EDUZONE: International Peer Reviewed/Refereed Multidisciplinary Journal (EIPRMJ), ISSN: 2319-5045
Volume 11, Issue 2, July-December, 2022, Available online at: www.eduzonejournal.com

Recent advances in Ultrasonic Welding of dissimilar materials: A Review

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ABSTRACT

One form of fusion welding process is ultrasonic welding, where similar and dissimilar materials can be joint effectively. All industrial applications, including those in the aerospace, automotive, medical, electrical, packaging, and textile industries, rely heavily on USW. Here we can easily join thin wire, foils and sheets with high quality welded joint without using any filler material, preparation of the surface and a shielding gas. The strength and quality of the joints were assessed using a variety of process variables, including vibration amplitude, weld pressure, and weld duration. With certain traits, different joint designs were feasible. For metal to metal weld plastic deformation occur and for plastic to plastic weld diffusion occur between the work piece's interface due application of vibration energy. The welding method is excellent for both hard and soft materials since it moves quickly and takes little time to dry. Ultrasonic vibrations have an impact on the joint's quality. The workpieces that were to be connected were pressed together and subjected to ultrasonic vibrations (range between 20 and 40 kHz). This essay tries to provide a survey of the literature on ultrasonic welding.

Keywords: ultrasonic welding; thermoset plastic composite; thermoplastic; energy directors; sonotrode; welding mechanism.

INTRODUCTION

The ultrasonic welding (USW) method is a quick joining technology that produces welds with outstanding strength. It is a technique that is preferred over traditional adhesive, mechanical fastening, and other joining processes since they introduce issues including stress concentration at joints, increase component weight, and are more labor-intensive, which increases the risk of human mistake. H. VanWijk investigated the process optimization of ultrasonic welding [1].

S. Sreekanth [2] optimised the parametric effect of ultrasonic welding, and the model can forecast temperature and stress distribution with various Sonotrode shapes. According to T. Zhao [3], a larger sonotrode causes a higher heating rate, which shortens the welding process to achieve the ideal welding stage. E.E. Feistauer investigated the parametric impact of the ultrasonic joining procedure on the mechanical characteristics of the metal-composite hybrid junction [4]. K. Anand reported on the modelling and multi-objective optimization of ultrasonic insertion parameters using fuzzy logic and genetic algorithms [5].

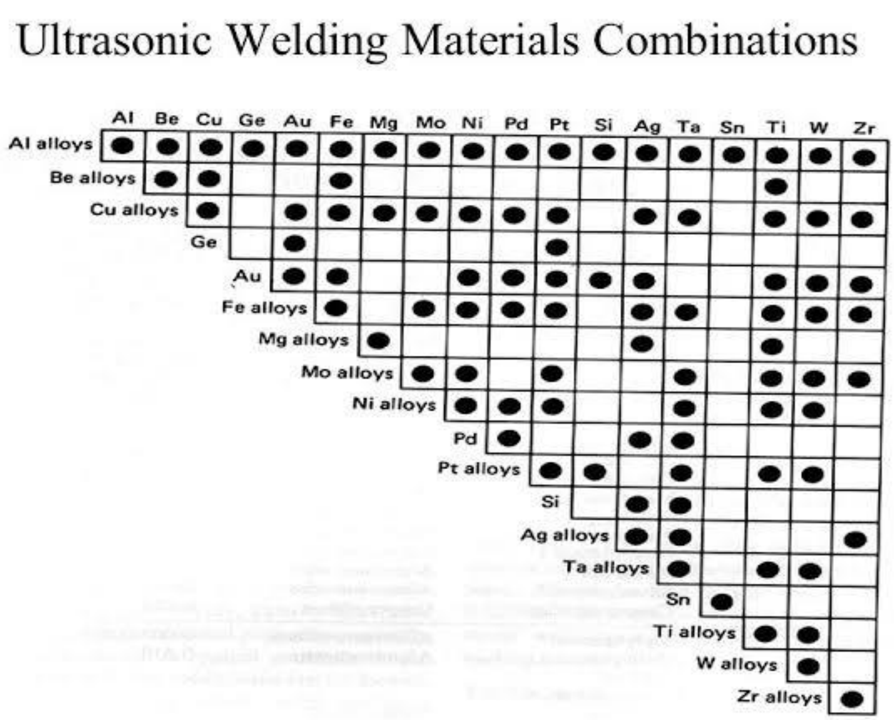
A second-order mathematical model utilising RSM was created, according to S. Elangovan's conclusion in [6,7], to forecast the maximum weld strength of seam and spot welds made by USMW employing aluminium sheets and Cu-Brass. Arthur Levy[8] developed a numerical study at the mesoscopic scale relating processing parameters, polymer flow, and adhesion quality. R. Kalyan Kumar examined experimental investigation and process optimization on ultrasonic welding of GF/PA6T composite[9].

