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Recent advances in the production of the automotive industry's spare parts by powder metallurgy

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Abstract

Powder metallurgy (PM) is a cutting-edge technique used for the manufacturing of spare parts out of metal, alloys, and composite powders with unique mechanical properties. Nowadays, PM manufactures more than 70% of the industrial spare parts. Due to its high productivity, ability to make more sophisticated shapes, and cost-benefit analysis. Production of items in net shape or nearly net shapes is possible. Iron, copper, and aluminum are the primary constituents of automotive spare parts. According to the European Aluminum Association (EAA), manufacturing automotive spare parts from aluminum has many advantages, e.g., the reduction of the vehicle's weight, which saves 0.6 liters of fuel per 100 km for every 100 kg. Using aluminum instead of steel in the production of automotive spare parts saves 300 kg weight with a weight of 1400 kg. This is more valid as it helps in the reduction of fuel consumption. Further decreases air pollution by about 20%. Cast iron was utilized in the manufacturing of brake systems in automobiles, but nowadays, more efforts are being made to replace heavy iron with lighter materials. So, by using PM, aluminum matrix composite (Al-MC) was utilized for the manufacturing of brake discs, brake drums, and other brake equipment with low density and superior mechanical properties. The purpose of this state of the art is to provide an overview of powder metallurgy techniques and their importance in the manufacturing and development of automotive spare parts in the automotive sector from the last century to the present.

Keywords: Powder Metallurgy, Automotive Industry, Aluminum Alloys, Ferrous and Non-ferrous Alloys, Titanium Alloys.

1. Introduction

Powder metallurgy is a process related to the manufacture of various parts from metals, alloys, or composite powders. It has become one of the most important technologies in the manufacture of auto parts, this is due to the high advantages of PM technology, such as increased productivity, low cost, low environmental pollution, and the production of mesh-shaped products. Or semi-network spare parts and manufacturing in advanced forms that cannot be produced by traditional methods [1].

Many motorized vehicles can be broadly categorized into transportation, engines, chases, and other many components [2]. Now, ten years after powder technology's proliferation, the technology roadmap's evaluation and improvement are all together again. At the same time, the main target for microparticle visualization remains the preferred source for metallic lattice-shaped systems. Significant developments and many changes have been made in the industrial technology field. Dozens of industry representatives made many efforts in many sessions to redefine the technical barriers, challenges, opportunities, and priorities that will drive the continued growth of the PM industry in the future.

Optimum characteristics, performance, durability, and reliability to manufacture comfortable and safe cars with less cost [3]. Powder technology is an economical method that is characterized by the reduction of the

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used energy. Also, it is an environmentally friendly technology that provides enhanced performance and good machinability more than the other traditional fabrication techniques such as normal casting, hot & cold extrusion, forging, and machining. Therefore, scientists are trying to reduce the weight of cars and fuel consumption by choosing new materials that are suitable for these issues.

Recently, PM methods have determined all the above-mentioned requirements, which will be the most common technique used for manufacturing many automotive parts [4-5]. PM engineering parts are in high international demand in the automotive sector due to their functional flexibility and cost benefits. It manufactures electric automotive parts, such as electrical components, tools, hydraulic devices, motors, and magnetic materials, that can be directly or indirectly manufactured. The annual sales of PM parts in the world are more than 30 billion euros [6-7]. The future of PM in the automotive sector is associated with more complex and high productivity than in the aerospace industry [8].

The automotive industry constantly needs to explore more advanced technologies to reduce vehicle weight and discover new materials to provide higher fuel efficiency and reduce pollution [9]. Engine downsizing is a new expression of PM's recent trend of auto parts manufacturing, which focuses on increasing performance through downsizing. PM can control additives which control properties and density (weight).

Nowadays, other metal powders rather than iron reinforced with different materials for manufacturing composites used in the automotive parts become more abundant in the automobile industry by powder technology. [10-13].

The study presents theoretical information about the fundamentals of PM processing and its developments in the automotive sector. This study aims to provide information about the different techniques of PM used in the manufacturing of automotive parts and the improvements in fine particle technology (such as pressure bleaching method (PSM), powder injection molding (PIM), metal injection molding (MIM), metal foaming and flame spraying method (FSM)) in the automotive sector from the past years until now. Also, flame spraying technique (FSM)) is used [10].

2. Powder Metallurgy Markets

The modern PM industry is mainly used for applications in the automotive market. The future penetration of fine materials markets over the next ten years includes electrical and electromagnetic, alternative energy, aerospace, medical, defense, applicable, and user products. The automotive segment is the dominant metal powder structural parts pressing/sintering market. On average, about 80% of all structural components of powder metallurgy materials are for automotive applications in all geographies. about 75% of these automotive applications are transportation parts (automatic and manual) and engines. From an environmental point of view, a major change will shift the focus of the automotive sector and the largest customer in the industry. Other energy sources will open new markets for using powder metallurgy techniques for the manufacturing of automotive parts. An aging population will create a market in the medical industry for PM methods. Nowadays, PM parts as structural components are rapidly developed, as the properties of the sintered steel used are better than those of forged materials. The following chart in Fig.1 represents North America's structural components sector of the traditional PM industry, which shows annual sales of powder equipment and parts manufactured by PM.

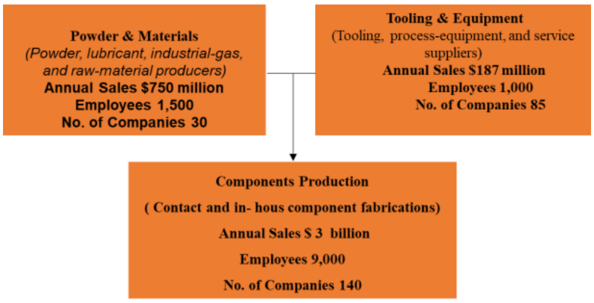

Fig. 1. Structural-Component Segment of the North American Conventional PM Industry [6].

3. Industry Overview

Powder metallurgy is a modern metal-forming process used to manufacture lattice or close-shaped products. These products are manufactured by mechanically mixing elemental powders, alloys, or compounds and compacting the mixture into one press mold. The resulting green forms are then sintered at an appropriate temperature in a furnace under a vacuum or inert gas atmosphere. The key point of the PM process is the high use of materials and flexibility to control the properties of the final product. PM applications are classified into three groups:

-The first group of applications: this is the main group addressed in this roadmap and consists of the traditional PM components that is more economical with low cost instead of the parts fabricated with castings and forgings. Products of this group include automotive, electrical, electromagnetic, aerospace, defense, and medical industries.

- The second group includes the applications of metal powders, mixtures, or composite powders for use in the welding process, bonding, and spray coating in the repair manufacturing industries.

