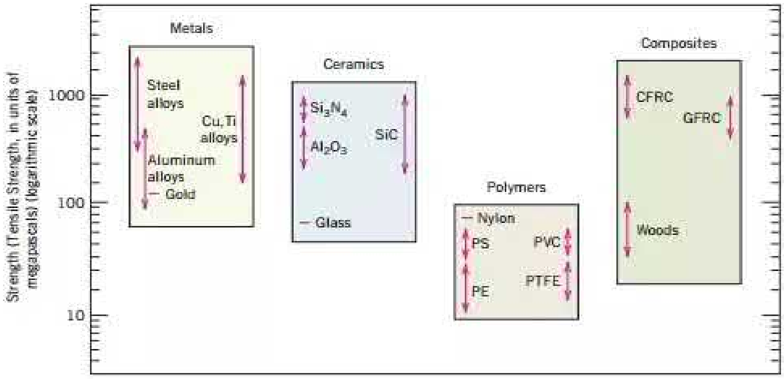

Figure 12: Comparative strength properties[14]

However, CFRP have some disadvantages as well.

- Very high cost can be around 5 to 15 times the cost of fiberglass. The cost widely varies between automotive, aerospace and commercial grade carbon fibres.
- Carbon fibres have high conductivity. While this is useful in some applications, it is a deterrent for safety where insulation is required for example ladders used near electric transmission lines

7.2. A Glimpse of composite manufacturing process

Manufacturing of FRP composite comprises manufacturing of fibres preforms followed by reinforcing these fibres with the matrix material by various techniques. Fibre preforms are made by processes such as weaving, braiding, knitting or stitching fibres in long sheets or mat structure shown in figure 14. Automation is adopted for production of preforms

Figure 13: Fibre Preforms[15]

- **Hand Layup:** In this process the fibre preform is placed in an open Mould after applying an anti-adhesive coating for easy extraction. The resin material is then poured or applied by brush on the reinforcement fibre preform. Roller is used to force the resin into the fibre layers. Further improvement of this process is to spray the resin onto the fibre reinforcement mat followed by use of rollers. This is known as spray up technique.

- **Vacuum bag moulding** - is an improvement over hand layup process. It uses a flexible plastic film or membrane (made from of materials such as nylon, silicon, polyethylene or

[14] How do properties like elasticity, ductility, and tensile strength of materials like metals, ceramics, polymers and composites compare with each other? - Quora
[15] Carbon fibre reinforced plastics (slideshare.net)

polyvinyl alcohol) commonly known as vacuum bag which is spread over the laid-up laminate (made by hand layup technique), to seal the part from the outside air. Vacuum pump is used to remove air from under the bag, while atmospheric pressure compresses the part. This technique eliminates chances of voids, porosity and possibility of improper impregnation (generally encountered in Hand layup). This helps to improve flexural and interlaminar shear properties by approximately 15% and 18%, respectively.

- **Resin Transfer Moulding (RTM) –** It is a low temperature, low pressure moulding technique in which a thermosetting pre heated resin is injected into a closed two-part mould set. The preform fibre reinforcement mat is placed on the bottom half of the mould. The schematic of the Resin Transfer Moulding (RTM) process can be seen in Figure 14.

Various combinations of fibre material including 3-D reinforcements can be used in RTM. It produces parts with high quality surface finish, dimensional accuracy, internal defect free high strength composite structural parts.

Some limitations of the process are cost of metal tools, part size limitation and consolidation of vertical sections.

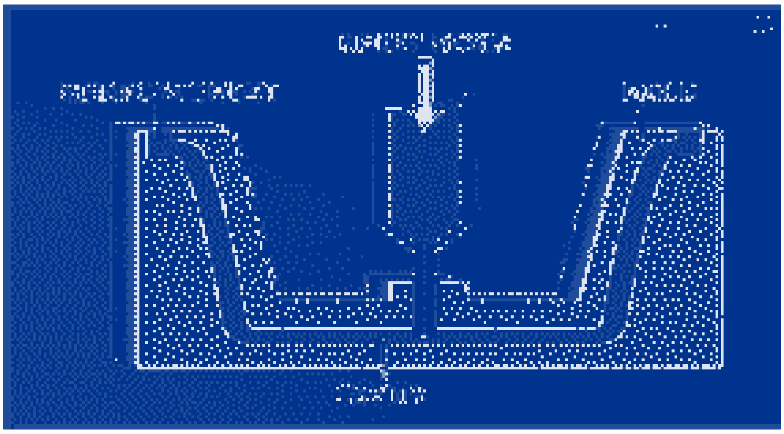

Figure 14: Resin Transfer Moulding[16]

- **Vacuum Assisted Resin Transfer Moulding -** Vacuum infusion or Vacuum Assisted Resin Transfer Moulding (VARTM) is an improvement over RTM process. Preform fibres are placed on the lower part of the mould. A vacuum bag or membrane is placed over it with a perforated tube positioned between the vacuum bag and resin container. The resin is sucked by vacuum through the perforated tubes over the fibres to consolidate the laminate structure, as shown in figure 15. Thus, no excess air remains in the composite structure making it possible to manufacture large and complex objects like boat hulls, wind turbine blades and in marine and aerospace applications. Fibres are surface treated to improve the strength of composites. Alkali treated flax fibre-reinforced epoxy acrylate resin composite fabricated using VARTM technique resulted in improvement of tensile strength by approximately 19%.

