Proceedings of the 2023 International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/12/20230337

A review of metal-to-plastic joinery in automotive manufacturing

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Abstract: Reducing weight and improving energy efficiency are key design goals in the automotive industry，In order to reduce the weight of the car body, engineers often use plastics in the parts of the car that require less strength. However, due to the difference in material properties, when using plastics to connect steel frames, there are disadvantages such as small interface area, large number of interfaces, and poor reliability of plastics, which may have a great impact on the safety of the car. Therefore, these plastic parts Joinery to the steel frame of the car needs careful consideration. Various methods, such as welding, bolt and nut connection, riveting, and crimping, were considered to connect plastic and metal in automobiles. This article first introduces the specific implementation of the joinery method between plastic and metal, and investigates their process difficulty, interface strength, vibration resistance and the least negligible cost. Discusses where these processes are suitable for use in the car, where they are currently used, and explores potential future developments.

Keywords: welding, crimping, rivet, bolts and nuts.

1. Introduction

In this modern day of automotive design, more and more automobiles incorporate advanced materials such as high-performance polymer. However, the advancement of material science, the chassis frame of most modern mass produced automotive still makes heavy use of metals such as aluminum alloys and steel due to their strength, however this gives rise to a variety of problems with joining high performance polymers reliably to the metal chassis frame of the automobile. Because of the substantial variations in polymer and steel/aluminum properties such as density, melting point, specific heat capacity, thermal conductivity, coefficient of linear expansion, and elastic modulus. Due to this, it is vital to understand the performance of different joining methods on their ability to hold under realistic conditions, as a failure would most likely massively increase the chance of catastrophic accidents.

Group technology is a kind of energy-saving and efficient green environmental protection Method of joining. In modern society, cars are used extensively to meet the requirements of transportation. It is

DOI: 10.54254/2755-2721/12/20230337

logically necessary to study the most efficient joinery method arrangement to construct cars. In the contemporary joinery process stage, the main joinery methods are welding, crimping and snap fit, rivet, bolts and nuts. In these joinery methods, bolts can be used for cylinder heads and cylinder blocks. Riveting is probably the most suitable means for aluminum alloy and steel in the automobile, while welding is most suitable for doors, baseboards and body components. Each of these different methods has advantages and disadvantages in application, because their theories and principles are quite different.

Several papers have been published on the topic of connecting plastics to metals. One commonly studied method is welding. Laser can directly weld metal and plastic. This technology has been proven to be very effective in manufacturing high-strength joints, but it can only be applied to thermoplastics. Ultrasonic welding of plastics and metals has also been shown to produce high strength joints with short welding times. However, it can only be used for welding small parts. Several studies have shown that the friction welding technique also produces good results. Lap joints with high shear strength have been obtained over a wide range of welding parameters. Snap fits are a kind of quick connector commonly used to connect metal and plastic. It usually consists of two parts: one end is fixed on the metal part, and the other end is fixed on the plastic part, and it is firmly connected by elastic force. Rivets and bolts-nut connections are very commonly used processes in the automotive industry, and there are a lot of researches on them.

This paper is structured into three sections. The first section, the introduction, provides an overview of the research background and introduces the various connection methods that will be discussed in this paper. The subsequent section focuses on a comparison of the identified connection methods with respect to manufacturing complexity, joint strength, vibration resistance, and corrosion resistance. Furthermore, the paper examines the extent to which these connection methods contribute to the lightweighting of vehicles in order to achieve fuel economic benefits. Finally, the paper concludes by identifying the most suitable connection method for different parts of the vehicles based on the aforementioned criteria.

2. Joinery mechanism

2.1. Welding

2.1.1. Laser welding. Generally, welding is used to connect two similar and thus compatible materials, like steel-steel, aluminum-aluminum, PE-PE, PC-PC, etc. However, welding between metal and plastic can be challenging because of their varying properties and the different techniques required to join them. Generally speaking, there are three methods to realize the welding of metal and plastic, which are laser welding, ultrasonic welding and friction welding.

Through-transmission laser welding, developed by Katayama et al., offers a precise and controlled process for joining two dissimilar materials, as shown in Figure 1. In this method, polyethylene terephthalate (PET) plastic and 304 stainless steels are first superimposed, and then irradiated with a laser to melt the plastic and fill the gap between the metal, creating a strong bond. For instance, joints created between a Type 304 stainless steel plate and a 30 mm wide PET plastic sheet had tensile shear loads of approximately 3000 N [1]. Similar laser welding studies have been conducted with other plastics and metals, such as carbon fiber reinforced plastic to aluminum alloy [2], carbon fiber reinforced plastic to zinc-coated steel [3], pa66 nylon composite material and 304 stainless steel [4], and PMMA Plastic and 304 Austenitic Stainless Steel [5].

The effectiveness of this technology in manufacturing high-strength joinery has been well established, as it can significantly reduce joint weight and increase design flexibility [6]. Additionally, the narrow and deep weld produced by this technology reduces oxide formation, making it a suitable choice for applications in which corrosion is a concern. To further mitigate the risk of corrosion, the welding process is often performed in an inert gas environment. The welded joints also demonstrate good airtightness [1], making this technology a suitable option for use in automotive pipelines and plastic-

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metal connections of car lights. However, laser welding has some drawbacks, such as its limited ability to weld relatively thin materials and the requirement for high surface quality of materials.

