A REVIEW ON LIGHTWEIGHT METAL COMPONENT FORMING AND ITS APPLICATION

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Abstract. The present research focused on reviewing forming technology and inspired various method forming processes for different lightweight materials. Nowadays, to improve modern automobiles' fuel economy while preserving safety and efficiency, advanced materials are essential. Since accelerating a lighter object requires less energy than a heavier one, lightweight materials offer great potential to improve vehicle performance. Innovative forming technologies are discussed concerning each approach and their contribution to lightweight material application. New metal forming methods are implemented to fulfill lightweight material applications in various fields.

Keywords: Bulk forming; Hydro forming; Metal forming; Lightweight materials.

1. Introduction

Forming lightweight material design processes typically substitute different materials with improved essential weight characteristics for the primary material. HSS or lightweight materials are used because the workpiece geometry has no significant effect on the work piece's weight. For almost every industrial production field, sheet metal forming is the essential manufacturing process for processing metal parts like transportation, machines, household appliances, food, energy, chemicals, etc. \cite{1} The automotive and aerospace sectors drive the development of the sheet metal forming industry. Four different methods are applied in metal forming, leading to lightweight design: functional, material, component, and lightweight conditional approach. Their primary objective is to decrease the weight of a part and save our existing resources\cite{2}.

The exponential growth of automotive components and the process's continuous expansion has necessitated developing new advanced metal forming methods. Among these methods, hot forming, which takes advantage of high temperatures' beneficial effect on improving formability, must be included: hot forming processes are inevitable even in some fields\cite{3}\cite{4}. In the new aerospace industries, relentless progress demands more robust and lightweight materials. This is the most powerful approach to minimize the weight of structural parts and equipment. Increasing the resistance-weight ratio implies using advanced component manufacturing techniques and processing processes primarily mass-processed to achieve this \cite{5}. In structural and body parts, the need for light metal has recently increased in the automobile and aerospace industries. As a substitute for steel, the use of aluminium alloys has
satisfied this need[6]. The critical material properties that are very important for industrial applications are strength and formability[7].

Due to the increasing penetration of electric vehicles in emerging nations such as India, Thailand, China, and Indonesia, the Asia Pacific market will see significant growth, thereby positively driving industry growth as shown in Table 1. China is Asia Pacific's largest electric vehicle market. Increasing revenue levels, growing concerns about fuel emissions, and government initiatives to boost electric vehicles’ production will further strengthen China’s electric vehicle market. In India, for instance, the government has launched a program called Faster Adoption of Hybrid and Electric Vehicle Manufacturing (FAME), which will drive India’s demand for electric vehicles[8].

**Table 1.** Asia pacific market size of automotive lightweight materials (https://www.graphicalresearch.com/)

| Year | Market Share(USD) |
|------|-------------------|
| 2017 | 70-80             |
| 2018 | 75-80             |
| 2019 | 80-90             |
| 2020 | 70-80             |
| 2021 | 75-80             |
| 2022 | 80-85             |
| 2023 | 85-90             |
| 2024 | 90-95             |
| 2025 | 95-100            |
| 2026 | 95-100            |

**Figure 1.** Weight distribution percentage of the vehicle(Ford car)

In a recent 2017 survey, the Center for Automotive Research (CAR) reported that the increased use of high-strength steels is projected to peak at about 15 percent of the overall composition of vehicle weight by 2020 as shown in fig 1, before declining steadily to around 5 percent by 2040 as other lightweight materials gain ground. Around the same time, from record highs of 55 % of vehicle weight to about 5%, mild steel content would decrease. UHSS steel and aluminium usage will rise steadily in lightweight materials, especially in safety cage components and components (e.g., frames and rails). The use of
steels of the third generation with improved formability properties can develop considerably [ATG AIV].

Table 2. Asia pacific market size of automotive lightweight materials (ATG AIV)

| Materials     | Today Vehicle | Future Vehicle |
|---------------|---------------|----------------|
| Steel         | 59            | 30             |
| Aluminium     | 9             | 37             |
| Iron          | 8             | 4              |
| Magnesium     | 0             | 4              |
| Plastic       | 9             | 10             |
| Glass         | 3             | 3              |
| other         | 12            | 12             |
| Total weight (kg) | 1711           | 1237           |

Figure 2. Comparison of material usage percentage in today and future vehicle(Ferrari)

For instance as shown in fig 2, Ferrari has produced unusual forms of aluminium, such as strengthening it with ceramics to reduce the weight by an additional 15-20% as shown in table 2. Ferrari prefers aluminium over CFRP because aluminium is more vital and simpler to repair in a crash-aluminium crumples when carbon fibre shatters.