[16] Resin Transfer Molding (RTM) | MasterBond.com

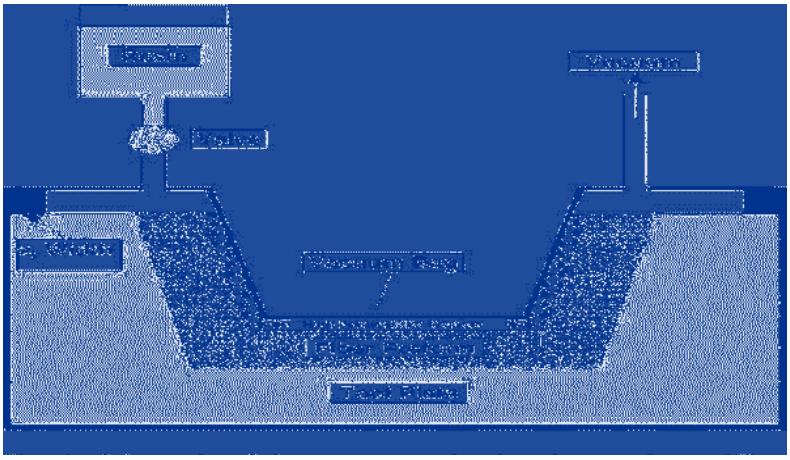

Figure 15: Vacuum Assisted Resin Transfer Moulding[17]

- **Sheet Moulding Compound-Compression Moulding-** Sheet moulding compound or Sheet Moulding Composite is a fibre reinforced composite with thermosetting resin, which can be readily moulded. Long strands of chopped fibres (glass or carbon) are dispersed in a resin – usually epoxy, vinyl ester, or polyester. The long fibres adds to the strength of the composite.

The chopped fibres are put in between two layers of resin paste to form a sandwich which is rolled and then allowed to cure. SMC rolls thus produced must be stored for several days to "cure" until it can be sold and used. The final "cure" takes place by heat and pressure in the compression moulding process. Figure 16 gives a schematic presentation of SMC process.

Part forming is done by compression moulding in a hydraulic press. The press consists of the upper and lower halves of the mould placed between two heated plates. Pre-heated SMC is placed into the lower half of the mould. The upper plate is then lowered, applying up to approx. 2000 psi of pressure to the Mould to form the part as per the mould cavity design.

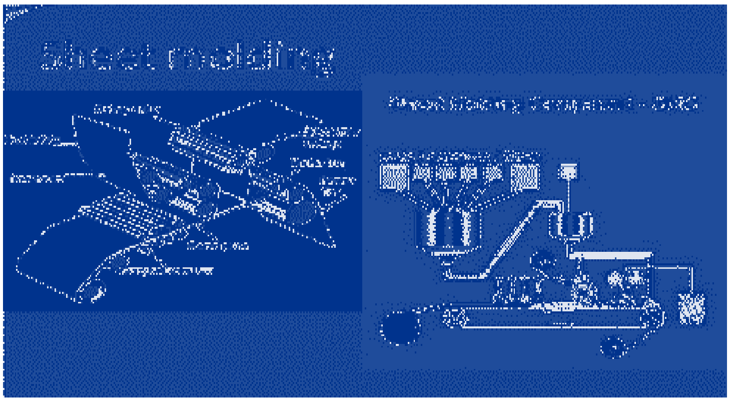

Figure 16: SMC Process[18]

Compression moulding can be used to create complex, detailed parts with great accuracy

[17] [PDF] Non-isothermal preform infiltration during the vacuum-assisted resin transfer molding (VARTM) process | Semantic Scholar
[18] Composite manufacturing processes (slideshare.net)

because consistent application of heat and pressure causes the SMC to spread and properly fill every part of the mould.

SMCs has advantage of bulk production of lightweight, defect free parts of uniform dimensional profile and aesthetics. This has helped SMCs to replace metal components as the primary material for several automotive parts. It is also used in manufacturing of baths, arena, cinema and stadium seats. Figure 17 gives a schematic of compression moulding sequence.

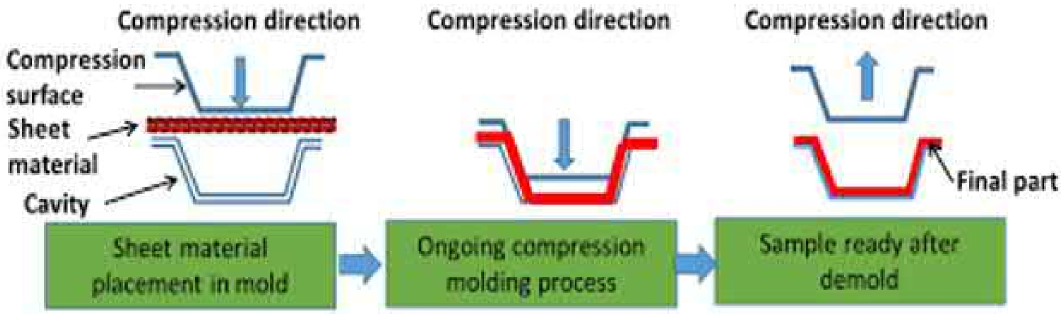

Figure 17: SMC Compression Moulding[19]

8. Elastomers

An elastomer is a polymer characterized by viscoelasticity (i.e., both viscosity and elasticity) and has weak intermolecular forces, low Young's modulus and high failure strain when compared to other engineering materials.