- The third group consists of advanced materials that are impossible to manufacture by any other technology, such as the manufacturing of cutting tools tungsten carbide or molybdenum carbide. The PM process also produces Bearing materials with a porous structure, filters, and many types of hard and soft magnetic components.

Estimated sales from the North American segments are more than $7.0 billion and employ more than 25,000 people. Most PM companies are classified as small businesses by US government standards. Over 350 automotive product applications totaling about 1,000 separate parts are estimated to be manufactured using PM methods.

This sector consumes 70+ percent of all ferrous particulates and is gradually increasing as an excellent alternative to manufactured or cast parts. PM methods are becoming more valid due to their grid-shape capabilities, high material utilization rates, and minimum energy input requirements. In addition to its positive environmental impact and environmentally friendly processes, due to the source of metal abrasives from powder materials, metal abrasives can be crushed by water or gas atomization techniques for use as a metal matrix in metal powder products.

The sustainable nature of the microparticle technology provides a positive contrast with other metal-forming methods. , which requires few steps and provides more excellent physical options using mechanical and physical properties not available with other metal processing techniques, such as casting. PM can provide sustainable manufacturing advantages from a value-added product advantage, such as lightweight automotive components or process efficiency.

4. Markets and Customer Demands

The industry must be developed to achieve all the customers' requirements and needs with agility and creativity while keeping the good characteristics of the final products. The vehicle's innovative designers must take care of the strategic advantages of sustainability of the produced parts with a reduction of environmental pollution. and the reduction of adverse environmental impacts. PM's sustainable value primarily stems from the ability to form a grid and use materials that have the ability to reduce energy and decrease environmental pollution. Improvement of fuel efficiency is the driving force.

For the PM ferrous industry, fuel efficiency increases more than other systems with the help of PM's variable valve timing (VVT), continuously variable transmission (CVT), direct injection, power steering, and turbocharging. However, the use of biofuels and ethyl alcohol has a main target for the safety of some current materials and provides a chance for choosing new alloys with developed characteristics.

PM industry has the opportunity to supply components for hybrid electric vehicles, such as insulated bipolar transistors (IGBT), fuel cells, electrical motors, and gears. For example, the PM industry is the essential method used in the manufacturing of transmission gearboxes, which is a strong catalyst as it is considered to be the entire PM market. Automakers consider heavy PM gears to be preferable, with good mechanical characteristics and surface finishes similar to towed gears.

4.1 Challenges

Density and porosity have a fundamental role in the mechanical properties. Achieving the highest possible density is usually the main target. As with increasing the densification, the metallic properties of the manufactured parts approach to those of the original metal, which has a high density. When higher density is achieved, the final product will possess a larger proportion of the overall market requirements, in which, from an economic point of view, the particle processing technologies are applied to higher densification products.

5. Innovation In the Automobiles

China has been the country more specified in the manufacturing of automotive parts since 2013, with a gradually increasing rate, as clear in Fig. 2 [14]. China has become a broad market for auto parts and accessories by the PM technique. Most of the PM automotive segments are essentially used in the body, chase, pump, hydraulic, transmission systems, and engine.

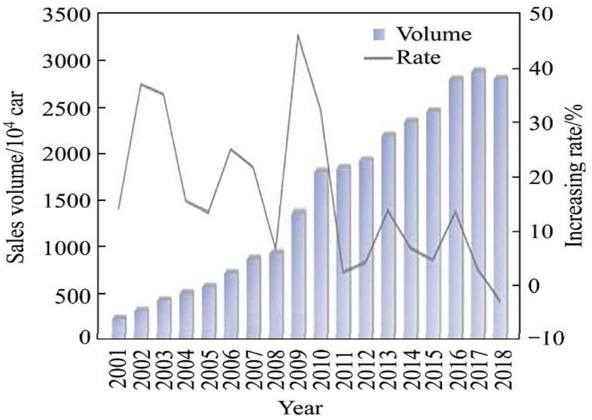

Fig. 2 China automobile sales volume and increasing rate [14].

Figure 3 [15] shows published forecasts for future payment technology breakthroughs. Electric and hybrid vehicles are important techniques to achieve future emissions standards. The hydraulic and transmission systems in conventional vehicles with PM products become smaller dimensions. In the next fifteen years, significant growth in electricity is expected, which makes the automotive market depend greatly on the PM industry. The impact of manufacturing of automotive parts by PM must be evaluated, which requires careful consideration. The gradual transition from a conventional internal combustion engine to hybrid or all-electric vehicles will present significant challenges

Manufacturing using PM still continues to offer solutions that can enhance the efficiency of conventional trains. However, Fig. 4 shows the average use of parts fabricated by PM for one car in China is only 3.97 kg, which is lower as compared with the others [16]. It indicates that a technology gap in China's powder.

6. Applications of Powder Metallurgy Parts in the Automobile Industry

New and different parts for cars and trucks are manufactured using powder metallurgy technology. However, many engineers and designers are making more efforts to expose what can be done with the advanced PM manufacturing process. Each powder metallic part is produced with a specific set of tools and parameters unique to each part.

Iron and stainless-steel powders are the main components of many auto parts. Steering parts such as: transmission components, connecting rods, bearing covers, variable valve timing (VVT), seating areas, exhaust applications, catalytic reduction system, fuel components, and engine Parts.

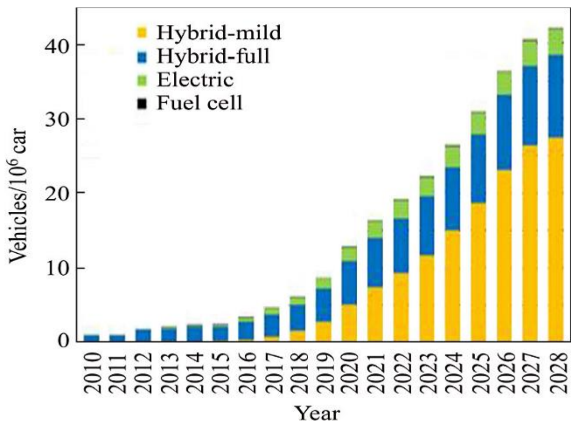

Fig. 3 Forecast of transmission type [15].

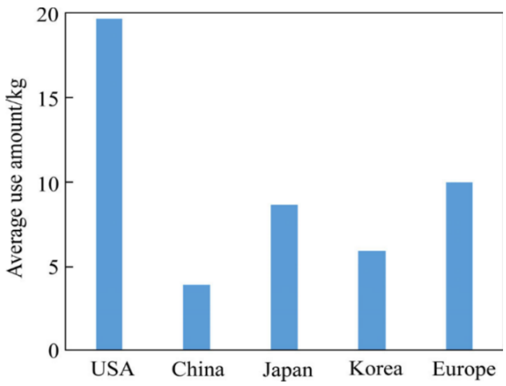

Fig. 4 Average use amount of powder metallurgy parts per car in different countries and regions [16].