G. R. Chavhan [58] Optimization of Test Parameters that Influence on Dry Sliding Wear Performance of Steel Embedded Glass/Epoxy Hybrid Composites by Using the Taguchi Approach. Digvijay Rathod [59] study on Characterization of aluminium-silicon carbide metal matrix composites. Lalit N. Wankhade [60] study on Tribological Behavior of Steel Reinforced Glass/Epoxy Hybrid Composites. Ganesh R. Chavhan [61] Multi-response optimization of wear parameters of steel embedded glass-epoxy hybrid composites using Taguchi Grey method optimization.

Table 1: **USW of metal to metal specimen**

Ref.	Year	Author	Material	Work	Conclusion
[10]	1998	Jiromaru tsujino	Al-Cu-Steel	Monitoring the increase in temperature at the welding surface	The maximum temperature at the weld surface was 480°C.
[11]	2005	I.E.Gunduz, T.Ando	Zn-Al	Enhanced diffusion and phase change during Zn-Al usw	The interface exhibits structures indicative of enhanced diffusion(value 1.9µm²/s and local melting of Zn-Al solid solution
[12]	2010	K.Kido	Cu-Cu	Development of Cu-Cu bonding by usw for IGBT module	investigated joint strength, how Cu hardness affected joint strength, and the connection between terminal bonding site and insulator layer damage in the module construction.
[13]	2011	V.K.Patel	Mg alloy	Influence of usw on microstructure in a Mg alloy	(A relationship akin to a hall pitch) Due to larger grains, hardness decreased as energy input increased.
[14]	2013	M.Shakil,N. H.Tariq	Al3003 and SS304	Effect of usw parameters on microstructure mechanical properties	The weld specimen created with energies of 125 J and 150 J displayed the strongest connection.
[15]	2014	C.Q.Zhang,J .D.Robson	Al alloy AA6111-TiAl6V4	High power usw mechanical characteristics and microstructural characterisation	The fracturing mode changed from "pull out" to "interfacial failure" following natural ageing because there was no discernible intermetallic reaction layer.
[16]	2015	F.Balle, J. Magin	Al-Ti alloy	Ultrasonic spot and torsion welding of Al-Ti alloy	Welding energy 1900J and 850J, welding force 2000N and 1500N, Amplitude 46 and 33, tensile shear strength 41.4 and 56.2Mpa
[17]	2016	Kunkunchen	Cu-Al	Acoustic softening's impact on USW's thermal mechanical process	The acoustic softening effect considerably enhances structural deformation, which is advantageous for joint formation.
[18]	2017	Z.Z.Hang	Al-Cu	Investigation of interfacial layer of usw Al to Cu joints	Formation of transition layer composed of nanocrystallines and amorphous phase contributing to bonding strength.
[19]	2018	Z.L.Ni	Al alloy	Al alloy spot ultrasonic welding	Numerous important concerns are treated here, including stress distribution, macrostructure, microstructure, interfacial

					temperature, material flow, and interfacial shear force.
[20]	2019	H.Li, B.Cao	Cu-Al	Pressure-related effects on high-power Cu-Al usw	The vibration amplitude of the sonotrode reduces earlier when the pressure reaches and surpasses 1975N, then it rises to the same value as the one at lower pressure.
[21]	2020	Faridhadadi	Al	knurl tooth angle's impact on the mechanical and thermal behaviour of Al usw	Joint strength is mostly decreased by knurl tooth angles (KTAs) less than 120°C and increased bond formation by KTAs more than 130°C.
[22]	2021	Bharat sanga,DS. Nagesh	Phosphorbronze(UNSC51100)	Weld joint characterization in usw of UNSC51100	Strong spot welds without defects can be produced with relatively little power and energy.
[23]	2014	C.Q.Zhang,J.D.Robson	Al alloy AA6111-TiAl6V4	High power usw mechanical characteristics and microstructuralcharacterisation	The fracturing mode changed from "pull out" to "interfacial failure" following natural ageing because there was no discernible intermetallic reaction layer.