The use of aluminium in cars is gaining momentum as the automobile industry is racing to reduce vehicle weight to conform to the proposed emission requirements. Cars would most likely use a multi-material blend over the long term, mixing different AHSS steel, aluminium alloys, carbon fibre, titanium, plastics, mild steel, and other materials to fulfill the goals of weight, cost, and efficiency. Cars would most likely use a multi-material blend over the long term, mixing different AHSS steel, aluminium alloys, carbon fibre, titanium, plastics, mild steel, and other materials to fulfill the goals of weight, cost, and efficiency[9].

2. METAL FORMING PROCESSES

A wide variety of production methods under which the material is deformed to take the shape of the die plastically. Depending on the type of operation, the equipment used for such deformation is called a die, punch, etc. Metal forming technologies produce structural parts and assemblies in various industries; it
includes automotive, aerospace, and electronics. Metal forming processes encompass multiple activities that shape sheet or tube metal to produce a complex shape component [10].

The goods that we use in our daily lives are human-made, manufactured components obtained from some manufacturing process from some raw material. All these products are made of several small parts that are incorporated into the finished product. For starters, the smartphone we use for contact is composed of several small pieces assembled. It is supposed that a car is an assembly of more than 20000 parts, produced by the different manufacturing process. To meet the necessities of various industries' ever-increasing demands, the manufacturing engineer needs to select the correct type of material and equipment for manufacture operation. The cost of production and energy consumption is minimal [11].

2.1 Classification of metal forming processes

Metal forming is mainly divided into two types as shown in fig3: bulk forming and sheet metal forming. Bulk-forming is achieved using a collection of tools and dies coupled with presses. It is a revolutionary process of deformation that results in massive changes in shape. The area-to-volume surface of the work is relatively minimal. It is usually done in hot working conditions. In Sheet metal forming, primarily applying tensile or compression or shear forces. Working on sheet metals, plates and strips consist mainly of sheet formation. This operation is principally carried out in hydraulic or pneumatic presses[12].

![Figure 3. Classification of metal forming processes](image-url)

2.2 Processing of Lightweight Metals

Forming involves various methods to convert raw material into a required shape. It includes bending extrusion, forging, roll bending and press drawing, etc. Due to increasing environmental concerns and higher performance demands, lightweight design is critical for success, especially in the transport industry and general manufacturing, machine tools, and architecture[13]. If the material is only used in product areas where stresses occur and the material is loaded near yield stress, lightweight structures are acceptable. As a result, such a structure is primarily built for resilience; i.e., it will not collapse. In automotive applications, designs are often engineered for stability, which means they don't flex too
much elastically. Although an airplane wing tip bends several meters until collapse is remarkable yet irrelevant, stiffness is a significant consideration in automobile applications[14].

Only when structures and components can be built and manufactured with lightweight, low-cost, enhanced performance and optimized properties can lightweight construction be successfully implemented. This is only possible if the material's total capacity, the design of load-optimized part geometries, and logical production methods are part of the integration process[15]. The multidisciplinary engineering of lightweight construction is the technology with excellent development dynamics that necessitates a systematic approach to the technological solution to the whole “design-material-manufacturing” system. Manufacturing and, in particular, forming-technology play an important role in this sense. Forming is the most important process for the manufacture of lightweight parts and structures, including advanced design and material characteristics, as a large-scale production technique, primarily for automobile and building applications.[16].

2.2.1 Sheet metal forming process

Forming semi-finished goods and parts into the desired lightweight construction parts would necessitate developing new adapted forming procedures. In semi-finished goods, customized blanks and tailored tubes are typical examples of high strength steels (HSS). To "build for strength" of materials, it is essential to improve the material's strength. Over the last two decades, the steel-industries activities have culminated in developing highly productive steel grades that now provide a wide variety of personalized qualities for any use. The use of HSS sheets causes significant problems, limiting construction options, as high-pressures and the formation of flaws results[17]. The distribution of materials is critical to achieving lightweight parts. The distribution of materials is essential to attain lightweight components. Typical sheet metal techniques, such as deep drawing, hit their physical limits. Hydroforming techniques are a viable technique for the efficient processing of such complex sheet metal components. Compared to traditional deep drawing, the use of hydroforming technologies provides substantial advantages, such as higher drawing ratios, increased geometric precision, and a more desirable scattering of residual stresses[18].