7. Advantages of Powder Metallurgy Automotive Parts

The advancement of metallic powder components in automobiles has been attributed to innovations in PM parameters, such as material development and the pressing process. The development can be achieved through the ability of materials to be compressed to a higher density, resulting in higher-strength materials with superior mechanical properties.

Advantages of powder metallurgy methods in manufacturing auto parts: the ability to manufacture materials of higher density and strength, manufacture of complex parts and automotive components at an affordable cost, the high productivity, and automotive parts are manufactured in the net or near net shapes.

- **Brain-storming about metal powder parts in cars:**

- What are the best materials used in the manufacture of metal powder in cars?

The Metal Powder Industry Association (MPIF) publishes "Standard 35". This International Standard lists the different types of metal powder mixtures available and provides the main mechanical properties of each mixture. By working with the MPIF Engineering community, clients can choose materials according to their expertise.

- Are auto parts made from powder metallurgy not as strong as parts made from other technologies?

Actually, no; By selecting a material with good and suitable properties in "Standard 35," one can obtain PM parts with good mechanical properties that are superior to those manufactured by other processes. Powdered metal parts can also be heat-treated for extra strength when needed. A secondary procedure can also be performed on PM parts to improve their properties

Performing secondary action on PM parts to improve their properties, such as cold and hot rolling, extrusion, and hot forming processes that provide outstanding surface finishes and surface hardness.

- Why should we consider powder mining when we already have a working part?

Metal powder parts manufacturing has many advantages, such as high repeatability, low cost, and environmentally friendly process. High-quality, heavy-duty parts and the ability to reduce the weight of the part by strengthening the base metal with a low-density material offer suggestions for combining two or more parts into one.

- Are crushed metal parts more susceptible to corrosion than other parts manufactured with other technologies?

Metal parts can be powder-coated and coated with a protective film. The stainless-steel parts provide good corrosion resistance.

8. Powder Metallurgy Process

PM technology has a good value derived from an economic point of view due to its low consumption of energy, the efficiency of the used materials, and minimal laboratory devices used compared to other traditional fabrication methods. The PM process can manufacture various parts from simple to complex shapes. Most PM parts have a weight of less than 2.27 kg (5 lb), although parts weighing up to 15.89 kg (35 lb) can be converted to conventional PM equipment. The three main steps of manufacturing parts by the PM. the process is conventional mechanical mixing, pressing, and consolidation processes. Figure 5 shows a schematic diagram of the traditional powder metallurgy steps from material initiation to the final product.

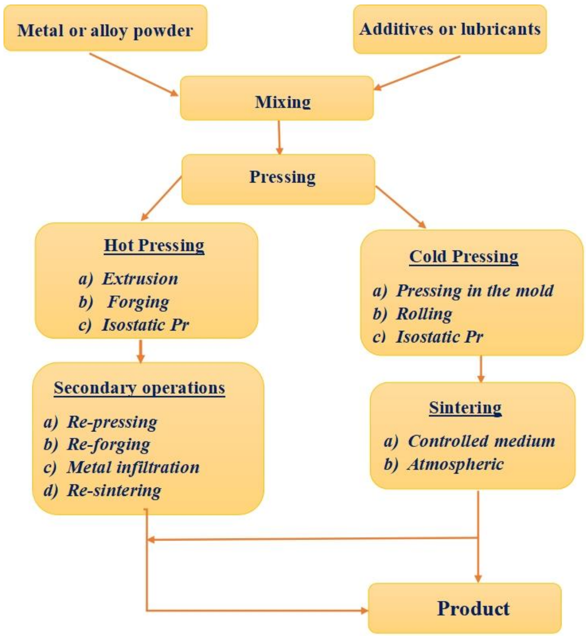

Fig. 5 Flow chart of the conventional PM process.

8.1 Mechanical Mixing

Primary powders, partially alloyed metal powders, pre-mixed metal powders, and compound powders are first mixed mechanically with lubricant materials or other alloying agents to produce a homogeneous mixture of all components. These additives aid in machining, improving hardness or tribological properties that are abrasion resistance and coefficient of friction. There are three main factors that affect the mechanical mixing process. The first is the ball-to-powder ratio, which increases (the balls are much larger than the powder ratio), and this helps in good homogeneity between the ingredients and reduce
Good in particle size, which has a positive effect on mechanical properties. The second parameter is revolutions per minute (RPM), which creates a coolant weld between the particles and then decomposes the particles into fine particles. The third is the mixing time, which is the main factor in the mechanical mixing process. Figure 6 shows one of the mechanical ball milling devices used in the mechanical mixing process.

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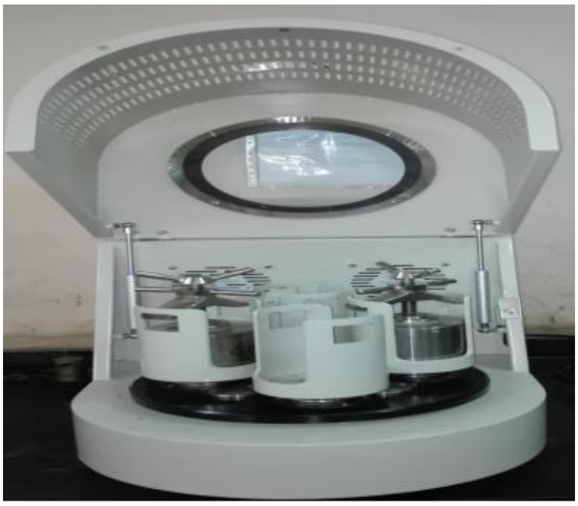

Fig. 6 Four Vails Mechanical Mixer.

8.2 Compacting

The controlled weight of metallic, alloy, or composite powder is fed automatically by gravity into a suitable mold and pressed at room temperature under pressures ranging from 150 MPa to 900 MPa, depending on the nature of the mixture, tap, and bulk density of elemental powders, which control the compressibility of the pressed powder. Typical pressing techniques use rigid molds placed in special mechanical or hydraulic presses. Some lubricants are added to help easily reject the sample from the mold without any problems. Compression of the loose powder results in a "green" pressed sample with a defined shape of the end part according to the mold used, which can be handled and transported to the sintering furnace. Figure 7 shows a single-axis hydraulic press used in the mixed powder compaction process.