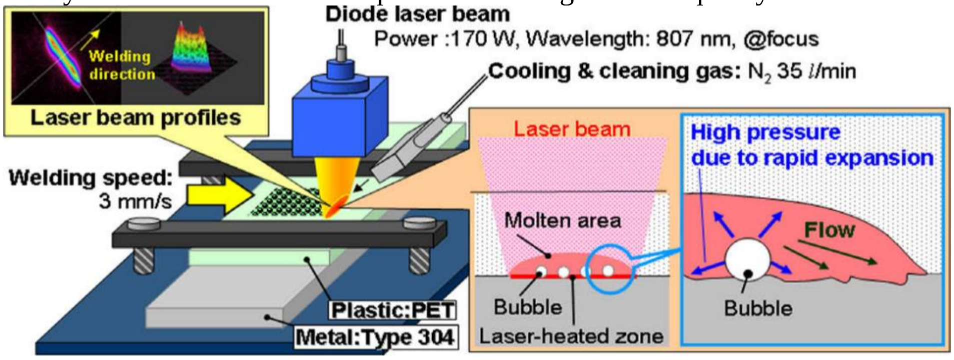

Figure 1. Schematic diagram of laser welding PET to 304 stainless steel.[1]

2.1.2. Ultrasonic welding. Ultrasonic welding is a versatile method for joining metal and plastic by using ultrasonic vibrations to generate heat at the material interface, which melts the plastic and forms a strong bond with the metal. Tsujino et al. discovered a new method for welding thick and large metal parts, and they tested the welding frequency parameters for different material sizes [7]. Balle et al. successfully welded aluminum plate and carbon fiber reinforced polymer (CFRP) in just 5 seconds, achieving a joint strength of 30 MPa [8][9][10]. Tang et al. directly connected 3D printed ABS-M30i with SLM-fabricated metal cellular structures by ultrasonic welding, achieving a shear strength of 17.7 MPa and a normal tensile strength of 15.2 MPa, which represents 55% and 48% of the ultimate tensile strength of ABS-M30i, respectively [11].

Ultrasonic welding is ideal for improving production efficiency in the automotive industry due to its ability to achieve high strength quickly. However, the difficulty of controlling welding conditions can lead to issues such as insufficient welding strength and cracks. This process is commonly used in automotive interiors, including sockets, handles, grips, car skirts, and front and rear bumpers.

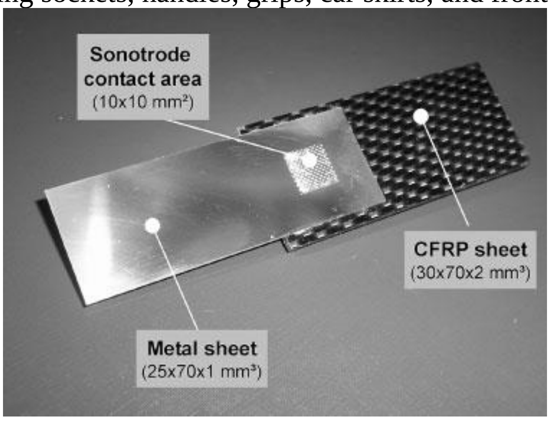

Figure 2. Metal and CFRP welding points[8].

2.1.3. Friction welding. Friction welding utilizes frictional heating to tightly join metals and thermoplastics. Yusof et al. investigated the connection parameters and mechanical properties of aluminum alloy (A5052) and polyethylene terephthalate (PET) using friction spot joining (FSJ) [12]. Liu et al. studied the use of friction lap welding (FLW) on aluminum alloy AA6061 and MC Nylon-6, and found that the highest nominal shear strength (NSS) of 7.8MPa was achieved at a welding speed of 200mm/min and a rotational speed of 3000rpm, as shown in Figure 3 [13].

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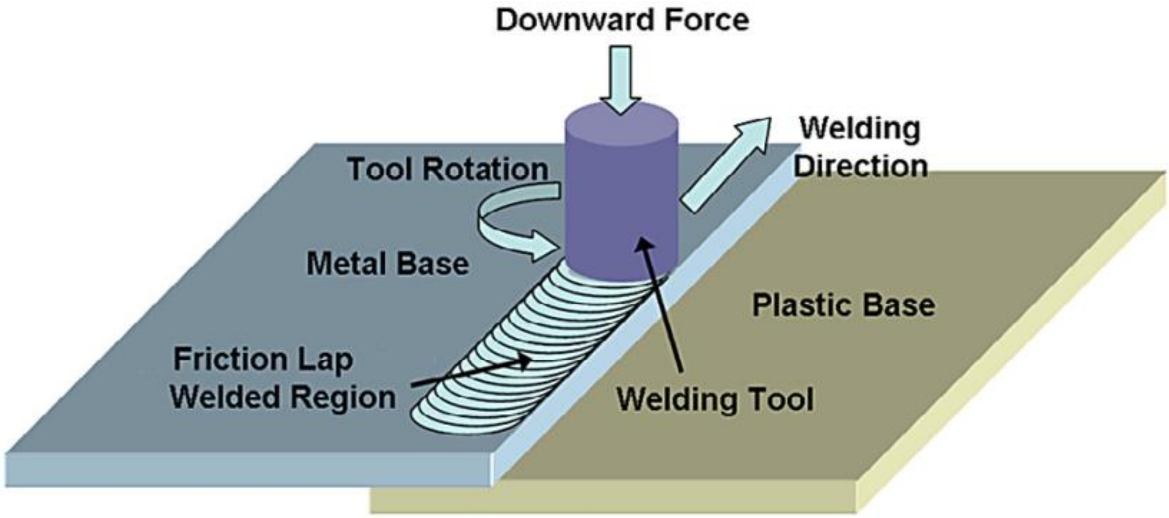

