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PLASTIC JOINING METHODS: ULTRASONIC AND VIBRATION WELDING

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Abstract: Plastic welding is a common method for manufacturing parts that can't be molded and has a complex geometry such as the part that has undercuts. The process is suitable for mass production, cheap and meets automotive requirements. The process helps the zero-emission target of the automotive industry, due to the biggest obstacle of the plastic use in this sector was the moldability of the complex geometries. Most of the engine parts such as thermostat, water pump etc. can't be molded as one piece. These engine components are manufactured by helping the plastic welding and decrease the weight of the automobile, therefore, improving fuel efficiency. Plastic welding technology has become more important especially in electrical vehicles, because metal to plastic replacement has a significant role in decreasing the weight of the vehicle. Selecting the welding method according to the polymer properties and the geometry of parts are the most important factors for the application area. All of the welding methods are basically based on the remelting of the welding surfaces of the parts and the consolidation of them under the pressure. In this paper, the vibration welding and the ultrasonic welding methods have been inspected. The most effective parameters of both processes have been discussed and shown.

Keywords: The Vibration Welding, The Ultrasonic Welding, Thermoplastics, Weld Strength

Plastik Birleştirme Yöntemleri: Ultrasonik ve Vibrasyon Kaynağı

Öz: Plastik kaynak, kalıplanamayan ve parçanın iç çaplardakeskin bir şekilde değişmesi ya gibi karmaşık bir geometriye sahip parçaların üretimi için yaygın bir yöntemdir. Süreç seri üretime uygundur, ucuzdur ve otomotiv gereksinimlerini karşılamaktadır. Karmaşık geometrilerin kalıplanabilirliğinden dolayı, proses otomotiv endüstrisinin sıfır emisyon hedefine yardımcı olmaktadır. Termostat, su pompası vb. gibi motor parçalarının çoğu tek parça olarak kalıplanamaz. Bu motor bileşenleri, plastik kaynaklama yardımıyla üretilir ve otomobilin ağırlığını azaltarak, yakıt verimliliğini artırır. Özellikle elektrikli araçlarda plastik kaynak teknolojisi daha önemli hale gelmiştir, çünkü metalden plastiğe geçiş, aracın ağırlığının azaltılmasında önemli bir role sahiptir. Polimer özelliklerine ve parça geometrisine göre kaynak yönteminin seçilmesi, uygulama alanı için en önemli faktörlerdir. Tüm kaynak yöntemleri temel olarak parçaların kaynak yüzeylerinin yeniden eritilmesine ve basınç altında birleştirilmesine dayanmaktadır. Bu çalışmada, vibrasyon ve ultrasonik kaynak yöntemleri incelenmiştir. Her iki prosesin en etkili parametreleri tartışılmış ve belirtilmiştir.

Anahtar Kelimeler: Vibrasyon Kaynağı, Ultrasonik Kaynağı, Termoplastik, Kaynak Mukavemeti

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1. INTRODUCTION

The polymers are classified as thermosets and thermoplastics. Molecular chains of thermosets are strong and chemically bonded by crosslinks. The form of crosslinks can be defined as network structure. The processing of thermosets is based on a chemical reaction between molecules. On the other hand, thermoplastics have linear structure of molecular chains. Thermoplastic molecules linked via van der Waals forces, contrary to chemical reaction (Teres, 2021). The plastic welding process is the only suitable process for thermoplastics. Because remelting of the polymer is the essential aspect for the polymer welding. Thermoplastic can be recycled by reaching its melting temperature. Thermosets can not be reshaped or recycled because of the strong chemical bonds (Whisnant, 2021). The biggest advantage of using thermoplastics is the compatibility for all welding methods (Ageorges, 2001; Ageorges, 2000; Hou, 1999; Eveno, 1988). Thermoplastics can be categorized as semi-crystalline and amorph. The molecular bonding of semi-crystalline materials is oriented with short, intermitted lines. Contrary to semi-crystalline materials, molecular bonding of amorph is randomly oriented and consists of highly intermitted lines (Flory, 1953). Thermoplastics are a demandable material for industry, especially for the automotive. High chemical resistance, good fatigue properties, low density compared to metals and reusability are the most important properties of thermoplastics in the automotive industry scope (Alrubaie, 2020). Table 1 shows the distinctive properties of semi-crystalline and amorphous polymers and Table 2 shows the properties of some thermoplastics (Bhudolia, 2020; Vaidya, 2008).