8.3 Consolidation Process

Pressed green samples are sintered in a vacuum or inert gas atmosphere furnace. The samples are sintered at a temperature below the melting point of the metal matrix, held at the sintering temperature, and then cooled to room temperature until the samples get out of the furnace. The sintered samples possess a high strength that meets the functional requirements of the required part application. There are some critical factors for the sintering process, that is, the sintering temperature is mainly related to the melting point of the components, which is the percentage. The second is the calcification time. It should be suitable for the sintering process, not low, as it should be sufficient to complete the sintering capacity and sufficient for neck growth between adjacent particles. The melting point of the base metal is also not high, which causes the sample to swell.

Fig. 7 Uni Axial Hydraulic Press.

The last parameter is the sintered atmosphere which may be a vacuum or an inert gas, depending on the nature of the sintered samples. The sintered samples are generally manufactured in a net shape that makes them ready for using after exiting from the furnace. However, components can be pressed, impregnated, machine-shaped, annealed, painted, or heat-treated to provide exceptional properties or features. Figure 8 shows a vacuum furnace used for the sintering process.

Fig. 8 Vacuum Sintering Furnace

9. Powder Metallurgy Methods Used in Automotive Sector

The following is the traditional powder metallurgy method used in the manufacture of auto parts, which was used in the past as the only method of the manufacturing process, also called the pressing and sintering method.

9.1 Pressure-Sintering Method (PSM) (Conventional Method)

PSM depends on mixing metal or composite powders with different lubricant materials and then sintering them in a vacuum or inert gas atmosphere. The compaction process, also known as pressing, squeezing, or pelletizing, is done either in a normal or hot state as required. When pressure is applied to the mixed powders, particles slide over each other, condensing under the applied pressure. For PSM applications, a high raw strength value is desirable. Figure 9 shows the flow chart for the manufacturing of PSM parts. To develop automotive parts metallurgy powder, recent advances in PM methods have been applied in automotive parts manufacturing,

PM is in the manufacture of auto parts, such as Powder Injection Molding (PIM), Metal Injection Molding (MIM), Metal Foaming, Pressing and Sintering Method (PSM) (this is the traditional technique), and Flame Spraying Method (FSM).

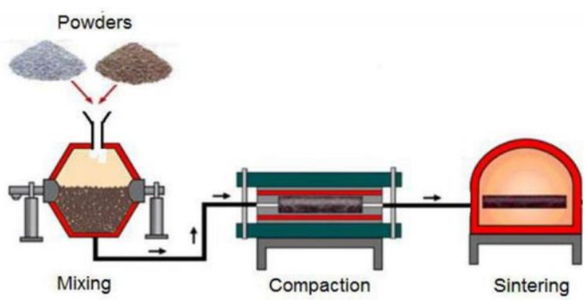

Fig. 9 The flow diagram in PSM production of parts.

9.2 Powder Injection Molding (PIM)

PIM is a fabrication process used for automobile components that combines both plastic injection and metallic powder [17]. It is a molding technique established by mixing fine metallic particles with binders and pouring the mixture into plastic injection machines. PIM is a newly developed process to fabricate simple and sophisticated shapes, accurate sizes, tolerances, and difficult-to-machine and process overcapacity parts at low cost [18]. It is implemented in four stages; Mixing, injection molding, grinding, and consolidation process [19], as shown in Fig. 10.g

9.3 Metal Injection Molding (MIM)

MIM is one PM method that includes metallic powders. The mixture contains both powder and binders is called the feedstock. For the preparation of starting materials, metal or ceramic oxide, carbide powders are mechanically mixed to obtain a homogenous mixture with a ductile binder or organic materials and lubricant material. The characteristics of the sintered samples are greatly affected by the original characteristics of the used raw material. Consequently, its composition should be accurate. The required material that flows from the injection mold is studied by rheology before the injection process in the mold. In order to avoid problems that may occur during the molding process. The mixed powders with the binding materials are mixed with determined mixing parameters to give the optimum rates and then granulated. Granular raw materials are formed into the required form by adjusting the injection pressure, cylinder temperature, and heating cycle.

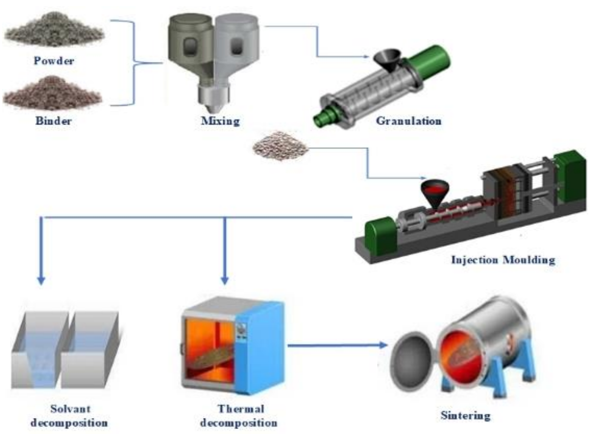

Fig. 10 Powder injection molding steps [19].

The pressure continues until the raw material enters the mold and its hardening occurs. The injection part is withdrawn from the device, and the mold is opened to remove the feature. This course must be achieved quickly and with the lowest cost, as shown in Figure 11. The next phase is the removal of links from raw specimens under controlled parameters. The synthesis mechanism can be done either with heat (pyrolysis) or solvent (hydrolysis). Then, the sintering process can get the required samples with good properties. Finally, a nearly low porous fraction that is fully densified is obtained.

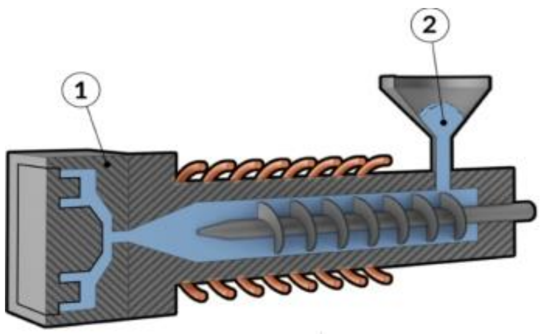

Fig. 11 Meal injection molding device.

The engine swingarms were made by C for TiH_2. This temperature is much lower than the melting point of aluminum. A foaming structure was obtained as a result of the thermal decomposition of the foaming material that happens at elevated temperatures.