Figure 3. Schematic diagram of friction welding[13]

The advantage of friction welding is that the joint has high strength, can withstand large loads and vibrations, does not need to add solder to avoid impurities affecting the performance of the joint, and has low production costs. The disadvantage is that the applicability is very limited, and only a few material combinations can be used. Friction welding metals and plastics is commonly used in the automotive sector to join parts such as hoods, doors, chassis, dashboards and fuel systems.

In conclusion, Laser welding uses a high-energy beam to precisely fuse materials, making it ideal for small or delicate parts and high-precision applications in the automotive industry. Ultrasonic welding creates a strong and consistent weld without external heat, making it suitable for temperature-sensitive materials. It is commonly used for fabricating instrument panels, lighting components, and bumpers. Friction welding joins materials through friction and heat, producing high-strength welds with minimal distortion. It is used for welding engine components, axles, crankshafts, and suspension components in the automotive industry. Each technique has unique advantages and is used based on material requirements and specific applications.

2.2. Crimping and snap fits

2.2.1. Definition. Nickname: snap fits; Buckle fixed mechanism; Buckle fit, commonly known as buckle fit, is a connection type of component, complete buckle structure needs positioning, locking, strengthening and other parts. There are many ways to connect the buckle, such as circular buckle, rotary buckle, cantilever buckle body attachment design is divided into two layers, the feature layer and the attachment layer. Studies of various integral attachment clasp features using hierarchical classification schemes to enumerate design options [14] [15] show that this classification of features leads to a systematic approach to the design of these integral features [16].

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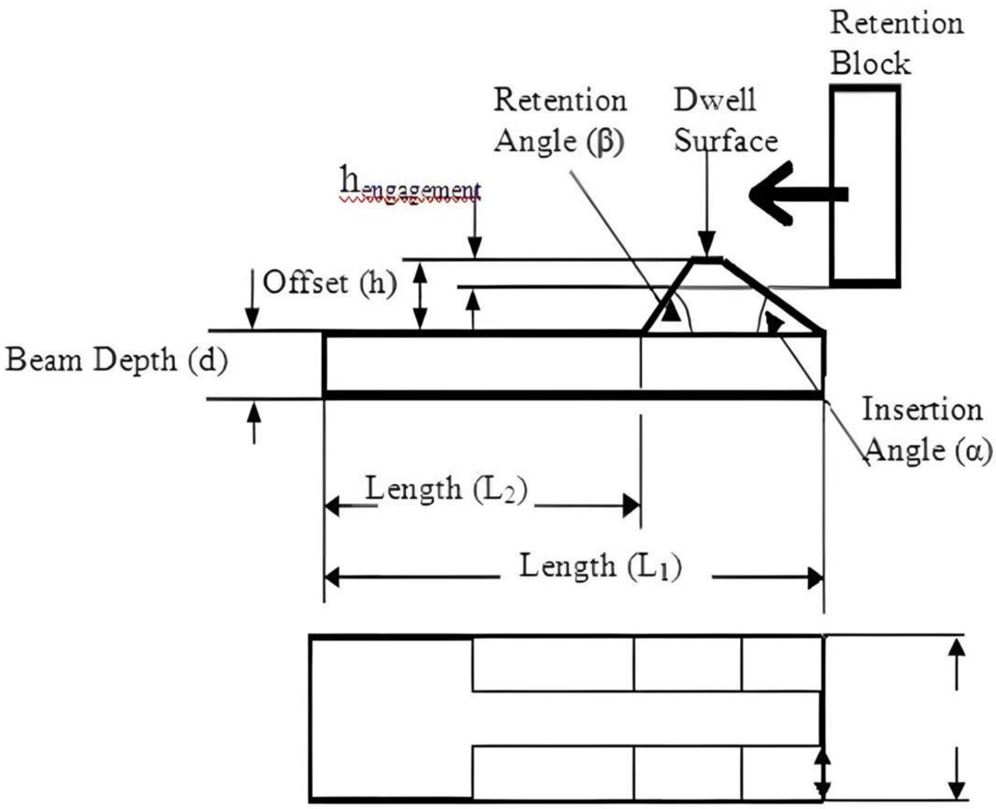

Figure 4. Front view and top view of a typical snap-fit member.