Table 1. Comparison Between Semi-crystalline and Amorphous Thermoplastics (Bhudolia, 2020)

Semi-Crystalline	Amorphous
Oriented molecules	Randomly aligned molecules
Melting temperature (T_m) is significiant	Softening temperature (T_g) is important
Hard to reshape without reaching T_m	Easy to reshape above T_g
Softness	Rigidity
Magnificent chemical resistance	Toughness, chemical and creep resistance
Non-transparent	Translucent

Table 2. Some of the Thermoplastic Properties (Vaidya, 2008)

<table>
<tr><th>Type</th><th>Thermoplastic</th><th>Density (kg/m^3)</th><th>Tensile Modulus (GPa)</th><th>Tensile Strength (MPa)</th><th>Melting Temperature (°C)</th></tr>
<tr><td rowspan="6">Semi – crystalline</td><td>Polypropylene</td><td>890-910</td><td>1.5-1.75</td><td>28-39</td><td>134-165</td></tr>
<tr><td>Polyethylene</td><td>918-919</td><td>0.15</td><td>10-18</td><td>104-113</td></tr>
<tr><td>Polyamide</td><td>1030-1160</td><td>0.7-3.3</td><td>40-86</td><td>211-265</td></tr>
<tr><td>Polyphenylene Sulfide</td><td>1350-1430</td><td>3.4-4.3</td><td>28-93</td><td>280-282</td></tr>
<tr><td>Polyether-ether Ketone</td><td>1300-1440</td><td>3.1-8.3</td><td>90-100</td><td>340-344</td></tr>
<tr><td>Polyethylene terephthalate</td><td>1300-1333</td><td>2.5-3</td><td>50-60</td><td>240-250</td></tr>
<tr><td></td><td>Polyetherimide</td><td>1260-1700</td><td>2.7-6.4</td><td>100-105</td><td>220</td></tr>
</table>

Amorph	Polyethersulphone	1360-1580	2.4-8.62	83-126	220

Although using thermoplastics has advantages, the manufacturing methods limit their use area. Metal to plastic replacement has a significant effect on the automotive industry especially the electrical vehicles technology to achieve zero emission (Karabacak, 2022). Plastic parts must meet the safety requirements and limitations of using it such as complex part geometry, abrasive resistant etc. must be figured out according to this aim. Injection molding is the most common method for plastic manufacturing (Gao, 2018). But the parts, have complex geometry to be molded and can not be produced by this method. In the absence of the welding methods of thermoplastic, the plastic parts which can not be molded as one piece because, the complex geometry was not used. Plastic welding is a common method for joining the parts which can not be molded as one piece by injection molding. Finding a proper solution for this disadvantage of complex parts manufacturing by injection molding plastic welding process have been used for a long time (Uluskan, 2021; Patham, 2011). The key of the solving this problem is basically based on dividing the complex part geometry into two or more parts, then consolidating them in one piece by using a suitable plastic welding method (Arabaci, 2022). The methods do not change the material chemical structure and need for the chemical materials to join the parts (Leisen, 2017). Figure 1 shows the polymer welding types (Grewell, 2007).