9.4 Metal Foaming

There are two methods currently in use for metal foam. The second smelting method is the PM method [20] three types of smelting foam can be produced: a) gas injection into the molten metal from the outside, b) adding foam to generate gas in the molten metal, c) mixing Pre-foam agents with molten material, which then generates foam in a specific medium [21-22]. Metal foam is produced by the smelting process mainly in three stages. In the first step, the metal or foamed alloys are melted. In the second step, a gas or foaming agent is added to form a porous structure. In the third step, the molten metal is solidified by cooling [23-24]. In the foam production process caused by the formation of gas bubbles in the molten metal, the gas bubbles tend to swell quickly to the surface due to the high lifting force of the liquid and where metallic foams are formed. Too high viscosity results in bubble suppression, while too low viscosity causes bubbling [25-26]. Therefore, controlling the viscosity of the molten metal during foaming is critical. Zirconium hydride (ZrH_2) or titanium dihydride (TiH_2) is generally used as a foaming agent in producing metallic foams. Other chemical compounds such as calcium carbonate ($CaCO_3$), calcium hydride (CaH_2), calcium and magnesium carbonate (C_2CaMgO_6), calcium sulfate ($CaSO_4$), ferrous sulfate (FeO_4S), lead carbonate ($PbCO_3$), lead oxide (PbO), and sodium nitrite ($NaNO_2$) can be used as foaming agents under Specific pressure and temperature conditions. Whether or not the metal will foam and whether it will be of the desired density depends on the rate of decomposition of the gas released when the foaming agent decomposes. The foaming agent material may be in the form of particles, granules, or powder so that it can be easily dispersed in the base metal [27-28].

The PM method is one of the most popular methods for producing metallic foam, and recently it has been extensively studied in this field. With the help of the PM method, it is possible to produce sandwich foams, spherical foams, and foam in profiles along with known simple foam products [27, 29]. In addition, particle-reinforced foam production is also preferred to increase the foam material's mechanical properties. In the PM method for metal foaming, metal powders (generally Al powder) are mixed with a foaming agent (usually TiH_2 or ZrH_2) and pressed.

As the temperature increases during the foaming process, the foaming agent separates in the hull, and H_2 gas is released. Decomposition is visible at about 400 °C for TiH_2. This temperature is much lower than the melting point of aluminum. During the decomposition process, expansion occurs at a high temperature, in other words, foaming occurs [27, 30,31]. Studies have shown that the foam's surface tension and viscosity of the liquid metal change if ceramic particles are added to the molten. It is, therefore known that the melt stability of the foam can be improved depending on these properties (in the face of tension and viscosity). For this reason, SiC, Al_2O_3, and various boron-containing molecules are often added to Al-based materials. Recently, it was discovered that powder-reinforced metallic foams (PMF) provide excellent energy damping. Hence, due to its damping properties, PMF is preferred in automobile shafts and chassis. The interest in aluminum foam is increasing day by day because of its low density and high deformation energy absorption, as well as being preferred in desirable areas for increased stability in automobiles. Due to the energy-absorbing properties of metallic foams, in automobile crash tests, it has been observed that the maximum impact energy in areas of high collision potential is dissipated by metallic foam, and deformation is also reduced [27,32]. Metallic foams are widely used as a filler for doors, bumpers, and similar parts in automobiles. Figure 12 shows the vehicle's aluminum foam areas used for collision damping. When considering the acoustic effect of metallic foams, it can be said that they can compete with various low-cost organic insulating materials in an impressive quantity.

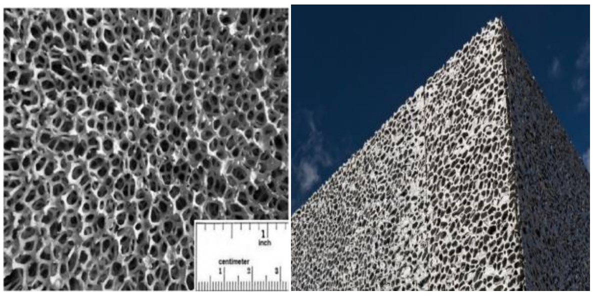

Fig. 12 Aluminum Foam [27].

9.5 Flame Spray Method (FSM)

In the Federated States of Micronesia, coatings in the form of particulates or rods are sprayed over the sample with a combustible material, explosive and carrier gases from the spray source. In this process, the particulate metal samples are sprayed to cover the surface with oxyacetylene by means of oxygen suction.

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It is called a cooling system, as the temperature of the sample surface must not exceed 200 ° C, and the heat must be about 330°C. The mechanical adhesion is achieved and the thickness of the coating layer is usually between 0.05 and 2.5 mm, which is related to the sample's shape Fig. 13 [33-34].

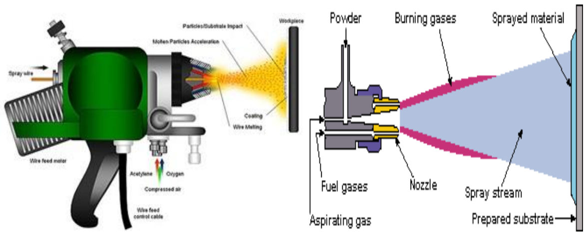

Fig. 13 Flame Spray Method [33].

9.6 Additive Manufacturing on the Supply Chain of Spare Parts Industry

AM metallurgical techniques are divided into three main categories: technologies based on powder layer melting, technologies based on deposition of energy by a direct method, and inkjet printing technologies. The first & second methods are also divided depending on the power source's nature, whether a laser or an electron beam. The metal powder layer melting process usually produces homogeneous parts of the metal and polymeric materials. The energy deposition method can process a more comprehensive area of materials and also has the ability for a multi-material composition. Inkjet printing, AM can handle most metal & materials powders, is compatible bonding systems are in place.

There are other design limitations of the inkjet printing method owing to the requirements of secondary methods to obtain the required physical & mechanical applications requirements. A lot of metals & materials available for additive manufacturing methods are impressive. The makers have the ability to choose materials, such as tool steel, stainless steel, aluminum and its alloys, copper & titanium alloys, and superalloys based on cobalt, chromium, and nickel. In the automotive sector, AM is a suitable technique for rapid prototyping with economic impact.

More sophisticated designs result in lower-density products and custom tooling. Every new car starts as a prototype before heading into manufacturing. By using AM, automakers can successfully test and modify the design. GM has established a rapid prototyping division that gives models exceeding 20,000 parts using selective laser sintering technology and stereolithography [35].

In 2014, a Swedish automaker used 3D printing for the manufacturing of its sports car. The company used rapid prototyping to ensure the different parts of the car, such as the footrest and mirror cover, were correct. Alongside this, a lot of product shapes have also been 3D printed, like a patented variable turbo cap ductwork, interior mirror parts, and a lighter-weight titanium exhaust end piece. By 400 grams [36].

9.6.1 Automotive Parts with Additive Manufacturing

AM is building bridges between the physico-digital worlds as a 3D Computer Aided Manufacturing (CAM) technology. AM is used in the manufacture of aircraft parts and is more convenient and efficient. In addition, AM technologies have drawn attention to the aircraft parts supply chain and can also support maintenance tasks. In general, an overview of the nature and importance of using AM technology in the manufacture of new generations of spare parts from metal powders.