An elastomeric material exhibits rubber-like properties and are characterized by material type, compound, and hardness (Shore A). Among elastomers, Rubber is an all-purpose material, natural from rubber trees and synthetic varieties, which are used for a wide range of domestic and industrial applications.

Apart from elasticity, chemical characteristics of synthetic rubbers render this material for a wide variety of engineering applications. Some of the important chemical characteristics are resistance to H_2S, CO_2, aromatics, H_2O etc.

Temperature resistance of an elastomer is another important consideration for deciding on usage.

The ten most commonly used rubber grades under discussion here are –

- **Natural rubber (Isoprene)**

Natural Rubber, also known as latex, is derived from the latex sap (white milky fluid) found beneath the bark of a rubber tree (Hevea brasilienesis). The latex consists of a colloidal suspension of small polymeric particles in water. 90% of world production of natural rubber comes from Asian countries e.g., Malaysia, Indonesia, Thailand, India and Sri Lanka.

Natural rubber has high tensile strength, abrasion resistance, tear resistance and resilience. On the other hand, natural rubber is moderately resistant to heat and light. It is also prone to ozone attack.

Some of the major usage are in gaskets, seals, shock mounts, hoses and tubing. Traditionally this elastomer is used in automotive tires along with SBR.

[19] sheet molding compound production process - Google Search

- **Styrene-Butadiene**

SBR is one of the most popular synthetic rubbers made of 75% Styrene and 25% Butadiene. It is a low-cost elastomer and is often used as replacement of natural rubber or in combination.

This rubber exhibits high tensile strength, good abrasion resistance and outstanding impact strength with good impact resistance. It has good flexibility at low temperature, although less than that of natural rubber.

SBR has poor resistance to ozone, steam and oils. Some of the shortcomings of SBR are compensated by additives such as carbon black, china clay, silica etc.

It is widely used in automotive tyres in combination with natural rubber. Other applications of SBR are in belting, hoses, gaskets etc.

- **Butyl (IIR)**

IIR is a synthetic rubber made by copolymerization of Isobutylene and Isoprene (~2%) rubber. It has excellent shock absorption characteristics apart from very good abrasion, flex cracking, water, steam, sunlight and ozone resistance. It offers exceptionally low gas and moisture permeability. It also has very good electrical insulation properties.

Because of its low gas and vapor permeability, this elastomer is preferred for tubeless tyres. Other automotive applications are in suspensions, shock mounts etc. General applications include O-rings, tank liners and sealants.

- **Nitrile (NBR)**

Also known as Buna-N this synthetic rubber is a copolymer of Acrylonitrile and Butadiene. NBR has excellent resistance to petroleum-based oils and greases. It also has good tensile strength, abrasion, tear resistance and low compression set. However, NBR has poor weather, ozone and flame resistance.

NBR is widely used in seal industry. Nitrile can work in a temperature range of between (-) 40 and +140 degrees Celsius.

However, it is not advisable to use NBR in contact with automotive brake fluid, ketones, phosphate ester hydraulic fluids or halogenated hydrocarbons.

- **Neoprene®(CR)**

Also known as polychloroprene, this synthetic rubber is made by polymerization of Chloroprene.

This rubber is characterized by high tensile strength and resilience. It has good to moderate resistance to petroleum-based oils and weather e.g. UV, ozone and oxygen and relatively low compression set. It also has good resistance to flex cracking and good insulation properties.

Automotive usage of Neoprene includes window and door seals, vibration mounts, shock absorber seals, seat belts etc. Other industrial usage is in corrosion resistant coatings, adhesives, sealing gaskets in electrical appliances among others.

- **Ethylene Propylene Diene Monomer (EPDM)**

EPDM (ethylene propylene diene monomer) is a synthetic rubber with a single bond molecular structure, which makes it extremely suitable for outdoor applications. It has excellent resistance to UV rays, ozone and ageing. EPDM is also steam resistant. Its operating temperature range is (-) 45 to (+) 175 deg C.

The other favorable properties are good flexibility, low electrical conductivity and low compression set. It is a cost-effective alternative to silicone. If correctly installed and maintained, EPDM can last long before embrittling.

EPDM rubber is widely used in HVAC and automotive applications such as wipers, O-rings and electrical insulation products.

- **Silicone(Q)**

Silicone rubber is a high-performance elastomer. The composition comprises of Silicone (polymer) along with other molecules of oxygen, hydrogen and carbon. It has good abrasion and heat resistance, chemical stability and ozone resistance.