2.2.2. Advantages and disadvantages. This part is usually simple in structure, and can often be mass-produced with little production cost and attached to the structure. Compared with most connection methods, the buckle connection has higher deformability and higher degree of freedom.

However, the exceptional diversity of part geometry and integral snap-fit features has made it seem that design possibilities may be unlimited. And the buckle and continuous metal members compared to poor stability, use alone is difficult to bear the supporting stress; And in order to improve the strength of the buckle connection, it is usually applied with glue. However, this collocation method will make the component as a whole appear stiff, and the durability is insufficient. And this kind of connection we can exploit the advantages and avoid the disadvantages, so as to reduce the quality of a part of the vehicle connection (such as the automobile suspension arm), so as to achieve the purpose of improving the efficiency of the fuel engine.

2.2.3. Application scenarios. Bayonet fit is widely used to connect plastic parts by integral accessories. Clasp fit has been a popular choice for plastic parts for over 30 years, during which time a wide range of clasp fit topologies have been developed and used, with workers often choosing the clasp fit topologies they are most familiar with.

1) Used to build Octagonal mesh. Its diameter thickness direction is consistent with the rigid (crystal) direction of the structure. A single thickness Ti-6Al-4V alloy sheet [17] was used as the starting material for the character assembly and the lattice was subsequently brazed in vacuum to join the points.

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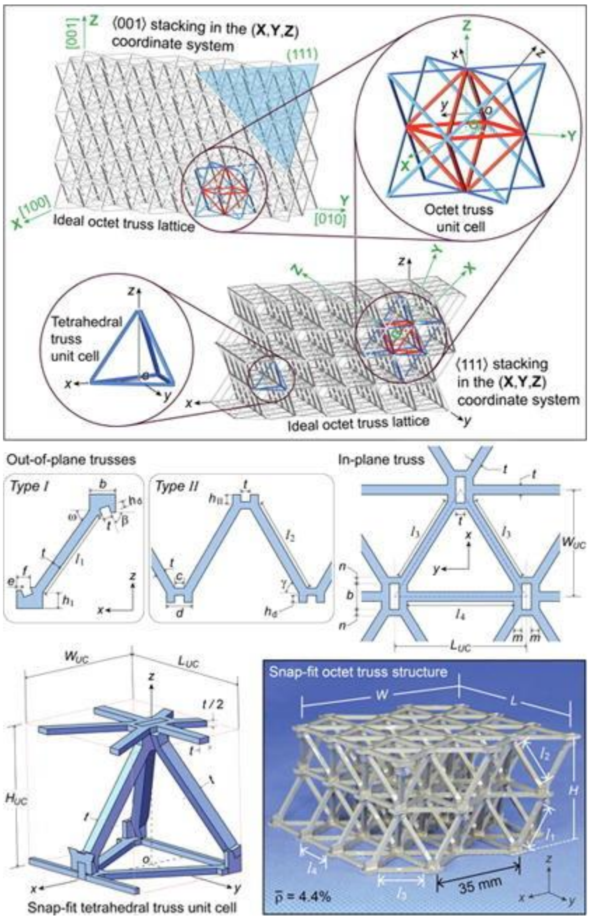

Figure 5. A snap-fit method has been designed to establish octet-truss lattice.

2) Ulti-stability of the metamaterial was achieved using snap-type elements. At the same time, the modular design was realized by decoupling the mechanical response of the parallel assembly units. The designed metamaterial showed good impact resistance and energy absorption ability in the demonstration experiment [18].

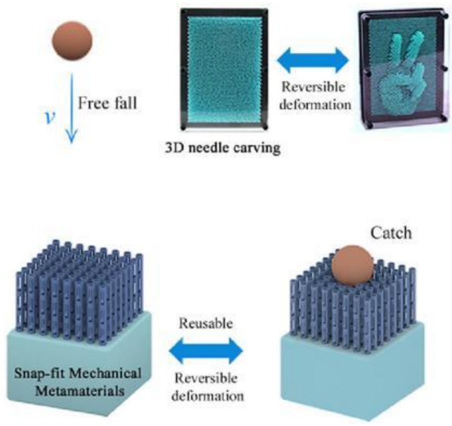

Figure 6. Design strategy of snap-fit mechanical metamaterials (SMMs)

2.3. *Rivet*

The rivet connection method is a widely recognized and established approach for joining materials in various applications. This technique involves the use of cylindrical metallic fasteners, commonly

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referred to as rivets, which are inserted into properly aligned holes in the materials that require joining. The deformation process is performed at the end of the rivet utilizing a specialized tool known as a rivet gun, which creates a mechanical lock between the materials. The 3D cross section model of rivet and sheets is shown in Figure 7 [24] In particular, the rivet connection method is widely acknowledged as an indispensable technique in the automotive industry, specifically for the assembly of body panels, frames, and brackets. In the formal paragraphs, the properties of rivet connection will be discussed. Based on the manufacturing complexity, joint strength, vibration resistance.