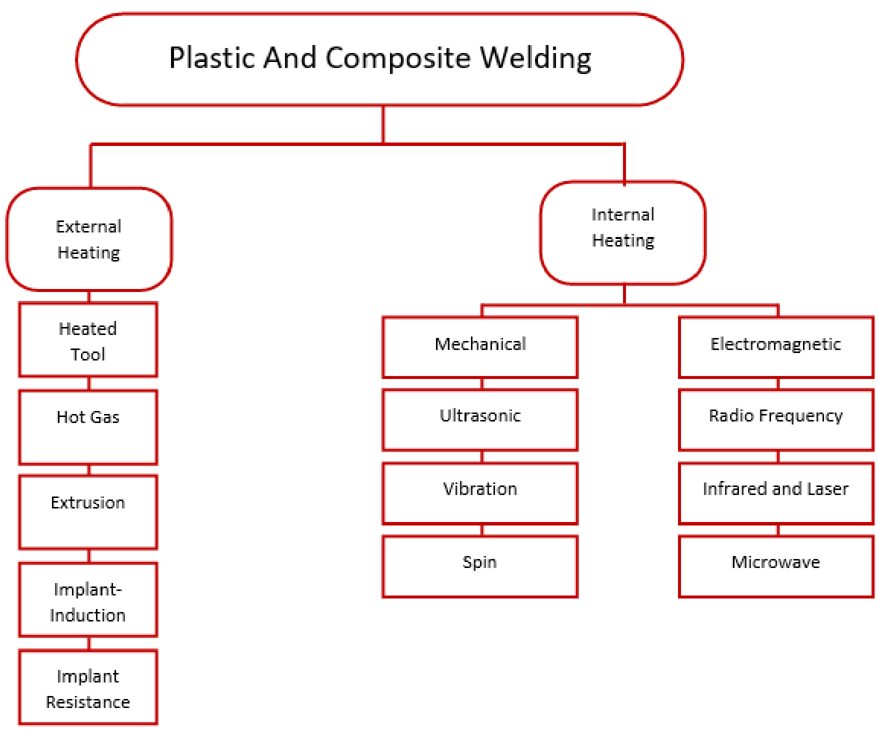

Figure 1:
Plastic Welding Methods (Grewel, 2007)

In this paper, vibration welding and ultrasonic welding were chosen to investigate.
Vibration or linear vibration welding and ultrasonic welding are categorized as internal heating or friction welding methods (Takasu, 2003). The process is suitable for large and medium parts such as bumper and censor bracket joining, air intake manifolds etc. (Froment, 1995; Bates, 2004; Lin, 2015).

Both ultrasonic and vibration methods are quite easy and applicable for automation, they are cheap and provide fast cycle (Leisen, 2017; Benatar, 2015). The methods simply based on heat generation from frictional force and then joining the parts under the pressure (Pal, 2016; Parmar, 2016). Bonding of two parts is done by friction forces between the part's surfaces. The most effective process parameters of vibration welding are the amplitude, weld pressure and time (Stokes, 1988).
On the other hand, the geometry of the welding zone, thermoplastic type such as semi-crystalline or amorph, type, ratio, and orientation of filler in the polymer are the other parameters that are effective on the weld quality and strength (Mofakhami, 2020; Chuah, 2000; Troughton, 2008).
Vibration and ultrasonic welding processes are divided into 4 phases. The melting temperature of polymer is reached by friction under the, $P_{0,}$ weld pressure.

I. In unsteady phase, melted material flows to the weld line with applied vibration.
II. In steady state, solidification and melting rates are equal.
III. This phase begins when the vibration is finished.
IV. The last phase begins when the vibration stops, and the process ends when the consolidated finishes.

Figure 2 explains the phases of the processes, ultrasonic welding, and vibration welding, as the time versus the penetration (Stokes, 1988; Nonhof, 1996).