It is well suited for use in environments of water, steam and petroleum fluids. The operating temperature range (-) 84 to (+) 232 deg C, however it can withstand short exposure below 100 deg C also. Fillers, additives and flame retardants are added to silicone rubber to enhance its properties.

In automotive silicone rubber is used in weather resistant and vibration parts as well as in coatings and varnishes. In general, this elastomer finds wide usage in food, beverage and medical industries. The binding property of silicone makes it suitable for joining metallic and nonmetallic parts and as sealants.

- **Viton® (FKM)**

Viton is brand name of Du Pont. It is a fluoro elastomer polymer (FKM). It has excellent resistance to a wide range of fluids. It has exceptional temperature stability from (-) 20 to (+) 205 degrees Celsius and has outstanding resistance to compression set. This elastomer is widely used for o rings, seals and gaskets where oil and chemical resistance are required. However, depending on application it is necessary to select the right grade of Viton.

In automotive the uses are in air management system, fuel lines and in axles. Viton® have some disadvantages like swelling in fluorinated solvents. The high cost factor of Viton is also an important consideration for selection.

- **Polyurethane (PU)**

PU rubber is a two-component system comprising of a base and a curative. Polyurethane exhibits abrasion and extrusion resistance apart from toughness.

It is available in wide range of hardness (20 Shore A to 85 Shore D), has good impact, abrasion and tear resistance. It has good electrical insulation properties and are suitable for application in harsh environments.

PU rubber is used in automotive interior parts, carpet underlay.

Other usage of PU is in bedding cushions, furniture and packaging. O-rings made from PU are used for hydraulic fittings, cylinders, valves and pneumatic tools as well.

- **Hydrogenated Nitrile (HNBR)**

Hydrogenated Acrylonitrile Butadiene rubber is produced by hydrogenation of Nitrile rubber. HNBR has superior fuel, oil and chemical resistance as compared to nitrile rubbers and can withstand much higher temperatures. It has very good resistance to hot water, steam and ozone. It has excellent tensile and tear strength, elongation and abrasion resistance, apart from good dynamic stability at elevated temperature. Typical working range of HNBR is (-) 25 to (+) 160 deg C.

Some disadvantages are poor flame resistance, limited resistance to aromatic oils, polar organic solvents and poor electrical properties. Also, HNBR is relatively expensive among the elastomers.

HNBR is widely used in the oil and gas industry for gaskets, seals and diaphragms. In automobiles it is used in timing and power transmission belts, high performance seals and hoses for hydraulic systems.

9. Glass-Usage in General

Different types of glass are used in engineering design as well as for domestic applications. Glass fibres are used in insulation, sound deadening, as fillers in plastics, and as reinforcement in plastic laminates. Glass can also be used to transmit or shield radiation.

The following is a non-exhaustive list of usage of glass -

- Automotive – windscreen (laminated glass), windows (safety glass – tempered)
- Packaging jars (for food, drinks)
- Tableware
- Building materials (windows, facades, insulation, reinforcement)
- Interior design and architecture (mirror, shelves, lighting)
- Appliances and electronics
- Life science – medical equipment

10. Ceramics

Industrial applications of ceramics include refractories, abrasives, bearings, heat and wear resistant components. Ceramics are also used in gas turbine engines. In automobiles ceramics fund usage in fuel injection pumps, spark plugs, high pressure pumps (for gasoline engines), piezoelectric based common rail fuel injection technology, brake discs, particulate filters and in ceramic composites. Porous ceramic preforms made by powder technology process are used in composites with aluminium alloy.

11. Emerging Lightweight Materials - Shaping the Future

Future materials are not just a buzz word, innovations are taking place at a great pace, which are likely to change our concepts of design and development. It is worth mentioning a few of these as below

11.1. Graphene

This material is made up of mono (single) layer of carbon atoms bonded together in a hexagonal honeycomb lattice. Layers of graphene stacked together form graphite. The honeycomb structure of the atoms allows graphene to be very flexible as well as porous and lightweight. Single atomic layer makes graphene the lightest material. It has tensile strength of 130 GPa, which is 100 to 300 times stronger than steel made in different forms. Graphene exhibits outstanding conductivity of heat and electricity. Other notable features are capacity to absorb impact energy (almost twice that of Kevlar, as used in bullet proof vests.

Another important feature is uniform absorption of light from visible to near infra-red part of the spectrum. The possible future usage of graphene can be in the fields of advanced electronics, super capacitors for energy storage, solar cells for power generation, solid state CMOS detectors, advanced surface protection technology, water purification systems and many others.

While this wonder material has great possibilities, it is still in the process of development to achieve the most optimum single layer material matrix with consistent manufacturability and material properties in a cost-effective manner.

11.2. Carbon Nano Tubes

Commonly known as bucky tubes, are in nanoscale (one nano meter is one billionth of a meter). Single walled CNTs (SWCNT) are cylindrical large molecules which consist of rolled up sheets of graphene (single layer carbon atoms). Multi walled CNTs (MWCNT) is made by rolling up multiple sheets of graphene.

