A Review On Ultrasonic Welding of Various Materials and Their Mechanical Properties

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Abstract. In recent years, in contrast with conventional welding methods, ultrasonic welding has been one of great importance among its relevant applications and materials. The bonding of different materials is always difficult, as the unregulated scale of the grain and the fragile mechanical properties are different than conventional welding techniques. In addition, this research paper offers numerous explanations and uses of the ultrasonic welding technique on different materials and its alloys such as aluminium, steel, titanium, nickel, magnesium and also on fiber reinforced composites and thermoplastics along with their mechanical properties. The key benefits of this method are also discussed such as clean and undamaged welding on outer sections, reliable and solid bonding, and saves time effectively.

Keywords: ultrasonic welding, fiber reinforced plastics, spot welding, aerospace industry, automotive industry

1. Introduction
The volume of passenger and traffic in global markets and industrial enterprises increased. Around the same time, lightweight innovations are rising in popularity and demand across economic and ecological boundaries. Consequently, the key target for creative growth in the automobile, aviation and rail transport industries is to decrease the product weight. Composite joints made of different metals, for example, stainless steel and aluminium or various material groups such as metal and glass or metal and fibre-reinforced plastics are necessary in order to produce sustainable lightweight goods and it is
represented in figure 1. However, successful linking methods are needed in the construction of these joints [1]. The industry is very common with the use of ultrasonic welding technologies. Ultrasonic welding is a process of pressurised welding which enables components to be connected to a solid state. The method of ultrasonic metal welding is a fast welding time. Climate change has pushed the automotive industry in the last decades to create alternatives that are more fuel-efficient. The reduction in vehicle weight is equally significant and can be accomplished by using lightweight materials, such as titanium, magnesium and reinforced carbon fibre polymers (CFRPs). Less examination than friction spot softener or resistance spot soiling technology has been attracted by ultrasonic spot solder [2]. In electronic applications where thin film welding is standard practise, the application of low-powers welding techniques was popular but only recent development of high-performance devices permitted thicker measurements to be applied. HPUSW is an appealing alternative to overcome issues due to welding methods for the integration of lightweight materials [3].

![Ultrasonic Welding](image)

**Figure 1.** Ultrasonic welding technique [4]

The interface between ultrasonic joints is known as ultra-fine grains arrangement by dynamic recrystallation. The texture transfers from Square, Iron, Steel, and Brass to Lower Square and stretches complex β-fibres in 6062, subject to ultrasonic consolidation and raising the clamping power, in which deformations are close to high-speed ultrasonic forces and increasing the strength. This reduction in texture is caused by tension, leading to a wider variety of distortions in pre-existing grains under minimal recovery [5]. Variations in the rotation speeds may also cause the non-steady state deformation mechanism to be seriously disorientated. Ultrasonic (USW) was a projected technique of binding: vertically, a fixing force (500-3000 N) is used to make contact with the metals by means of a horn, so metals through the horn must be oscillating at a high frequency (20 kHz; 20-60 μm, respectively). Binding characteristics in USW depend heavily on welding parameters such as adequate intensity and amplitude of binding. More energy may also be used to bind hardened metal to carry out the welding process (for example, higher tightness or oscillation amplitude). Ultrasonic soldering creates plastic strains in modules that are joined together at extremely high stress rates in one fraction of a second [6].

2. **Effect of ultrasonic welding on Aluminium alloys**

In the aerospace industry, weight and cost savings are a big problem in terms of fuel costs and increasing aircraft performance. Ultrasonic metal welding needs considerably less energy than competitive methods like spot welding; has a variable cost amount less than self-perforating riveting; is distinguished by low heat inputs, thereby alleviating the problem of partial distortion, property deterioration of aluminium alloy and protection of component handling. Moreover, aluminium ultrasonic welds have a good consistency compared with other types of joints, which are both quasi-static and dynamic [7]. The wedge, diagonal, and torsion-configurations are used in ultrasonic spot welding systems. Ultrasonic
vibration is provided in all systems by one or more transducers, translating the higher-frequency electric energy created by power supply into the same frequency mechanical vibratory energy [8]. and Zhu. et.al. studied the effect on the mechanical properties, microstructure of interface, microhardness and the composition diffusion of the welded joint is studied by ultrasonic welding parameters. Ultrasonic soiling has shown the likelihood of the Ti6Al4V layer and the A6061 aluminium alloy blade. After ultrasonic soldering and diffusion in the welding interface the hardness of both the matrices increased [9]. A number of welding pressures and solder times were used and the soldered joint strength with a welding pressure of 0.4 MPa and a soldering time of 170 ms was at its maximum value. In the battery-packed and electrical industries, joints of aluminium alloys and copper are favoured due to their high conductivity [10]. The fast growth of the IMC sheet is a big obstacle in the fusion welding of these various metals. The increase in the intermetallic thickness due to the short bonding time and low heat input could be partly restricted by ultrasonic soldering (USW). Ultrasonic spot welding (USW) is an energy-saving technology that produces powerful connexion in less than one second for complicated combinations of different materials, for example for aluminium to steel sheet soldering. In the regulated processing parameters of the clamping forces and welding times, a cross face reaction between aluminium 6111-T4 and two separate zinc coated steels with strong DX56-Z and DX53-ZF dipped [11].