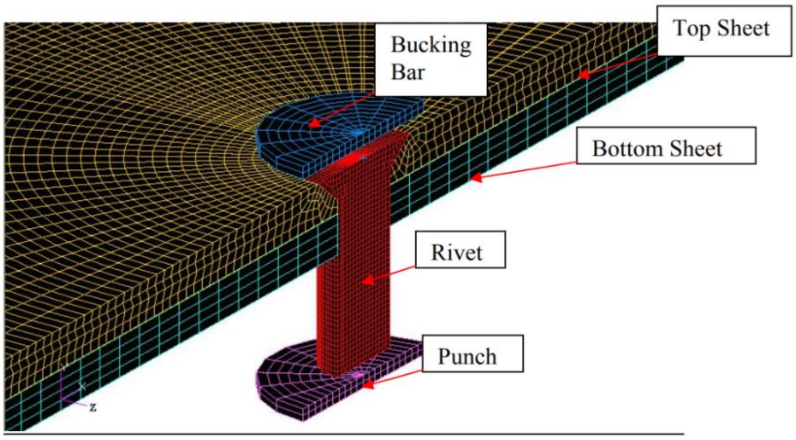

Figure 7. 3D cross section model of rivets and sheets.

Rivet manufacturing is an established process that involves either stamping or forging the rivet from a metal or alloy. In comparison to other joining techniques such as welding, this process is considered less complex. The automotive industry relies heavily on rivets due to their ease of fabrication and installation. However, the quality of the resulting riveted joint is largely influenced by the variation in rivet installation. In this regard, S. Hossein Cheraghi [24] elucidates the significance of clear and controllable parameters of rivets. Cheraghi then utilized finite element modeling to gather data and ultimately determined the maximum allowable tolerances on drilled holes, with a range of force values, while taking into account variability in rivet diameter, rivet length, and countersunk depth. The study concluded that various riveting process parameters, such as squeeze force, rivet length, rivet diameter tolerance, hole countersunk depth, and hole diameter tolerance, have a significant impact on the quality of formed rivets. The reduction of countersunk depth is recommended for ensuring higher rivet quality with reduced gap and lower required squeeze force.

The body panels of an automobile are frequently composed of sheet metal or composite materials that demand a joining method that can generate a sturdy and long-lasting bond. In this regard, rivets represent a judicious choice. The joint strength of riveted joints is widely recognized for its superior properties, especially in lap joints where the load is distributed evenly between the sheets being joined. Moreover, rivets exhibit remarkable durability, rendering them a dependable choice for long-term applications. When properly installed, rivets can facilitate a robust and long-lasting connection that can withstand the stresses and loads encountered by vehicles during operation. To improve the joint strength of the rivets, we can use different materials to produce them. The study by Benedikt Uhe, Clara-Maria Kuball, Marion Merklein, and Gerson Meschut [25] evaluated the potential of using high nitrogen steel rivets as an alternative to conventional rivets in joining sheet metal and composite materials. Rivets are known for their superior joint strength and durability, making them a popular choice for automotive applications. The results showed that the joint strength achieved using high nitrogen steel rivets was comparable to that of conventional rivets in material combination 1, which used high-strength steel on both sides. However, for material combination 2, which used aluminum alloy on one side and high-strength steel on the other, the joint strength was lower compared to conventional rivets. The study also identified deviations in the target geometry and the actual geometry of the manufactured rivets, resulting

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in reduced forming stroke and a smaller head diameter of the high nitrogen steel rivets, which led to lower joint strength. Overall, the study confirmed the potential of high nitrogen steel rivets as a viable alternative to conventional rivets, but further research is needed to improve joint strength and examine corrosion resistance.

The utilization of rivet connections has become increasingly prevalent in the automotive industry, as they offer significant advantages over other joining methods, particularly with respect to their exceptional ability to withstand vibration. Their durability and ability to minimize the likelihood of component failure due to vibration make them a popular choice for use in vehicle frames and the assembly of brackets. Nonetheless, it is important to note that rivet joints can be vulnerable to fatigue failure over time under cyclic loads, which can lead to the initiation and propagation of cracks in the rivet and/or surrounding material. In light of this, researchers Chun-yu Zhang, Rui-bin Gou, Min Yu, Ya-jing Zhang, Yin-hu Qiao, and Shu-ping Fang [26] conducted a series of tensile and fatigue tests on various shear and tensile SPR joints of cast aluminum alloy AlSi10MgMn and three different types of dual-phase high-strength steel sheets. The aim was to examine the impacts of different overlapping types on the mechanical and fatigue performances of the joints. The researchers assessed the maximum tensile load and F-N curve of each SPR joint to characterize its mechanical and fatigue properties, while also analyzing the effects of the steel sheet thickness and strength on the behavior of both types of joints. The findings showed that shear SPR joints outperformed tensile SPR joints in both mechanical and fatigue tests, likely due to better performance. The thickness and strength of the sheet material were also crucial factors in determining the behavior of both types of joints, influencing factors such as fracture location, joint strength, and sensitivity to fatigue loading. The primary failure mode observed in the study was fatigue failure in the sheet material, with the location of the crack varying according to sheet thickness and strength.