Remarkable electrical and thermal conductivity and exceptional strength is some of the unique features of this material. Ultimate Tensile Strength of CNT is almost 300 times that of steel, while its density is approximately one sixth of steel, while being extremely thin. They are highly stable chemically and therefore have excellent corrosion resistance. The hollows in CNTs can be filled with various nano particles, which can give a big boost to nanomedicine in drug delivery systems. CNTs can be a revolutionary material in the fields of electronics, energy generation, transportation, biomedicine, optics, environmental science and many others. With the advancement in nano technology this field of development is expected to break many barriers.

11.3. Aerogel

It is a synthetic material made from gel. It is porous and has extremely low density and low thermal conductivity.
The liquid potion of gels of alumina, chromia, tin oxide or carbon are extracted by 'super critical drying' or 'freeze drying' to produce aerogel. 99.8% empty space makes aerogel semi-transparent. Graphene aerogel has a density lower than helium and is only twice that of hydrogen at 0.16 mg/cm3.

Aerogel is an excellent insulator because of the porous structure of the nanomaterial which makes it difficult for heat to pass through. This makes aerogel a preferred material for light-weight insulators. Of late a few Aerogel companies are offering thin blankets that serve as replacements for traditional fibre glass, foam or cellulose insulation. The other fields of usage development are in optics, electromagnetic shielding, fuel cells, components in energy absorbers and many others.

11.4. Micro lattice

Micro lattice resembles human bone structure, with a solid outer wall and hollow inside. Thus, it becomes a very strong material with high load bearing capacity and remarkably light at the same time. A metallic micro lattice is a synthetic material made up of ultra-light metal foam. With a density as low as 0.99 mg/cm3 it is one of the lightest structural materials known till date. Scientists call it a material with 99.99% air.

Metallic micro lattice can be a game changer for structural including those of aircraft, by bringing down the weight drastically. Boeing is actively developing this material for aircraft structural parts. This will also be a very suitable material for thermal and vibration insulators such as shock absorbers. Potential usage can also extend to battery electrodes and catalyst supports. However, being a new technology, it is very expensive in the current scenario.

12. Emerging manufacturing processes which can revolutionize the future

12.1. 3D Printing

'3D Printing' or 'Additive Manufacturing' as it is popularly known, is a process by which a three-dimensional object is build layer by layer from a digital three-dimensional drawing e.g., CAD drawing. This contrasts with the traditional 'Subtractive manufacturing' (material removal by machining) or 'Formative Manufacturing' (e.g. Casting or Forging). 3D Printing process, started decades back initially was with the objective of rapid prototyping and tooling development.

The process was developed mainly for thermo plastic materials. However, with rapid technological development this process is now seen as a viable alternative for industrial production of parts and objects with composites, ceramics and a wide variety of metals as well.

Various types of 3D processes have been developed, in which materials are melted, deposited or joined under computerized control to form a three-dimensional object.

ISO/ASTM 52900 (Additive manufacturing - General Principles - Terminology) describes seven broad categories of processes as below –

- **Binder Jetting (BJT)** - In this a liquid bonding agent is selectively deposited to join powder materials.
- **Directed Energy Deposition (DED)** – A focused thermal energy (e.g. laser, electron beam or plasma arc) is used to fuse the materials by melting as they are deposited.
- **Material Extrusion (MEX)** - A process in which material is selectively dispensed through a nozzle or orifice.
- **Material jetting (MJ)** - In this droplet of feedstock material are selectively deposited.
- **Powder Bed Fusion (PBF)** - A process in which thermal energy selectively fuses regions of powder bed.
- **Sheet Lamination (SHL)** – In these sheets of material are bonded to form a part.
- **VAT Photopolymerization (VPP)** – A process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.

The categorization as above have been done based on the way the material is deposited to build the part layer by layer and the type of material used.

12.1.1. Plastic 3D Printing

The most commonly used process for thermoplastics is **'Fused Deposition Modeling'** (FDM), also known as **'Fused Filament Fabrication' (FFF)**. In this process a filament of thermoplastic material is fed into the heated moving extrusion nozzle head of the 3D printer, which heats and fuses the material to be deposited in a controlled manner to build the object.

In another variation of the process, fusion is done on selective parts of the layer which moves upwards and adds another layer. This process uses the unfused media to support overhangs and thin walls in the part being produced.
Another development is to 3D print directly from pellets to avoid the conversion to filament. This process is known as **'Fused Granular Fabrication' (FGF)** or **'Fused Particle Fabrication' (FPF)**, which has the potential to use recycled material.

12.1.2. Metal 3D Printing

In case of metals, powder forms are generally used for processing and building the parts by various techniques. The most popular processes are –