Additive manufacturing is considered a designing route that increases revenue for the aviation industry through the reform process and the supply chain [37]. AM offers new chances for sustainable, topologically optimized, low-density parts for aero planes. Many complex parts and subcomponents, such as those shown in Fig. 14 are assembled and require a multi-level fabrication structure. Therefore, extensive inventory and supply chain work is required to continue the smooth running of aircraft assembly. So, process developments are needed to make sure safety and quality in the aviation sector.

Fig. 14 Spare parts by additive manufacturing technique [37].

9.6.2 Quality Assurance and Standardization

Ingredients require rigorous evaluations to obtain certification. ISO/TC261 and ASTM F42 were established standards for terms, materials, techniques, and testing steps [38]. Meanwhile, SAE International works space-joined with the AM standards, in which the ISO and ASTM are responsible for AM applications

[39]. Consequently, the FAA and EASA have certified to examine the service requirements in the desired parts [40].

This effort makes the certification process more rapid and establishes the continued operation safety of the aviation industry to adopt the automated manufacturing system [41]. However, firm standardization is not been made, and the technique is not economical and takes a long time.

9.6.3 Material Choice for Additive Manufacturing

Parts are hard to predict because the required pattern is choppy. More efforts have been made to reduce the cost and timing. which makes manufacturing of parts more sophisticated [42]. So, companies should keep a high stock of spare parts to achieve all the requirements. AM allows the production of small-volume parts away from continuous manufacturing operations. By removing defective parts while incorporating smaller sample dimensions from conventional manufacturing methods [43-44].

AM reduces the risk of supplying low-demand parts while conventionally manufactured parts are not available in low quantities [44]. However, the limited size of AM, insufficient performance, and secondary-processing requirements are the actual challenges [45].

9.6.4 Material Standards

Titanium, aluminum, nickel, stainless steel, tool steel, etc., are used in AM for aerospace applications [46]. So, the most commonly used metals are nickel-titanium alloys owing to the relatively high-temperature characteristics that are well suited to aerospace applications [47].

Furthermore, silver, gold, and platinum can be used for specific applications in aviation [48]. Moreover, Ti6Al4V alloy is widely used as it has a good strength and crack hardness, low weight, low coefficient of thermal expansion, and so on [49]. Besides all these properties, titanium alloys are widely used in the manufacture of turbine blades for applications in commercial airplanes [50, 51].

9.6.5 Future perspective

In the future, the improvement of the AM process manufacturing of larger products will be established. It is expected that larger parts, such as aircraft wings, will be made with AM technology in the future. By considering the parts integration and composition optimization, AM can be used in the manufacturing of multifunctional components that perform multiple jobs simultaneously.

10. Various Classes of Metals Used In The Auto Parts Industry, According To PM

Figure 15 shows the vehicle's potential locations for fine particle applications. Components fabricated by powder technology are applicable in many components of cars, trucks, buses, and others.

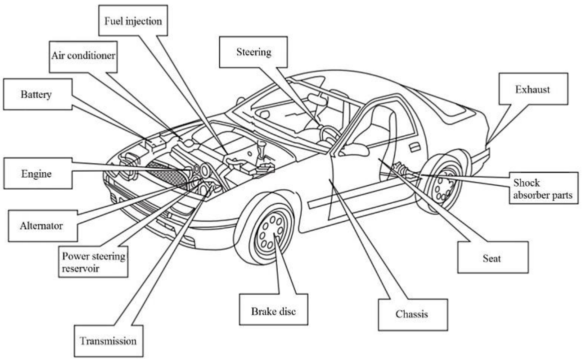

Fig. 15 Different areas for PM applications in an automobile.

10.1 Aluminum Automotive Parts

Now, aluminum and its alloys are widely used in the manufacture of auto parts due to their low density, high corrosion resistance, and good strength. Powder technology is preferred for the manufacture of metallic aluminum foams used in automobiles. This is due to the low density and high impact energy absorption properties. The European Aluminum Association (EAA) reports that reducing weight per 100 kg in cars saves about 0.6 liters of fuel every 100 km. Aluminum used in a medium-sized car weighing 1,400 kg, 300 kg in weight savings can be achieved. This increased value develops to twenty percent of the total weight.

The fuel consumption reduction for a vehicle over its lifespan reaches up to 3000 liters, and air pollution is reduced by about 20% [52]. More efforts have been made to reduce the weight of automotive brake systems, as aluminum matrix compounds (Al-MC) are used to manufacture brake discs and other brake equipment using a PM method. Gray cast iron is usually used as brake disc material.

In the study of Arslan et al. [53], the cameras were produced and characterized using silica-reinforced silicon alloy 7075 using conventional PM technology.

In action with the support of ESTAŞ Eksantrik San. Powder company used. and Pb and Mg to help the consolidation technique and paraffine wax is used as a lubricant.

Composite powders are homogeneously mixed in a metal cam mold and then pressed under a pressure of

300 MPa. Consolidation process takes place in a furnace at 600 °C in the presence of an N_2 gas environment. Mechanical properties recorded that the hardness, transverse rupture strength, and wear resistance increase with increasing reinforcement content, as shown in Fig. 16.

Fig. 16 SiC reinforced Al-7075 matrix composite cams manufactured by PSM [53].

Closed-cell aluminum foams are increasingly used in sections required to reduce weight and increase vehicle reliability. PM-tech aluminum foam is an attractive alternative material for vehicles as it saves weight with the advantage of high rigidity and high-impact energy absorption. Powder injection molding (PIM) and metal injection molding (MIM) technologies are widely used in the automotive industry.

About two decades ago, the makers of automotive and researchers reported that aluminum and its alloys have good properties such as low density, high strength, high modulus of elasticity, and good corrosion resistance. Various aluminum alloys widely used in manufacturing auto parts by PM are 2014, 6061, 7075, and Al-14Si, while pure aluminum compounds are mostly applicable.

Aluminum powder can be manufactured by traditional gaseous atomization technology in which the metal abrasive is converted into a fine powder for use in the production of auto parts, which has a positive economic effect. However, fully pre-made Al powders cannot be used due to insufficient compressibility and sintering activity due to the aluminum oxide layer formed on their surface.

Cams and camshafts were previously manufactured using traditional solid rails and forging methods, which are more time-consuming and not economical. Using PM technology, it can be made from composite materials in a single step in the form of mesh. Therefore, PM can be used to produce composite cameras and intermediate rings, as shown in Fig. 17 [54].

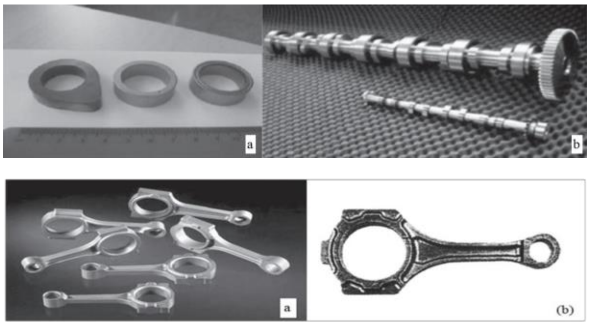

Fig. 17 Composite motor components produced by PSM: a) Cam and intermediate rings, b) Camshaft [54].