In the context of the automotive industry, the corrosion resistance of riveted joints is a critical factor for ensuring their durability and reliability, which ultimately impacts the overall performance of vehicles. Although rivet connections typically exhibit high levels of corrosion resistance, the susceptibility to corrosion can be significantly influenced by the type of material used and the environmental conditions. Hence, it is imperative to undertake a comprehensive analysis of the causes and effects of corrosion and implement effective mitigation strategies. Recent research by Hua Qian Ang [27] highlights common types of corrosion that occur in SPR joints, including galvanic, crevice, and filiform corrosion, and proposes methods to reduce the risk of corrosion. For instance, using rivets made of the same material as the sheets being joined and applying coating can minimize galvanic corrosion. Optimization of the SPR process can minimize crevice corrosion, while applying a protective coating with low water vapor transmission rates can minimize filiform corrosion. Sheet thinning is a common effect of corrosion in SPR joints, and using thicker sheets is recommended for better mechanical stability. Moreover, the application of clinching with adhesive bonding can improve the mechanical performance and corrosion resistance of the joints. To this end, L. Calabrese, G. Galtieri, C. Borsellino, G. Di Bella, and E. Proverbio [28] conducted a salt spray fog test on rivets with adhesive bonding and compared them with those without adhesive interlayers. The results show that the presence of aluminum oxide in the overlapping area reduces the interlocking force between sheets, leading to their detachment at a lower load in joints without adhesive interlayers. In contrast, the adhesive interlayer in hybrid joints provides effective protection against corrosion by preventing the formation of an oxide layer in the overlapping area. This is evidenced by the absence of an oxide layer in the overlapping area in St1.5/Al1 hybrid joints after five weeks of ageing, as shown in Figure 8b.

DOI: 10.54254/2755-2721/12/20230337

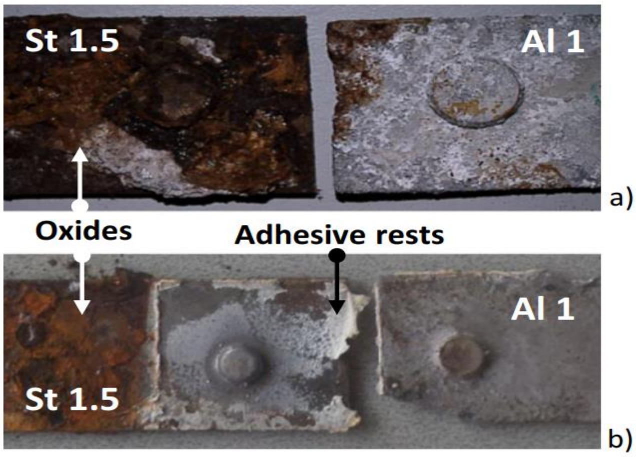

Figure 8. Comparison of failure surface of the St1.5/Al1 joints at aging 5 weeks, a without adhesive and b with adhesive.

In conclusion, rivet connections are widely used in the automotive industry for the assembly of body panels, frames, and brackets due to their ease of fabrication, simple installation, and resistance to vibrations. Ongoing research efforts to enhance the durability and reliability of rivet connections can inform the development of robust designs for different parts of vehicles.

2.4. Bolts and nuts

The bolted joint is one of the most often used parts in machine and building design. It comprises of a male threaded attachment (like a bolt) holding other components together, and a female screw thread that is the same size as the male thread holding the male thread in place. Tension joints and shear joints are the two main types of bolted joint designs (see figure 9). By carefully regulating the stiffness of the joint and the bolt, a tension joint's bolt and clamped components are made to work together to transmit an applied tension force through the joint via the clamped parts. Any external tension forces working to separate the joint should never be able to surpass the clamp load, hence the joint should be constructed accordingly. In order to transfer the applied force in the shear of the bolt shank, the second type of bolted joint depends on the bolt's shear strength. Only incidental tension stresses are applied to such a joint. Even while preloading is still done, joint flexibility is not as heavily considered as it is when loads are transferred through the joint under tension. different shear joints of this sort rely on different methods to maintain the integrity of the bolt rather than preloading the bolt since they are designed to allow joint movement around the bolted joint.

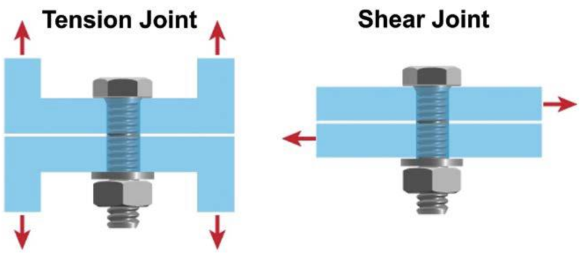

Figure 9. A visual representation of both types of joints.

Due to its simplicity of use, as it only matches a screw or bolt with a threaded counterpart, such as a nut or tapped hole, and operates with a straightforward torque instrument. This sets it apart from rival technologies: Bonding is a method that depends on the operator's capacity to assess its suitability and quality. Press tools are necessary for this building, which makes things more difficult. Failure is conceivable when welding because it calls for complicated equipment and a skilled welder. Advantages of a bolted joints are that first, a proper clamping force on the joint parts of the shear joint prevents relative motion of those parts and inducing wear of those parts, both of which could lead to the formation of fatigue cracks. Also, because it is not subjected to the entire amplitude of the load when under cyclic tension loads, the fastener's fatigue life is prolonged; nonetheless, if the material has an endurance limit, the fastener's lifespan is almost limitless and If the external tension loads on a joint do not exceed the clamp load, the fastener is not moved in a way that would cause it to loosen, negating the need for locking mechanisms.