- **DMLS (Direct Metal Laser Sintering)/SLM (Selective Laser Melting)** – Both are powder bed fusion processes, suitable for high end applications e.g. parts with high geometric complexity required with excellent material properties.
  In SLM complete melting is done for certain pure metals. IN DMLS, metal particles fuse together on a molecular level, the process being suitable for most metal alloys.
  Post processing steps from DMLS/SLM after printing are stress relieving, any additional heat treatment (as required) and polishing for surface finish.
  Generally, the dimensional accuracy achieved is +/- 0.1% and internal porosity encountered is < 0.5%.
- **Binder Jetting –** best suited for low to medium batch production in an economic manner, where high investments for subtractive manufacturing (e.g. CNC machining) are not justified and part complexities cannot be effectively achieved by formative manufacturing (e.g. casting or forging) processes.
  In this process, binding agent is spread by an ink jet on a thin layer of powder bed. The process takes place at room temperature and hence it is free from thermal stresses as encountered in DMLS/SLM. After printing the resulting 'green part' is processed to remove the binding agent and then sintered to bind the metal particles. Generally, the dimensional accuracy achieved is +/- 0.2% and internal porosity encountered is 0.2 – 2.0%.
- **Metal Extrusion –** It is a comparatively low-cost process adopted for metal prototypes and one-off parts with complex geometries that would otherwise require very expensive CNC process. In this process metal particles bound together by polymer or wax is extruded through a heated nozzle to be deposited layer by layer.
  In principle the process is like FDM process for thermoplastics. After printing the 'green part' is washed in a solution to remove the binder and then sintered in a furnace to bond the metal particles. Generally, the dimensional accuracy achieved is +/- 0.5 mm and the internal porosity encountered is 2.0 - 4.0%

12.1.3. Advantages of 3D Printing

- Lower turnaround time for part development through rapid prototyping.
- Possible to manufacture parts with intricate geometries including hollows, which cannot be achieved effectively with other subtractive or formative manufacturing processes.
- Possible to achieve near net shape (NNS) without any further machining, except for finish machining for some unique parts.
- Minimum material loss as compared to subtractive and formative manufacturing processes.
- Merging assemblies into a single part rendering enhanced part functionality.
- Environmentally friendly processes, with very low greenhouse emissions.

12.1.4. Limitations of 3D Printing

- Not suitable for large volume manufacturing as compared to traditional machining, casting or forging processes used for bulk manufacturing.
- High cost of equipment for precision techniques, making the process cost intensive, especially for lower volumes.
- Post finishing operations like sintering, heat treatment etc. are required mainly for Metal 3D Printing processes. Surface smoothing are required in all processes
- Additional design intervention is required for layered part building.
- Lower internal soundness than wrought products, leading to lower fracture toughness and fatigue life, for example in case of steel a forged component will have higher internal soundness than parts produced by Metal 3D Printed parts. Likewise, for composites, conventional SMC with hot compression moulding is superior as compared to additive FDM process.
- Not suitable for dynamically loaded parts for critical applications such as transmission gears. Steel forgings with inherent grain flow will have better integrity with regard to fracture toughness and fatigue strength required for such parts.

12.1.5. Materials for 3D Printing

- **Plastics -** Thermoplastic grades such as PA 11/12 (Polyamide/Nylon), PET (Polyethylene Terephthalate), ABS (Acrylonitrile Butadiene Styrene), PLA (Polylactic Acid), PETG (Polyethylene Terephthalate Glycol), TPU (Thermoplastic Polyurethane) etc.
- **Composites-** GFRP and CFRP are used for 3D printing. With fast growing technology, 3D filaments of thermoplastic infused with ‘Graphene’ and ‘Carbon Nanotubes’ (CNT) are being used to build conductive, high strength and light composite parts.
- **Metals -** Stainless steels, Tool steels, Aluminium and Copper based alloys, Titanium based alloys, Nickel based superalloys, Cobalt based alloys, Precious metals (platinum, gold, silver), other metals like Palladium, Tantalum.

12.1.6. Applications of 3D Printing

Some examples are as below -

- **Automotive -** Concept design, rapid prototyping of car models and parts, design validation, prototypes for tooling as well as jigs and fixture modelling and manufacturing.
- **Aerospace & Defence** - Additive manufacturing is ideal in areas of complex, low volume part manufacturing in these areas. This technology is extensively used for lightweight plastic or composite parts for aircraft interiors, where it is preferred, compared to costly injection moulding for low volumes.
  In the field of defence, 3D Printing has helped to speed up designing and prototyping of electronic systems such as PCBs and antennas. Development in the areas of parts for jet engines, surveillance drones, submarine hulls are ongoing.
- **Biomedicine -** Drug delivery systems, prosthetics, anatomical models for surgery, bio implants. Nitinol (Nickel, Titanium alloys) are used in dentistry and for stents. Researches on bio printing of tissues and organs are also being actively pursued.
- **General industrial usage -** 3D patterns for Investment and other metal casting processes.
- **Domestic and other usage -** Jewellery, artifacts, toys, high end sports equipment

12.1.7. Future of 3D Printing

Emerging developments –

- **Robotics in 3D Printing -** Combinations of robotics with 3D printing can help to make large parts with accuracy and repeatability. 3D Printer can not only be attached to a robotic arm for printing large objects on a separate build platform, this digital technology can also be used to build robotic parts.
- **4D Printing -** This a new dimension where 3D printed part can change its shape through external stimuli such as heat, light, humidity, magnetic field, electricity etc. This technique combines shape programming along with use of shape memory materials and alloys such as 'Shape Memory Polymers' (SMPs e.g. PU, blends of PU & PVC, Acrylates), Shape memory composite (e.g. PU with Graphene), 'Liquid Crystal Elastomers' (LCEs composed of liquid crystals and elastomers) and Shape Memory alloys' (SMAs e.g. Ni-Ti, Cu-Zn-Al, Cu-AL-Ni).
- **The Indian scenario** -In India 3D Printing as a technology is still in an early stage, mainly because of the prohibitive landed cost of imported printers and because of lack of adequate awareness in the industrial sector about the emerging prospects. However, in the current decade this technology is likely to see a surge due to upcoming indigenous start-ups and increased availability of indigenous Printers at competitive prices.