An example here is the manufacture of a bike petrol tank with a hydro mechanical deep drawing, a very complex geometry in which die is replaced by a fluid. Due to the zero-emission regulations, this stainless-steel tank replaces the traditional plastic fuel tank.

| Table 3. Data for plastic and steel tank[18] |
| Tank material | Polyethylene | Stainless steel |
| Wall thickness (mm) | 4.8 | 0.4-0.7 |
| Weight (kg) | 8.9 | 7.2 |
| Capacity(liter) | 71.5 | 74.3 |

The development of such a complex shape was only possible thanks to the extensive use of FEM simulation to optimize the process parameters. Table 3 shows that the stainless steel tank is 20% lighter and 4% more capacity than the plastic tank due to thinner wall thickness. A specific cross-section design of the components that use the materials only provides another opportunity for weight reduction and product property optimization.

The most potent lightweight components are now a content delivery that is load-adapted. Forging or extrusion techniques may be used to achieve a dynamic material distribution in bulk formation. It has been researched and improved the ability to build and transform tailor-rolled-blanks into a lightweight structure using the following process chain as shown in fig 5.
This research concentrated on the flexible rolling manufacturing of stainless steel profile formed structural parts using bending to process semi-finished parts. The successive profile-closing laser welding and the three-roll bending method for bending to the desired target radii[9]. Customized tubes are mainly helpful as flexible semi-finished components for additional shaping by the tube-hydroforming process, as shown in fig 5. Manual hydroforming of curved tubular parts with complex geometries is an excellent method for lightweight construction. On the other hand, workpiece formability is limited by the total amount of extension, which must always begin at the smallest perimeter[20][21].

Tube hydroforming is a manufacturing technique that uses pressurized fluid to mold a portion of a tubular blank to drive it into the die cavity shape. Hydroforming provides a range of advantages over traditional stamping methods, such as improved structural rigidity, aggregation of components, reduction of the associated cost of tooling and operation, enhancement of repeatability of output, and dimensional measurements[22].

2.2.2 Bulk-forming techniques

The most important components of a lightweight space frame conception in automobile, railway, and aerospace design are curved extrusion profiles. For mechanical structure, aerodynamic or design purposes, they are sometimes used. The traditional process for the manufacture of curved profile semi-finished goods includes the extrusion, stretching, and bending of the profiles in sequence[23]. Curved profile extrusion enables lightweight construction. It enables profiles of minimal wall thicknesses to be curved. Besides, curved profile extrusion does not require a cross-section profile bending pattern, which in most cases increases the weight of the part. Finally, curved-profile formability is as strong as that of straight-profile, enabling more processing to provide a lighter design[24].
Sheet metal forming requires various bulk forming methods, as seen in fig. 6, which are classified by tool motion and sheet size variant. The tool may travel in either a transverse or rotational direction, which impacts the forming region's extension.

![Diagram of sheet metal forming methods](image)

**Figure 6.** Different sheet-bulk metal forming processes [23]

Mori used a similar technique when it came to square cups. Deep-drawing, the square cup from a conventional blank of even width, standard blank of even width, reduces each corner's thickness, causing a rupture in this region [25]. As a result, it was proposed that a customized blank with confined thickening be used. First, a sheet with two hat-shaped inclined sections. It is then compacted using flat dies, with the two inclined sections kept from thickening on both sides. The same compression and bending process are repetitive after a rectilinear revolution of the sheet to achieve a restricted thickening right-angled direction. The constrained drawing altitude of the trophy was raised from 21.3 mm for uniform blanks to 28.3 mm for deep drawing of customized blanks made of 1.5 mm hardened pure aluminium. [21].