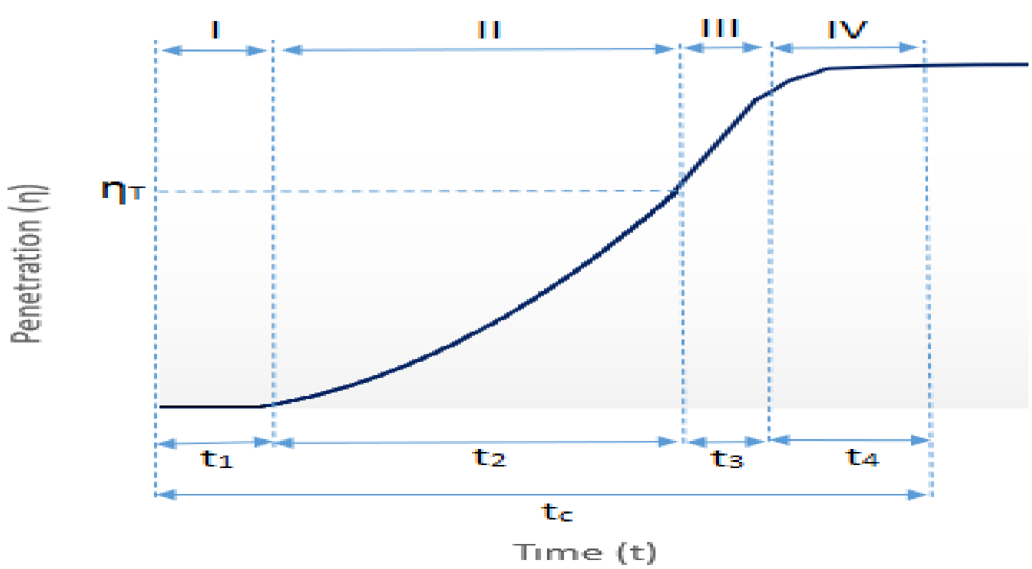

Figure 2:
Vibration and Ultrasonic Welding Phases According to The Time versus The Penetration (Stokes, 1988)

The vibration welding operation components are described in Figure 3. The typical vibration welding parameters which are weld pressure, frequency, and amplitude, are generally around 0.5-5 MPa, 200 Hz and the order of 2 mm, respectively. The weld zone geometry also must be taken in as an effective parameter. The process is categorized as two headlines, transverse and longitudinal. The transverse vibration welding process can be defined as the vibration motion which is created on the y-axis. However, if the vibration motion is occurred on x – axis, contrary to transverse, it is called longitudinal (Bates, 2004).

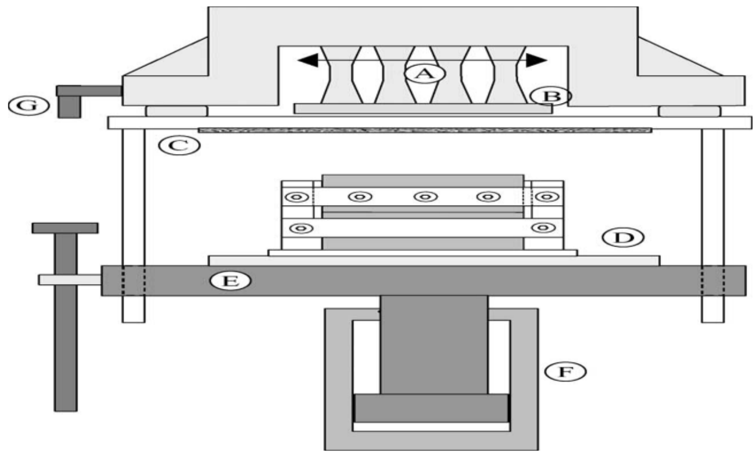

Figure 3:
Vibration Welding Machine Components (Bates, 2004)
A (Vibration Source), B (Transfer Plate), C (Head Fixture), D (Bottom Fixture), E (Hoist), F (Hydraulic System), G (Transducer)

Another widely used friction welding method, the ultrasonic welding, can be explained as a process chain in which the vibration energy dissipates on the surface, heat generation occurs, material flows in the weld zone, fusion bond establishes by diffusion and consolidation. The process variables are the frequency and the amplitude diverse from 10 to 75 kHz and 0.1 to 100 µm respectively. But the most encountered frequency is 20 kHz (Lin, 2015). The most effective parameters can be classified as the weld time, the weld pressure, the hold time, the trigger force, and the amplitude (Nguyenv, 2017). These parameters might be varied according to the welding equipment and machines used (e.g., welding energy, weld speed etc.) Typical ultrasonic welding components consist of piezoelectric converter, booster, and horn. Figure 4 shows the schematic representation of components of ultrasonic welding (Costa, 2012). The near-field and the far-field welding considerations have an important role in the ultrasonic welding operation (Rani, 2009). Basically, it is based on the thickness of the part. If the thickness is bigger than 6 mm, the process can be categorized as far-field (Benatar, 1989). Otherwise, the process is classified as near-field (Benatar, 1989).