Mechanical mixing and alloys were developed to obtain optimum stress response and sintering to obtain good mechanical and tribological properties. Liquid phase sintering can be used in manufacturing as Al-14Si-2.5Cu0.5Mg alloy and Al-6Zn-2.5Mg-1.7Cu alloy.

The physico-mechanical characteristics of Al alloys manufactured by PM are generally more than those manufactured by casting technology. Unfortunately, however, PM aluminum auto parts cannot meet the needs of extended requirements that require high modulus, and corrosion resistance and keep these properties at temperatures [55].

Several other components that PM can make are provided to the motor, such as the connecting rod [56]. Other components, such as the G rotor and gear-type oil pumps, are shown in Fig.18.

Fig. 18 Automobile parts manufactured by PSM: a) Oil pump, b) Transmission parts [55].

The camshaft and crankshaft gears, timing gears, water pump impellers, distribution pulleys, and fuel pump can also be manufactured by PSM, as shown in (Fig. 19 a and b). Also, aluminum compounds (Al-MC) have been used in the automotive industry, especially the Al-SiC compound used in the manufacture of brake discs Fig. 20 [57].

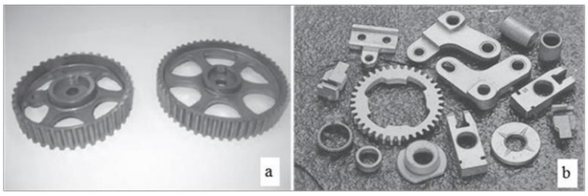

Fig.19 Parts manufactured by PSM: a) Distribution pulleys, b) Fuel pump parts [56].

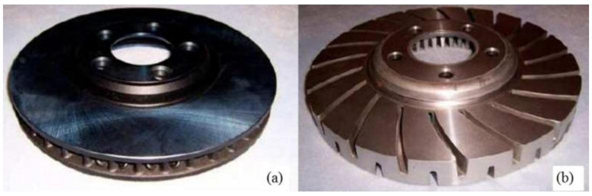

Fig. 20 a) Brake disk (weight: 8.44 kg), manufactured from gray cast iron used in the sedan automobile, b) brake disc made of Al-SiC composite material (weight: 3.32 kg) specially designed for the same automobile [57].

10.2 Ferrous Alloy Components By PM

Several ferroalloys are used in the manufacture of particle structure parts, including iron-carbon (Fe-C), iron-copper-carbon (Fe-Cu-C), pre-alloyed steel, low-alloy steel, hardened and sawn alloy steels. It covers a wide range of materials from low strength to high strength [58]. Some alloying elements, such as molybdenum and nickel, have been added to improve the properties of PM parts. There is a significant change in the prices of used metal powders, as shown in Fig. 21. This has a negative impact on auto parts productivity by PM 2005-2018 [59]. PM technology is less capable of competition with other manufacturing techniques, such as forging and casting. The strength of manufactured auto parts is determined by sintering coefficients with heating and cooling rates. These parameters significantly affect the density of the samples produced. Density is an important parameter in determining the mechanical and tertiary properties of the final product.

Densification of the produced samples can be increased by a secondary process, such as cold or hot rolling, setting fire, or re-batting [60, 61]. Iron precast Mo powders and diffuse alloy powders reinforced with copper, nickel, and neodymium are used in high-performance applications. Cr and Mn have recently been used as alloying elements that give an automotive part good hardness and strength [62, 63].

However, Cr and Mn have a high affinity for oxygen, so chromium-containing powders pre-sintered with high sintering temperatures improved the strength of the sample [64]. Therefore, an improvement was made to develop new materials with high quality to be compatible with medium to high strength. The sintering process is an essential step in enhancing the properties of Aluminum parts [65].

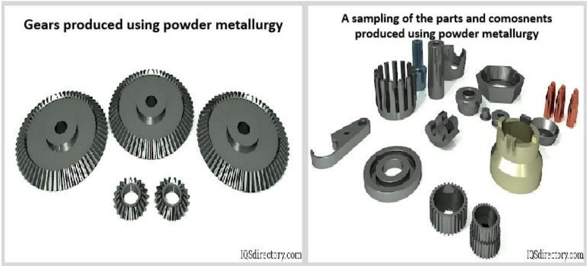

Fig. 21 Composite components produced by PSM [59].

10.3 Non-Ferrous Alloys Components By PM

Brake pads are fabricated by powder technology [66], and the materials that make up the brake lining (BM1: copper powder, aramid, rock wool, BM2: graphite powder, coke, ZnS, BM3: $ZrSiO4$, Fe_2O_3, cashew powder) were mechanically milled in a rotary electric mixer for 300 seconds up to the complete smoothing. After milling, the mixtures (BM1, BM2, BM3) were put by the same weight into a cavity of 8 molds located in the pistons. Then, the samples were molded under a pressure of 7.5 MPa and a temperature of about 150 ° C for 300 Sec. Both the top and down plates of the pillow-shaped powder mixture were polished by a grinding device, and then the sintering process was established Fig. 22.

The brake pads were exposed to a friction test. Besides the experimental work, the brake pad produced by PSM from mineral powders is widely used in practice. One of the most important powder metallurgical spare parts is the main crankshaft bearings coated by FSM using Pb, Sn, Cu, and ZrO_2 composite powder, which has good strength and good wear resistance, which is shown in Fig. 23.

Fig. 22 The brake pad manufactured by PSM [66].

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Fig. 23 Crankshaft master bearings coated by FSM using a new alloy of Pb, Sn, Cu, and ZrO_2 powders.

10.4 Titanium Automotive Components By PM

Titanium metal is one of the materials that should be a choice for different applications. However, due to its relatively high cost, it is used with some limitations., as in luxury cars. Several studies of low-cost titanium have been devoted to promoting its use in automobiles. Attention will be drawn to Ti products due to the high performance of mechanical properties and weight saving. Since 1990, Ti powder has been widely used in the manufacture of engine parts, brakes, chassis, and exhaust systems, with a weight reduction of approximately 55%; so, the dimensions of Ti parts in automobiles are limited in vehicles.

To expand the use of Ti parts by PM, a significant challenge is the high cost compared to competing materials, such as steel or aluminum. A good advantage of making Ti parts with PM technology is to obtain a product that is close in shape. The high price of Ti metal is a major obstacle in the manufacture of metallic Ti powder parts. PM Ti products have two different manufacturing methods: elemental alloying (BE) technology and pre-alloying (PA) technology. BE is a low-cost route, although its properties are insufficient as compared with the forged Ti samples. The strong affinity of Ti for oxygen needs a controlled atmosphere during the manufacturing process to prevent TiO_2 formation.