Forming processes are well developed and recognized for the best quality and minimal quantities of raw-material waste at room temperature. Such procedures place a comparatively small ecofriendly problem while improving the work pieces' strength by hardening the pressure. The formation of bulk sheet metal forming as a new class of production processes is one possible response to the increasing demands of usable incorporation into lightweight parts made of high-strength steel through manufacturing processes [26][27]. The Viscous pressure forming was patented in the form of a patent in 1992, and the use of viscous-materials as a force-transferring medium varies from traditional deep-drawing processes. In the VPF phase, higher pressure from the viscous medium is applied to one side of a sheet metal blank to replace rigid punches. Backpressure is applied at the same time to improve formability. Complex-shaped components with good surface quality and high dimensional exactness can be produced using the viscous-medium forming technique while reducing leakage. Manufacturing high-strength parts and extra light metals that are difficult to shape using conventional sheet metal shaping techniques are also advantages of the VPF process. [28].
The innovative Solid Granular Medium Forming (SGMF) technology addresses hydroforming disadvantages, such as leakage and low heat resistance. A granular medium replaces water, oil, or viscous ingredients as the force-transferring medium in this method. Since most room-temperature fluids are only stable at about 350 °C, using a solid granular medium allows for higher temperatures. It can fully eliminate the risk of leakage [29]. In addition, the non-uniform distribution of solid granules' internal pressure will greatly improve the operation's formability. The interaction of the solid granular medium with the sheet metal area can also significantly minimize the workpiece's thickness [22].

To achieve a lightweight architecture of metal parts, lightweight systems must be implemented. The basic principle of lightweight product design is that it is only used in areas where it is required. For this reason, additional material is added to highly loaded part regions while the material is extracted from low-load areas. Assuming the use of invariant components, an adjustment in the part's geometry results in a weight reduction.[30][31]. This relation between load adaptation and weight reduction is seen in the automobile industry, for example. Car bodies have an amount of opportunity for weight reduction. Following hot extrusion, a mechanically processing technique was developed to change the profile geometry locally to meet local specifications. To integrate electromagnetic formation in the extrusion processes and to reduce the workpiece cross-section nearby, a tool coil for compression was mounted behind the die exit and coaxial to the extrudate.[32].

Single-point incremental sheet metal forming is a versatile, revolutionary sheet metal forming technology focused on layered manufacturing concepts. It converts complex geometry data into a set of 2D layer parameters. It then performs layer by layer plastic deformation using computer numerically regulated movements of a spherical forming method to produce complex-shaped sections. Due to rapidly changing customer demands, metal forming versatility is more important than ever. It paves the way for better management of uncertainties in metal forming process production and implementation[33]. Although versatility has been sought from different perspectives in terms of machines, materials, processes, working environments, properties, etc., a detailed examination of the definition was conducted to address manufacturing competitiveness issues and emerging challenges in the manufacturing setting[34].

The detailed view of the various method of forming process for lightweight materials and its application as show in table 4.