13. Usage and Development trends during the current decade

In the field of materials sweeping changes as mentioned in the foregoing sections will continue to happen at a faster pace. Industry wise expected development trends are summarized as below –

Automobiles - With focus on non-fossil fuel powered vehicles, the quantum of steel usage will see a drastic change, being limited to major structural and dynamically loaded parts.

In currently manufactured conventional cars, with the increased thrust on light weighting and safety, the expected pattern of changes in the current decade are summarized in Table 3.

Sr.No.	Material type	Estimated % of curb weight	
		2020	2030
1.	Conventional Steels – IF/LC /MC/HC/LC and MC Alloyed/HSLA	50	26
2.	AHSS	16	25
3.	Non-ferrous alloys (mainly Al) + Mg, Cu, Pb	10	20
4.	Polymer/Composites	14	19
5.	Glass, Rubber and Others	10	10

Table 3: Expected shift in material usage in passenger cars

However commercial vehicles will continue to be steel intensive, with comparatively lesser reduction in usage than in passenger cars.[20]

- **Aerospace -** Advanced metal alloys (Aluminum, Steel), super alloys of Titanium, carbon fibres reinforced composites, ceramic composites and super adhesives to name a few will be the materials of choice.
- **Defense –** Developments trends in nano wires for multi spectral imaging, graphene/CNT reinforced polymeric composites (for lighter and stronger body armor), shape memory alloys (Ni-Ti and others), radar absorbent paints and rubber composites (for stealth of

[20] Steel in autos to drop sharply through 2040: CAR (argusmedia.com)

aircrafts and drones), sound absorbing composites for submarine hulls (to avoid sonar detection) to name a few, will continue.

- **Bio Science -** Bio compatible polymers, ceramics, Titanium alloys, nano structured 3D polymers, shape memory alloys and many others emerging materials will revolutionize the scenario for dentistry, implants, tissue regeneration, surgical fields etc. Majority of these developments will be driven by advances in nano technology and advent of smart materials.

14. Opportunities for the MSME Sector

MSME sector in India which is a major contributor towards the country's GDP is engaged in a wide range of manufacturing activities with multiple technologies, mostly of conventional nature. With the focus on development in materials science and engineering, Micro, Small and Medium enterprises have great opportunities to embrace this technology revolution to contribute towards a faster pace of growth. A few suggested areas are mentioned below.

14.1. Demand for Metallic Materials

While demand for metallic materials continues to grow, the industries processing ferrous and nonferrous metals will have to build capabilities to deal with the new generation materials and processes

14.1.1. Global High Strength Steel Market

The global high strength steel (e.g. high strength low alloy, Dual phase, bake hardenable etc.) market is estimated to be USD 29.6 billion in 2019 and is projected to reach USD 44.2 billion by 2024, at a CAGR of 8.4% during the forecast period from 2019 to 2024. Increasing consumption of high strength steels in the automotive and construction industries to improve the fuel efficiency of automobiles and ensure high strength and improved safety features of buildings are driving the growth of the high strength steel market across the globe.

14.1.2. Performance of the non-ferrous metals

The performance of the non-ferrous metals industry (primarily Aluminium alloys) in India has outperformed the global trend in the last few years. The key end use sectors of these metals such as automobiles, Power generation and defence manufacturing have grown consistently in the recent years. India has huge raw material availability (approximately 10% of the world's Bauxite reserves).

Growing demand with a relatively low cost, high volume downstream part manufacturing processes act as the major driver to the development of the non-ferrous metals industry. This has resulted in adequate supply to meet the domestic demand and is also creating good opportunities for export.

MSME sector also has the opportunity of developing and augmenting appropriate downstream processing facilities for the manufacture of Aluminium foils and Copper wire, a good percentage of which are still imported.

14.2. Plastics, composites and Hybrids

Another major opportunity for the MSME sector lies in the emerging field of Plastics, Composites and Hybrids.

Along with the global trend the Composites industry in India is poised for a strong growth, in areas such as Wind energy, Automobiles, Chemical industry, Aircraft, Railways and others.

The industry has hitherto suffered due to the following factors –

- Inadequate availability of quality raw materials
- Price sensitive market, with rising raw materials costs
- Inadequate availability of skilled labour in rural areas
- Lack of awareness of composites and other advanced materials in the Indian industrial scenario.

Majority of the composite processing facilities in India are in the small-scale sector, mainly using low cost, low technology ‘Hand Lay Up’ process. RTM (Resin Transfer Moulding) and VARTM (Vacuum assisted Resin Transfer Moulding) along with SMC (Sheet Moulding Compound) are available mostly in the Medium scale sectors.