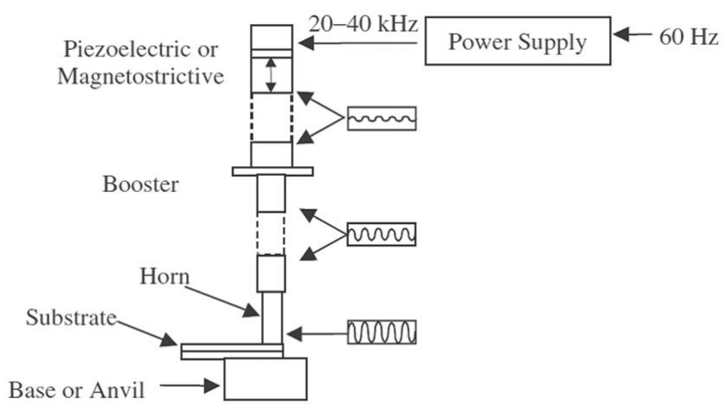

Figure 4:
Ultrasonic Welding Machine Components (Costa, 2012)

Designing of the weld zone must be considered as an effective parameter (Teres, 2021). Therefore, the weld zone geometry or joint geometry must be selected as proper as possible considering the application area of part such as, sealing applications, manifolds, thermostats etc. These geometries can be classified in two groups. One of them is called energy director (ED) or butt joint (BJ). Figures 5, and 6 show the ED designs (Chuah, 2000; Teres, 2021). The other is called shear joint (SJ) design. Figure 7 shows the different kinds of the SJ designs.

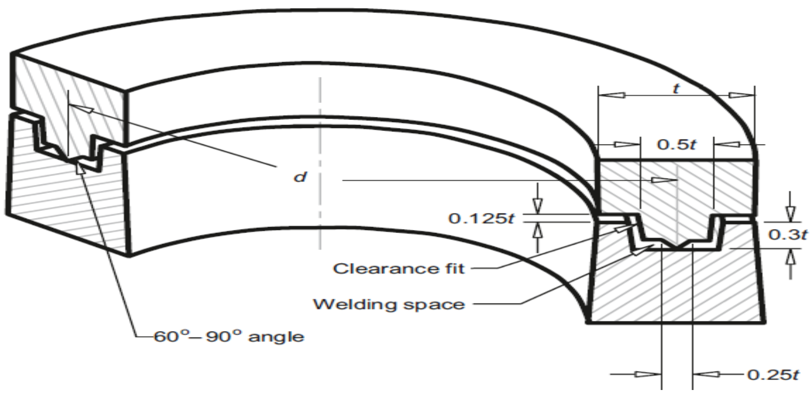

Figure 5:
Triangular ED Design (Teres, 2021)

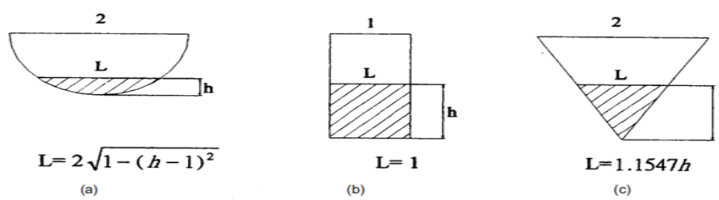

Figure 6:
Energy Director Designs (Chuah, 2000)
a)Semi-Circular, b)Rectangular and c)Triangular