2.4.1. Types of failure. Engineers must select the material or tool that will best complete a task at each step of a project's planning and construction. The basic form of the structure usually dictates the kinds of joints that will be used. The design engineer must, however, also consider implementation time, cost, and overall effectiveness. Fastened connections can have several drawbacks depending on these added circumstances.

Bolted connections may malfunction because of an issue with the connection itself or with the components connecting it. Since they are insignificant, we should give the others our full attention. A few failures can arise, such as tension failure of the plate happens when the fasteners are stronger than the connected plates. Also, low-strength screw bearing failure happens when high-strength plates are attached to them. In this failure, the bolt is crushed across half of its circumference as the connecting plates move as a result of applied force. Another important failure is a fastener that fails through shear is torn or sliced along the shear contact. There could be one, two, or more stress surfaces depending on the joints. Depending on the quantity of shear lines, a bolt may break under single, double, or other shear conditions. Shear stresses are created when applied pressures cause surfaces to slide. Another common failure is when low-strength plates relate to high-strength bolts, bearing failure of the plate happens. The bearing issue could get worse if there is a nearby screw or an edge that faces the weight direction. When shear forces are applied to regular bolts, the bolts shift and meet the plates. The plate may be crushed if the attachment material is stronger than the plate material. Lastly plate splitting failure happens when high-strength fasteners are used to connect high-strength plates. It's been a while since I've been here. Bolts may occasionally need to be positioned closer together than required, which might cause plates to break away. A piece of material within the bolted region consequently splits from the adjacent area. A few more important things to consider are that bolted joints have lower axial tensile strength. The probability of the bolted joint breaking rises in locations that experience heavy axial pressures. Also, that there is a considerable vibration effect from the bolted connection. Thus, the joint's strength is decreased by the moving weight.

As bolted joint structures are prone to fastener loosening due to environmental and practical vibrations, which can compromise structural integrity. As bolted joints are usually used in the connection between the wheel and the axial and is also extensively used the vehicle engines. Such a failure in those locations would be fatal to the occupants, however there are a few different methods used to detect these loosened joints before failure occurs. Huang, Liu, Hao and Deng [29] did a excellent analysis on this matter. They studied three main groups of detection methods which are sensor based, percussion based and vision based. They have concluded that while several loosening detection methods have been created and improved in recent years because to advancements in signal processing, sensor, and computer technology, certain issues still need to be addressed. To begin with, wired data transfer and electricity are needed for the sensors used to detect preload directly. As a result, measuring the preload of threaded fasteners in operation in real time is difficult for these instruments. As a result, their actual uses are limited. Most instruments can detect tightening only before or after a machine is turned on or off. However, sensor based ultrasonic detection by far have the best accuracy, but is not as practical as other types of methods. Recently Zhang, Shen, Li and Qu[30] conducted a analysis on the potential applications of sub-harmonic resonance for detection purposes, as the method improves accuracy while is easy to conduct on field, eliminating the issues presented earlier by Huang.

2.4.2. Locknuts. Locking devices prohibit the undoing of bolted connections. They are essential in machines where bolted joints' security is critical and when vibration or joint movement will lead to a reduction in clamp weight and joint failure. for example, those used in automotive applications. The

DOI: 10.54254/2755-2721/12/20230337

device known as a locknut (See figure 10), which is a fastener that doesn't undo when subjected to vibration and pressure, is the most popular sort of locking mechanism. There is a part of prevailing torque screws that elastically deforms to provide a securing action. There are locknuts that rotate freely, which has the benefit of needing less force to seat them. There as been some recent advances in locknuts such as a new type of locknut based on shape memory alloy by Li, Du, Sun and Shen[31], they described a new type of locknut based on Fe-based SMA. They showed that the iron-based shape memory alloy smart nut works with the bolt without altering the original nut's structural size, which not only significantly boosts the self-locking friction torque and achieves the goal of preventing breaking and loosening but also makes processing easier and allows for reuse.

According to a study by Chen, Chang, and Lee[32] on the impact of corrosion and continual vibration on a bolted joint with a locknut, joints that are constantly vibrating and exposed to the weather would ultimately come loose even with locknuts. It was discovered that the degree of rust reduced the locknut's axial force ratio and anti-loosening ratio. After dynamic testing, the locknut's anti-loosening ratio decreased by 23.4% after a 4-hour soaking in 5% NaCl solution. However, moderate uniform corrosion holes could serve as local lubricant stores with corrosion therapy to improve lubrication between contact surfaces. As a result, the tightening tension needed to produce the specified axial force was almost identical to that of the locknut without corrosion.