Many efforts were made to develop a new powder production process, which focused on lowering the low price of TiO_x or TiO_2. The FFC-Cambridge process is one of the most common techniques used in electrochemical processes to convert TiO_2 to Ti by cathodic oxide polarization in a $CaCl_2$-based molten salt solution. Zhang et al. [68] recently applied the direct thermal reduction method to a solid Ti-O solution in this process. The HAMR process has the advantage of low oxygen content in the powder product and the potential for cost reduction. Advanced work reported that rare earth elements effectively reduce the oxygen content of PM Ti during the sintering process. In addition, the addition of alloying elements such Fe and Mo are very important at low cost; Therefore, PM Ti densification and mechanical properties can be significantly improved [69-71]. Figure 24 shows various titanium alloy auto parts and transmission knobs.

Fig. 24 Titanium & Titanium alloys (a) automotive spare parts (b) Titanium Gear shift knob [69].

10.5 Soft Magnetic Composite for Automotive Parts

Soft magnetic composite (SMC) materials become very important in automobiles. Several soft magnetic materials were developed in the latter decay, including iron, phosphorous iron, silicon iron, nickel-iron, cobalt iron, and stainless steel. These materials are called first-generation magnetic materials and are mainly used in direct current applications.

This group has advantages because it combines high magnetic saturation, low eddy current loss, the ability to carry 3D flux, and the PM process's cost-effective production of 3D lattice-shaped components [72]. For automotive applications, many potential opportunities for SMC will be created in traction engines, pumps, and ignition systems, some typical applications of SMCs are shown in Fig. 25.

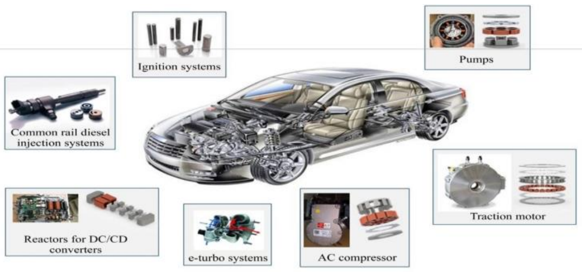

Fig. 25 Main applications of SMC in automotive [72].

11. Activities of Central Metallurgical R & D Institute in Automotive Parts Manufacturing

11. 1 Manufacturing of Carbon Brushes for Automotives

The carbon brush is an integral part of the DC motor, which is based on the meeting to transmit electric current from the rotating part of the machine. Also, the brush is responsible for changing the wind in the conductors during the spinning process. Copper is made from copper compounds and is hardened with various proportions of a lubricant, such as graphite, in a small proportion that does not affect electrical or thermal conductivity. Carbon brushes should not be placed inside the power tool for a long time as they can be damaged by the effect of heat generated during the operation process. So, by the PM process, reinforcing materials must be added to reduce the coefficient of thermal expansion (CTE) of the manufactured copper compound.

11.2 Manufacture of Composite Friction Materials for Vehicle Brake Applications

In the Powder Metallurgy Department (CMRDI), friction materials are manufactured by PM for use as vehicle brakes. It is made of nano-reinforced copper composites such as alumina (Al_2O_3) and carbon nanotubes (CNTs). Effect of nano additives on mechanical and tribological properties of advanced friction composite materials used in vehicle brake applications. Figure 26 shows a model of automobile brakes made of copper composite reinforced with different ratios of alumina nanoparticles and CNTs.

Fig. 26 The vehicles brake.

11.3 Manufacture of Chain Brake Pad Materials for Automotive Applications

Manufacture of aggregates from copper powder to be used as brake chains for tanks and lift wagons. It must have specific properties to be useful in these applications, such as high wear resistance, hardness, and good corrosion resistance. Therefore, the copper mold has been hardened with a certain percentage of iron to give graphite strength and particle resistance properties as a self-lubricating material that improves the tribological properties, namely, abrasion resistance and coefficient of friction. Figure 27 is a photograph of the powder-coated sequential brake assemblies. As it turns out, it consists of two parts: the thick upper part representing the copper compound by PM and the thin part, which is an ordinary iron plate that acts as a contact layer between the brake lining and the reservoir chain.

This study presents theoretical information about the fundamentals of PM processing and the developments of these methods in the manufacture of spare parts in the automotive industry. The innovations, improvements, and advantages of PM techniques in the manufacturing of automotive parts are explained in detail through examples. Also, why do automakers choose PM methods in vehicle production in this research work? In general, automakers focus on efforts to reduce vehicle weight, discover new materials that provide fuel efficiency, and reduce emissions values.

PM methods in recent years have successfully implemented these requirements. It is believed that PM will spread to cover many automotive parts productions in the near future.

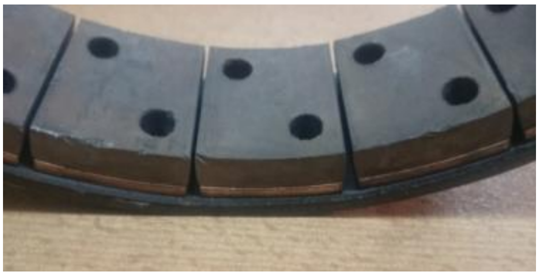

Fig. 27 Chain brake pads.

12. Conclusions

This study presents theoretical knowledge about the principles of processing PM methods and the developments of these methods in the manufacturing of spare parts in the automotive sector. The innovations and advantages that PM methods bring to the automotive industry are explained in detail through examples. Also, extensively studied why automakers choose PM methods in vehicle production. In general, automakers focus on efforts to reduce vehicle weight, discover new materials that provide fuel efficiency, and reduce emissions values. PM methods in recent years have successfully implemented these requirements. In the coming years, it is believed that PM will make contributions in many areas in the automotive sector.

Future Trends

- All automakers developed the processing technologies for the manufacturing of automotive parts by powder metallurgy. This is achieved by introducing another secondary process on the final PM product, such as hot or cold rolling, hot foreign, or extrusion. All these technologies improve the microstructure and enhance the densification, also making grain refinements that improve both the physical and mechanical properties.

- The development of the used materials by making a coating of the powders by nano metals for the capsulation of the used reinforcement with a wettable layer to obtain a homogenous structure that affects greatly the mechanical properties.

- The fabrication of aluminum foaming materials for the crash area of the automotive by powder technology by economic methods.

- The manufacturing of brake pads from recycled copper scrape utilizing more affordable lubricant ingredients.

- Also, modification of the manufacturing processing of the automotive parts by addition of a secondary process such as forging, rolling or extrusion of the sintered samples to improve the mechanical properties.

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