Source AWS handbook

Figure 1: Ultrasonic welding materials combinations

Table 2. Summary of selected researches on ultrasonic welding of thermoplastic composites to thermoplastic composites

Ref	Year	Author	Material	Work	Conclusion
24	2001	Liuetal.	GF/PP	Effects of ED, weld pressure, and weld time	Optimized weld strength of 13.77MPa
25	2002	Liuetal.	GF/Nylon6	ED, weld time, and weld pressure effects	Optimized weld strength of 17.11MPa
26	2010	Villegasetal.	CF/PEI_CF/PEI	Optimization of parameters	Optimized weld strength of 37.3MPa
27	2014	Villegasetal	CF/PEI	Effect of weld pressure	Optimized weld strength of 36.6MPa
28	2015	Villegasetal	CF/PPS	Effect of ED	Optimized weld strength of 37.1MPa
29	2017	Palardyetal.	CF/PEI	Impact of ED	Flat plate ED are prefered
30	2017	Zhietal.	CF/PA66	Effect of thermal breakdown and weld energy	Weld energy should be properly applied
31	2017	Luetal.	CF/Nylon66	Effect of preheating	Preheating causes effective welded joint
32	2018	Gaoetal.	CF/Nylon 66	Possibility of welding Four-millimeter laminate	Weld joint of above 3mm thick should be performed at higher energy
33	2019	Gotoetal.	CF/PA6	Effect of weld energy	Weld energy should be properly applied
34	2019	Taoetal	CF/PEEK	Weld time's impact	Weld time should be 1.1s to get weld strength of 28MPa
35	2019	KalyanKumar etal	GF/PA	influence of weld time	Weld time should be 0.6s to get weld strength of 3.1MPa
36	2020	Bhudoliaetal	CF/Elium	Fatigue response and effect of weld time	Weld time should be 2s to get weld strength of 17.2MPa
37	2020	Choudhuryeta l	Bamboofiber /PLA	the impact of weld time	Weld time should be 7s to get weld strength of 3.7MPa

Table 3. Summary of selected researches on ultrasonic welding of thermoplastic composites to other materials

38	2009	Balleetal.	CF/PA66-Aluminum	Al alloy's impact on shear strength	Optimized weld strength of 30MPa
39	2013	Wagneretal.	CF/PA66-Aluminum	Impact of heat treatment and Al alloy on shear strength	Optimized weld strength of 58MPa
40	2015	Villegasetal	CF/PEEK-CF/Epoxy	NA	Optimized weld strength of 28.6MPa
41	2018	Villegasetal	CF/PEEK-CF/Epoxy	PEI film's impact	Optimized weld strength of 28.6MPa
42	2018	Lionettoetal.	CF/PEEK-CF/Epoxy	Effectofco-curing	Optimized weld strength of 25MPa
43	2019	Tsiangouetal	CF/PEEK-CF/Epoxy	Effectofcocuredfilm and lose film	Optimized weld strength of 37.7MPa

There have already been several studies carried on welding sheets with USW. The material combinations found in the literature are mentioned in Table1, 2 & 3. Although a specific material combination can be welded, it is important that every parameter will be chosen correctly, this ensure best weld quality. All experiments have shown that there are several factors which influence ultrasonic welding.

Ultrasonic welding characteristic

Welding quality of plastic were related to ultrasonic vibration, density and viscosity [44]. In contrast to welding pressure, vibration amplitude and holding duration had a greater impact on the material's welding strength[45]. On thermoset composites, thermal deterioration has shown excellent results[46]. The amount of strain generated by plastic deformation, which promotes the creation of intermetallic compounds, and the welding amplitude determine how thick the intermetallic layer will be [47].The degree of interface friction and plastic deformation were employed to quantify the welded junctions' performance characteristics [48].