Among the big manufacturing houses, Tata Advanced Materials Limited (TAML), a TATA group company, is the largest manufacturer of Composite Products in the Private Sector. They are engaged in Design, Manufacture & Supply of composite products for Aerospace, Armor, Transportation and infrastructure Sectors.

With increasing demand and favourable industrial environment, there is ample scope for the MSME to invest suitably in this sector for improved technology and augmenting capacity of part manufacturing, specially by the SMC process (up to mid-size components), for consistent quality and productivity.

While CFRP (Carbon Fibre Reinforced Plastic) is one of the most sought-after composites, the usage is restricted by prohibitive cost. Here the industry along with the process technologists should work together to develop cost effective processes for this important material of the future.

Other areas where major opportunities are likely to open are in the fields of bio science, electronics, aerospace, defence, new generation of building materials, component manufacturing in industrial robotics and renewable energy e.g. solar panel cells, by adopting alternate materials and processes. This would call for a well-planned and integrated strategy for market survey, planning and investment along with technology acquisition.

Cost economy will however be a major challenge. For introduction of any new technology there will be incubation periods with low volume production. Hence an integrated strategy to trigger demand creation for the alternate materials and processes are very important. Low Cost Automation with a well-defined quality system to achieve ‘conformance and consistency’ will be some of the major initiatives.

15. Role of MSME Technology Centres

MSME Technology Centres (TCs) can play a major role as facilitators in the emerging scenario. The new technical Centres with large and modern infrastructure have elaborate training facilities equipped with machining Centres, electrical, electronic and other training modules. Plans are afoot for setting up material testing and gauge calibration laboratories in some Centres.

With such infrastructure, the Technology Centres can build necessary capability for facilitating new materials and technology adoption by the industries.

The suggested approaches are as below –

- Setting up small scale pilot manufacturing and training facilities for the regional MSME industries in the identified area –
    - Such facilities can be set up in a few regional Centres with the support of eminent national institutions such as CSIR, IITs, TIFR, CLCRI etc. Integration will be essential to realize the synergy among such Centres.
- Building internal capability
    - This will call for intensive training of TC personnel in areas like plastic and composites processing, laboratory testing of such materials apart from inducting qualified and experienced manpower.
- While majority of the MSME TCs are equipped with or are planning for setting up facilities of contemporary manufacturing techniques such as 3D Printing (for plastics and/or metals), they can enhance the scope of activity by systematically designing and developing cost effective processes for optimum utilization of such technology, which will be immensely beneficial to the industries.
- Setting up region wise taskforces with the industry representatives under the leadership of respective TC
    - To start with six potential industrial regions may be identified for setting up such task forces. Networking needs to be done among these regional Centres to ensure effective collaboration.
- Setting up region wise testing Centres chains for identified material categories for supporting the industries –
    - Routine material testing laboratories have already been planned for a few upcoming technical Centres. Some existing TCs also have such laboratories. Such laboratory facilities need to be to be enhanced for testing non metallics such as rubber, plastic, composites etc. There should be a central plan and budget for putting up such laboratories.
- Identification and assessment of demand and future growth for specific material-process combinations
    - Extensive market survey needs to be carried out for data collection and analysis to formulate short and long-term plans for this strategy.
- Proactive demand creation through intensive engagement –
    - This will be a crucial step to bring together the academics, researchers, users, marketing agencies and the industry. Projects with time bound action plan and cost benefit analysis need to draw up and regularly monitored.
- Facilitating investment for the industries for setting up manufacturing facilities in the identified new process and technology areas -
    - TCs can consider taking upon the role of facilitating new investments required for upgrading or setting up new facilities. This will go a long way in helping the industries in small and micro sectors. The modalities need to be worked out.
- Facilitating new start-ups in such areas
    - This will call for due identification and assessment of potential, followed by necessary technical and managerial support.
- IT and e-commerce support to the micro and small industries
    - Most micro and small industries will be lacking resources in this area. Providing IT advisory and e commerce platform for identified groups will be of immense

help to such industries who can use the IT and e-commerce support for marketing of the materials developed by them.

While the regional focus will be different, the entire strategy should be guided by a centralized uniform and integrated material upgradation policy.

16. Conclusion

In recent times, researches in material science and engineering have been used in developing materials and processes for sustainable environment, renewable/alternative energy, reducing carbon footprint with less energy embedded and lighter yet stronger materials. While ferrous materials, mainly steel and some nonferrous material such as aluminum alloys are going to remain dominant for structural and transportation sectors, especially for parts subjected to dynamic loading, non-metals in the form of composites and hybrids will rapidly gain ground for many other applications. Usage by number and types will thus overtake metals in many engineering sectors.

Advantage India will be all about:

- Robust demand - huge domestic market and high export potential
- Investments in the manufacturing sector - domestic and foreign investments are likely to rise
- Policy support - Initiatives like ‘Make in India’ and ‘Atma Nirbhar Bharat’ are already making huge impact in making India a global manufacturing hub.
- Competitive Advantage - Increasing focus on researches in material science and engineering, backed by young and large trainable workforce. The need of the hour is to bring about a centralized strategy towards future material and associated process development to make India future ready

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