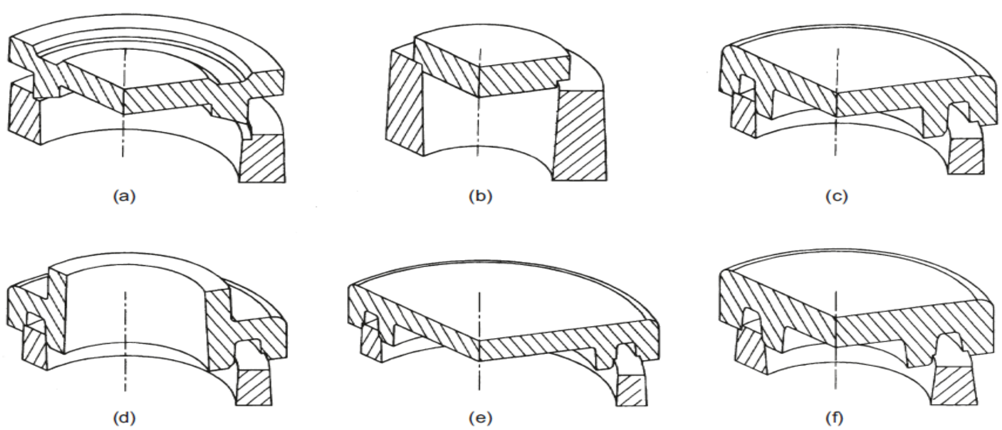

Figure 7:
The Most Common Shear Joint Designs (Teres, 2021)
a)Wedge, b)Flat, c)Guided, d)Control, e)Double and f)Double Split

In this review article, thermoplastic types, process parameters, weld zone geometries, filler types, filler orientations such as transverse or longitudinal and moisture effect on vibration and ultrasonic welding are examined comprehensively.

2. POLYMER FRICTIONAL WELDING

The aim of this paper is to inspect and discuss two of the frictional welding methods, vibration welding, and ultrasonic welding. The ultrasonic welding evaluations are based on welding machine parameters. On the other hand, the vibration welding, the glass fiber orientation, injection gate location etc. have been evaluated for the vibration welding.

2.1. The Ultrasonic Welding (UW)

UW is widely used in the industry, especially for the automotive. UW is a preferred method for bonding between censor brackets (Polypropylene homopolymer reinforced with 10% talc) and rear bumper. To understand the effect of UW parameters on weld strength, the amplitude, the weld pressure, the weld time and hold time were changed in every step of this experiment. To better see the effect of each parameter, the rest of the three were always kept stable, only one parameter was changed in the experiment. Table 3 shows the experiment steps and constant parameters (Demir, 2019).

Table 3. UW Test Parameters (Demir, 2019)

Changed Parameters	1	2	3	Constant Parameters
Weld Pressure	2 Bar	4 Bar	8 Bar	Amplitude: 100% Weld Time: 0.9 s Hold Time: 1 s
Amplitude	50%	75%	100%	Pressure: 4 Bar Weld Time: 0.9 s Hold Time: 1 s
Weld Time	0.9 s	1 s	1.2 s	Pressure: 4 Bar Amplitude: 100% Hold Time: 1 s
Hold Time	1 s	1.5 s	3 s	Pressure: 4 Bar Amplitude: 100% Weld Time: 1 s

Figure 8 shows that the weld time is the most effective one, compared to the other parameters. The second one is amplitude, it can be said that hold time and pressure are the least effective parameters as to the increasing rate of the tensile strength (Demir, 2019).