Performance of USW

The location and distance between the joint interface affect horn efficiency [49]. Choosing the size and shape of the welding is critical, according to the energy director [50]. Peel tests for joints between dissimilar metals were used to examine various interfaced layer strengths [51]. By regulating morphological parameters, such as the reinforcement of the material structure in polymer composites, the welding performances were enhanced [52]. In USW of copper-nickel materials, the impact of process variables on joint efficiency were identified [53].

Welding factors

Ultrasonic welding is affected by a number of factors, including welding frequency, material consideration, the impact of joint design, tools and fixtures, and welding parameters like weld time, weld pressure, and weld amplitude [54]. The quantity of heat produced during this process varied with changes in vibration amplitude and applied load [55]. For thermoplastic polymers, welding performance was inversely correlated with frequency [56]. To enhance the welding performance and its features, many welding parameters were utilised in advanced welding processes [57].

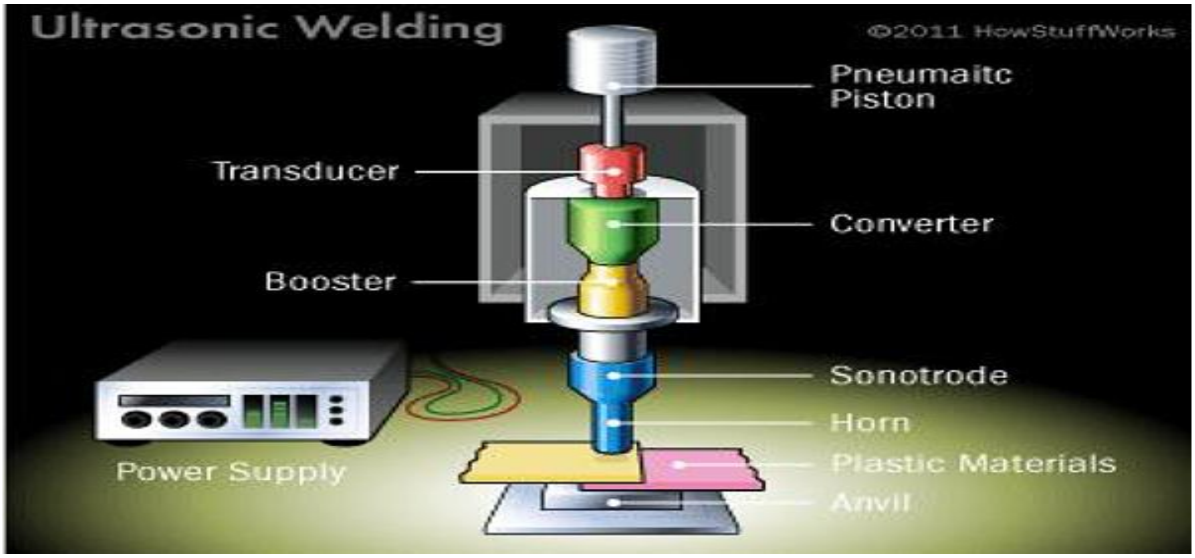


Figure 2 : Parts of ultrasonic welding machine

Figure 3: USMW Machine

Figure 4: USPW Machine

CONCLUSION

Based on an examination of the literature on ultrasonic welding, a conclusion was reached. Despite the fact that a lot of study has been done on ultrasonic welding of different materials but there is no research carried out on the following combination of materials:- 1) Glass fiber composite-carbon fiber composite, 2) Metal- glass fiber composite 3) Metal-thermosetting composite. For different materials ultrasonic welding were performed with quality weld. The quality of weld depends on various welding parameters. By changing different factors influencing USW the desired outcome of the joint were attained. Based on what kind of material is selected for performing usw we have to choose a proper type of ultrasonic welding machine, we have to design proper fixture, thickness of specimens to be welded should be maintained, use of energy director, type and shape of sonotrode and most important is proper selection of welding parameters leads to high quality weld strength.

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