3. Steel and its alloys
Ultrasonic welding is considered a solid state process for linking steel to aluminium and appears promising to do so. There are, however, very few experiments to apply ultrasonic welding to them [12]. and Takehiko. et. al. discovered that the A5052 aluminium alloy sheet containing magnesium could be ultrasonically offered SS400, a mild steel sheet. the optimum value was found for the clamping forces, with a clamping force of over 5 88 N, since a high clamping force decreased the frictional action at the interface for several clamping pressures and continuously 1.0 s soldering cycles, the joint strength has been welded. At 2.5 s, a steady clamping force of 588 N and different welding times sweetened the joints' strength. However, the joint strength soiled by 3.0 s time decreased because of the formation at the interface of Fe2Al5 intermetallic compound [13]. By means of a commercially pure aluminium insert metal, the joint strength was successfully improved and the welding potential was around three times higher than the connexion without an insert metal using a 3.0 s soldering cycle. In the automobile and aerospace industry, aluminium and steel are commonly used. Ultrasonic spot welding, a new solid phase welding, is an efficient means of producing high-resistance joints as shown in figure 2 [14]. The findings show that in this paper 3 kinds of fractures are present in the event of ultrasonic soldering on aluminium over dissimilar alloys, with various solder parameters. The tensile strength is not significantly determined by the tensile forces and vibration rate. Although the value is similar to the threshold, the tensile strength is highly determined by vibration duration [15]. There can be considerable impact on the traction strength of the soldering parameters. Changes in bonding strength and interfacial structure were studied during ultrasonic welding of steel and Ti. As the temperature of the joint rose above 600 ° C during USW, it was observed that the bonding strength strengthened dramatically and resulted in a base-metal fracture. Interfacial, fracture, compositional, and crystallographic analysis has shown that the transition step in Ti from 5-007 (hexagonal close-packed: HCP) to β (body-centred cubic: BCC) has resulted in increased deformity at elevated temperatures, which promotes extensive bonding by eliminating gaps near the bonding interface. Joints with good bonding and strength can be obtained by this process [16].
4. Titanium

The common method of combining dissimilar metals is ultrasonic welding. A special metal alloy of interest to the automotive industry is titanium of aluminium. In such welds, output, including segregation and precipitation, is also managed using interface processes. Moreover, Al-Ti welding is better mechanically (bend angles), with Si segregation than Al-Ti welding, without Si segregation, the maximum temperature during the Al/T ultrasonic softening may reach 450 ° C for comparable thermal treatment time, thereby allowing the rapid forming of Mg oxide on the surface [18]. The dissimilar ultrasonic welding of Ti6Al4V to AA6111 in the as-soiled joint interface showed heavy accumulation of silicone, magnesium and oxygen. On the other hand, the device was not segregated from other components of allegiance such as Cu and V. Titanium is extremely reactive chemically and so the tool material either quickly dissolves or reacts chemically during manufacturing, causing chipping and premature tool failure. In order to mitigate the effect of titanium components in production by the use for automotive industry performance, USAM was used to examine the working properties of titanium alloys with different tool materials. Ultrasonic hollows are possible without over-damaging the base, in particular by ultrasonic boiling, for commercially pure titanium, Ti15 (ASTM grade 2) and Ti31 (ASTM grade 5) titanium alloys [19].

5. Magnesium

Magnesium (the Group II in the periodic table in particular) is an alkaline earth compound that has an excess of available material on the earth's surface. Magnesium has an approximately 650 ° C comparatively limited melting point. The USW system is based on five main elements, electric power supply and electric pulses producing the high frequency. The wedge, used for the intensified amplitude vibration, facilitates the uniform pressure and vibration against the metal composite to be soldered, pneumatic cylinder providing a clamping pressure on the neighbouring materials during welding, and the high-frequency electric energy is usually 20 kHz, a piezo transducer which converts electric energy into a mechanical energy (vibration). In the course of vibration at the neighbouring surface, combined with the pressures of the clamping device, interrupts the oxide layers in the process [20]. Patel and. And. al. USW AZ31BH24 Mg-alloy with set input strength, impedance and clamp. A study was performed of the effect of solder energies on various factors, such as microstructure, crystals, hardness and lap shear strength (LSS). Due to the small slip system activation, low stacking fault energy and high grain border dissemination, they observed during soldering that recrystallization occurred in the nugget zone (NZ). Notable basal texture shifts at the NZ were also illustrated for the Mg-alloy layer and correlated with the extreme localised plastic shear flow and complex recrystallization phenomena [21]. In the U.S.-weaved AZ31B mg alloy, Leon et investigated the effect of vibration amplitude and welded duration on the consistency, strength and morphology of joint fractures. The weldability of Mg alloy was inferred by lap shear checks, temperature acquisition, and microstructure analysis. Higher temperature was
detected at the surface of the neighbouring layer relative to that at the tip of the horn in contact with the
neighbouring upper surface of the sheet. Such activity was attributed to a substantial generation of heat
friction. In fact, in the greater range of vibration amplitudes, surface friction energy dissipates faster into
heat, thereby maintaining higher temperatures [22]. In this state, improved weld strength and higher
failure loads were assessed.