3. Where snap fits is already used in the automotive space

3.1. Application background and current situation of hub Snaps at home and abroad

Nowadays, the development trend of the world automobile industry gradually draws closer to the lightweight, the reduction of automobile fuel consumption and emissions can achieve this goal, so the lightweight body structure comes into being, and the fixed part of the hub can be used to achieve the purpose of lightweight.

Chen Yan [19] from Jiangnan University studied the buckle connection structure of Pos machine, discussed and analyzed in detail the selection of key dimensions and the size of assembly force, and finally developed an excellent design module based on VC++ and Pro/Toolkit module development tools, which simplified the buckle design to a great extent. It greatly improves the efficiency of the actual modeling output applied to the production.

Yu Haihua from Nanjing University of Science and Technology selected the topic of cantilever hook and buckle, conducted three-dimensional modeling of buckle and related parts in the way of three-dimensional modeling, and then used simulation software to conduct realistic simulation, considered the mechanics of materials, assembly stress distribution analysis in engineering stress, and optimized the various factors affecting the stress of buckle by mathematical modeling. In this way, the optimal results with practical benefits can be obtained. The experiment shows that the optimal design of the buckle is largely affected by the structural parameters of the buckle itself.

3.2 The composition and classification of wheel hubcap clasp

(1) Positioning part

The positioning part is accurate in the basic position of assembly and basic parts [20]. The positioning section can provide precise positioning position, and it can also provide special torque resistance through additional structure. As shown in the figure 10.

Figure 10. Different functional parts of positioning constraints.

(2) Locking parts

DOI: 10.54254/2755-2721/12/20230337

The locking part is the part with restraint function, and the assembly holding force provided can be completely restrained, so as to effectively fix the part position. It is an important part of the fastener. As shown in the figure 11.

Figure 11. Locking function.

(3) The clasp reinforcement part

This type of component is different from the tangible functional part. In fact, it is another kind of joint surface functional part. Its role is to improve the strength and stability between the connectors, and may also have the ability to extend the service life of the member. The reinforcement can make the use of the fastener more reasonable, but it will lose a small part of the reliability. As a type of reinforcement, directional parts have a guiding function to help the relevant personnel complete the initial connection, reducing the wear caused by non-directional installation of the firmware. As shown in the figure 12.

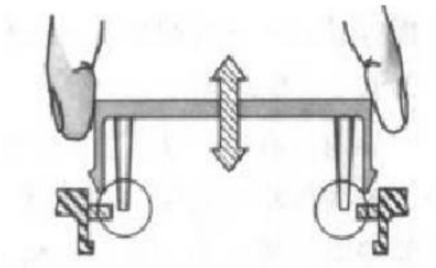

Figure 12. Guidance function.

4. Conclusion

Snap connectors can run multiple loops and are more visually attractive. In space-intensive applications, they are often used to assemble complex injection molded parts, such as building blocks [21], electronic appliances [22], and automotive interiors [23]. Strength, restraint, compatibility and robustness have been identified [23] as key requirements for snap-fit design. The first three can be easily achieved at the design stage by following design principles, but robustness must be achieved at the assembly stage [17]. The proposed snap-fit technique has demonstrated its ability to achieve robust lattice mechanical properties better than most material-topological combinations. And extending the range of existing topologies applicable to snap-fit production, the technology may offer some technological breakthroughs if it can be applied to the automotive industry.

Welding between metal and plastic can be challenging due to their varying properties, but there are three methods available: laser welding, ultrasonic welding, and friction welding. Through-transmission laser welding offers a precise and controlled process, while ultrasonic welding is ideal for improving production efficiency. Friction welding utilizes frictional heating to tightly join metals and thermoplastics, offering high strength and low production costs. Each method has its own advantages and limitations, and is commonly used in different applications in the automotive sector, such as joining hoods, doors, chassis, dashboards, and fuel systems.

Rivet connections are a widely used and established method for joining materials. Their ease of manufacturing, simple installation, and resistance to vibrations make them an ideal choice for various applications. In the automotive industry, particularly for the assembly of body panels, frames, and brackets. However, the manufacturing complexity, joint strength, vibration resistance, and corrosion resistance of riveted joints need to be thoroughly considered during design and installation. Ongoing research efforts to enhance the durability and reliability of rivet connections can inform the development of robust designs for different parts of vehicles.

Bolted jointed connections are a well-known and mature technology, it is a widely used technology in the automobile industry in places such as the engine and axial connections, mainly due to their accessibility, cheap maintenance cost and easy removal, however it is also true that bolted joints do come with certain disadvantages such as not as resistant to vibrations as other types of joints such as welding or riveting. These disadvantages will need to be considered when considering the use of bolted joints. Current research should be focused on a fast and accurate detection method of loose joints which can be used on field without extensive supporting instruments, while also research could also be conducted on developments of novel lock nut types which can improve performance under conditions with high vibrations such as in a vehicle.

Compared with the welding, no dipping, cleaning and other processes, not only improve the production efficiency; Save the material, reduce the cost. And then snap fits are more varied than crimping. Production is less difficult and less expensive. However, the stability, rigid strength and compressive strength of the connecting materials are not as good as that of crimping. So, each has its own strengths.

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