| Author                          | Material used                              | Process                          | Application                     |
|---------------------------------|--------------------------------------------|----------------------------------|---------------------------------|
| Dong kyu kim et. al. [35], H. Karbasian et al.[36] | 22mnB5 steel, HSS | Hot stamping                     | Aerospace and automotive applications |
| Serkan Toros et al. [37]        | Al–mg alloys                               | Warm forming                     | Automobile industry.            |
| P. J bolt et al. [38]           | Copper, aluminum, low carbon steel         | Hydroforming (oil as pressurizing medium) | Automotive appliance            |
| Limb et al. [28]                | Plastic-magnesium hybrids                  | Combination of deep-drawing & back-molding | Noise reduction purposes        |
| Fuchizawa et al. [39]           | Steel, aluminum, and copper                | Situ hybridization               | The automotive industry, electrical connection parts |
| M. Ahmetoglu, Hopmann et al. [7]|                                            |                                  |                                 |
| Napierala et al. [29]           |                                            |                                  |                                 |
| Author | Material used | Process | Application |
|--------|---------------|---------|-------------|
| Gallus et al., Hermes et al., Grzancic et al. [32], Staupendahl et al. | Titanium | Incremental tube forming | Medical |
| Bai, Y., Dodd, et al. | Steel, aluminum, and copper Advanced high-strength steels | Incremental profile forming Adiabatic Blanking | Automotive industry, |
| Valery Rudnev et al.[20] | Aluminum and copper | In situ inductive heating and progressive | Electrical connection parts |
| Miller, w.k. et al.[6] Mennecart, T., et al.[21] | Metal–polymer-metal | Deep-drawing process & resin transfer molding | Automotive industry, |
| Napierala O. et al. [40] | Multi-material components (steel-aluminium pairing) | Simultaneous deep Drawing and cold forging | Aeronautical, aerospace, defense, and automotive sectors |
| Sieczkarek, P. et al. [41] | Steel, aluminum | Incremental sheet-bulk metal forming. | Novel Five-axis forming press |
| Müller, M., Gies, S., T, et al.[14] | Hybrid sheet metal components | Die-less hydroforming Of profiles | Aeronautical |
| D. Pieronek et al., R. Neugebauer et al.[42] | Metal–polymer composite sheets | Sheet metal processing - FE models | Acoustic application |
| M.S. Niazi et al. [27] | Aluminum sheet alloys | Hot die forming - flat | Transport applications |
| Heggemann T, et al. [43] | Fiber metal laminates | Deep drawing | Automotive lightweight structures |
| Kahrimanidis et al. [44] Merklein et. al. Geiger, M. | Aluminum | Tailor heat treated blanks (THTB) | Automotive sector |
| M Tisza, et al. [4] Herrera Ramirez, et al.[5] | Steel, aluminum alloys Aluminum alloys, magnesium, and titanium Titanium | Sheet metal forming Unconventional techniques Plate forging | Automotive parts Aeronautical, aerospace, defense, and automotive sectors |
| Z.g. Wang, et al[45], | Carbon steel (s35c) | | Automobile part |
| Liewald, Mathias et. al. [46] | Hybrid materials, magnesium and aluminium alloys Hybrid components like fiber–metal, polymer-metal, and metal-metal composites | Sheet metal forming Deep drawing or combined forming processes | Electro mobility Automotive components |
The integration of additive manufacturing (AM) and shaping technologies is a modern concept for producing lightweight components. Low process efficiency currently exists in additive manufacturing of highly complex parts with interconnected features, such as cooling channels, sensors, or connector components, due to short manufacturing cycles and inefficient use of construct chamber volumes during the AM process [48].

Rosenthal et al. suggested a new approach to solving this problem that incorporates the benefits of additive manufacturing and shaping technology. The resulting shaping of additively manufactured components allows for the virtual fabrication of fat sheets with a central structure and combined functions stacked in the built chamber. On the device lightweight construction level, shape-memory MMCs are an innovative method to manufacturing components. In the field of metal, many scopes are there for research work based on today’s world expectation for material processing. Fig 7 shows the research gap flow chart in some of the fields like automotive and medical application.

![Figure 7. Identification of research gap](image)

3. CONCLUSIONS

The improvement of new procedures is adapted by arranging inventive preparing techniques for molding new kinds of materials, principally in the car and airplane ventures. The need for modern and creative processes to support lightweight construction solutions has been identified. The lightweight architecture has been divided into three categories: device, structure, and content. The lightweight machine architecture can be seen as a systematic approach that considers the whole vehicle. Structural lightweight architecture is a subcategory of lightweight device design that takes into account component-level considerations. Lightweight material design, a subset of structural lightweight design, is the most basic lightweight design level. This paper's layout is based on this classification, and it shows innovative processes at each point, revealing new light architecture possibilities.
Weight reduction is achieved in lightweight material design by using lighter materials with specific properties. High-strength steels, aluminium or magnesium alloys, and composite materials are examples of this. The processes described in this paper are thermally supported processes such as press hardening. Complex components with extremely high strength properties can be created by shaping and heat treating them simultaneously. Also, adiabatic shear cutting is used to demonstrate the post-treatment method for hardened steels. This method allows for a significant and concentrated rise in temperature because of the high local deformation rate, lowering the necessary cutting power. Due to the need for lightweight materials, the sheet forming process has undergone significant changes over the last two decades. While there are many process parameters in the sheet forming process, the most important ones are blank holder force, cavity pressure, punch force, and temperature, all taken into account in this paper. Also, minor changes in these parameters have a significant impact on the formability process. Flow stresses affect the formability of any material, which are influenced by temperature and strain rate. The loading paths and punch forces can be adjusted to regulate the strain rate. Even though many researchers have used various techniques to study the process parameters, the warm hydroforming process still has many promises. More attention must be paid to this field to achieve potential advances in automotive applications.
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