6. Fiber reinforced composites
Effective methods of joining are required for multi-material structures such as lightweight metals and
fibre reinforced polymers (FRPs). The high strength joints between different aluminium alloys and
carbon fibre reinforced polymers (CFRPs) are created with the use of Ultrasonic Metal welding
technology as represented in figure 3 [23]. The bonding processes were characterised by light optical
and scanning electron microscopic (SEM). The study shows a bonding region that was intensive
interfered by ultrasonic welding between the metallic surface and the carbon fibre load carrying of the
CFRP. Precipitation tensile shear strengths up to 58 MPa of hardening aluminium alloy AA2024 could
be attained [24]. Ultrasonic metal soldering can be a unique way to create new joints for the automotive
industry or the aviation industries relative to current joining techniques. In order to create a soldering
zone between metal components, the steel and the glass and the al-interlayer is the ultrasonic soldering
of materials with delicate materials like glass or ceramic since aluminium is the only part that enables
soldering with glass or ceramic in normal atmospheric conditions [25]. Strong vacuum welds were given
for which tensile shear resistance up to 50 MPa were obtained for metal / glass joints and up to 120 MPa
for metal / ceramic joints. In order to create a soldering zone between metal elements, the steel and the
steel and the al-interlayer is the ultrasonic soldering of materials with delicate materials like glass or
ceramic since aluminium is the only part that enables soldering with glass or ceramic in normal
atmospheric conditions. Vacuum proof welds have been made available for metal / glass fittings with a
tensile shear strength of up to 50 MPa, and metal / ceramic fittings up to 120 MPa [26].

Figure 3. Ultrasonic welding technology for composites [27]

7. Thermoplastics
Ultrasonic welding has to basically be subdivided from a kinematical point of view into plastic and metal
welding. During ultrasonic oscillation, the single tonne welding force is applied through the sonotrode.
The key distinguishing attribute between polymer and high-powered metal welding is the ultrasonic
pulse intensity [28]. In order to solder thermoplastics, the ultrasonic wave should be started in the same
manner as the welding force. The substance is then pressurised at a high frequency, which contributes
in particular to the use of the concentrating energy planner, the liquid polymer at the interface. The
ultrasonic metal welding is, in turn, parallel to the joint partner's surface with an oscillation. No melting
of the metal joining partners happens in this situation; the welding process is constant. Ultrasonic
soldering of thermoplastic materials is carried out by the application of the components to be joined
together with fast vibrations of high amplitude [29]. The energy of vibration is dissipated as heat that
increases the plastic temperature to a suitable extent to allow the bonding between materials. It is usually preferable to make the heating near the interface where the connexion is to be created as easily as possible. Ultrasonic soldering, which is fast, inexpensive and simple to automate, is one of the most popular techniques for heat pump attachment. In close-field ultrasonic welding, the distance between the kernel and the joint interface is 6 mm or less. Ultrasonic sealing of amorphous polymers (acrylonitrile-butadiene-styrene and polystyrene), semi-crystalline polymers (polyethylene and polypropylene). Improved energy dissipation and solder strength by increasing vibrational strength. For semi-crystalline polymers, soldering time improved by over 1.5 s, while power was off. The soldering intensity for amorphous polymers strengthened with an increased soldering time up to 0.8 s; the power required was too high in order to solder inefficient soldering for longer periods. Valuable soldering output information was provided by tracking the energy dissipation and static displacement or loss [30].

8. Conclusion
All experiments have shown that there are several factors behind the construction of ultrasonic welded joints. There are various metal compositions demonstrate the different choices for joining mechanisms. There is still an enough space for discovering a uniform theory that can forecast a popular process. It can be inferred that IMCs are formed in dissimilar combinations of metals or alloys which reduce the joint strength in most cases, but a well-chosen interlayer can boost the joint strength in some of the metal combinations by having a very thin layer of IMCs of parent metals. A specific principle of enhanced dynamic diffusion due to rapid dislocation assimilation has been established as the key cause of extreme deformation during ultrasonic welding. This phenomenon decreases the melting point of the parent metals and supports the idea of 'welding due to melting' that opposes 'no melting in cold welding.' Similarly, the existence of HAZ and TMAZ suggests that ultrasonic metal welding can be believed to be an application of fusion welding and opens up the need for further research.

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