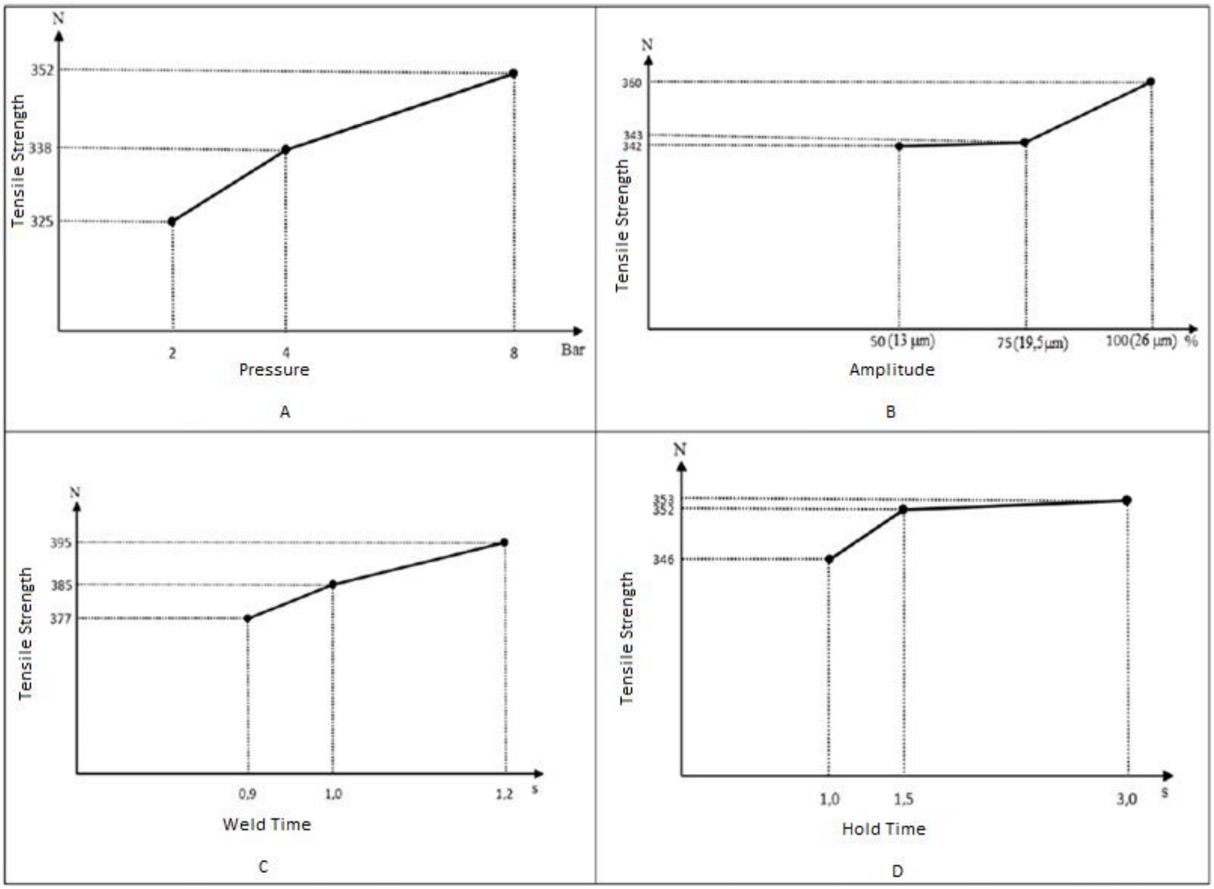

Figure 8:

Effect of Parameter on Tensile Strength (Demir, 2019)
(A) Pressure versus Tensile Strength, (B) Amplitude versus Tensile Strength,
(C)Weld Time versus Tensile Strength and (D) Hold Time versus Tensile Strength

Polypropylene has been a widely used area compared to other thermoplastics due to low cost, good chemical resistance, and its mechanical properties. Also, compatibility with other reinforcement additives such as carbon fiber (CF), glass fiber (GF) etc. makes it more convenient for the automotive industry. The UW of PP via triangular ED and without ED were studied and shear strength was evaluated. Politetrafloroetilen (PTFE) was used as weld zone stabilizer, limiting the welded area in sonotrode and fixture border. 50% GF reinforced PP parts were welded with Herrmann Ultraschalltechnik HiQ Evolution Speed Control ultrasonic welding machine. To better understand welding time effect on each of the two processes, ED and without ED, the operation is conducted five times. After the welding process, the effect of welding time on shear strength was evaluated (Kiss, 2020). It was found that low welding time causes the poor connection between parts and high welding time caused the crack during the operation (Kiss, 2020).

The geometries of the weld zone have been showed above. Basically, the ED gives a direction to heat generation which is created by the frictional forces between the welded surfaces. Therefore, the shape of ED has a significant effect on the lap shear strength and power (Villegas, 2019). Three different ED were prepared and tested to explain the effect of ED design. The tested ED geometries are classified according to the height 0.5mm and 0.25mm, respectively. CF reinforced polyetherimide

(PEI) welded and the lap shear strength of the parts were evaluated by power(w), welding time and conjugation ratio. The samples were welded by the Rinco 300 US welding machine. For all the ED height, the welding parameters joining force and time, power and amplitude were adjusted same for all ED height, 1000N, 4000ms, 500N and 86.2μm, respectively, were kept constant for the evaluation of lap shear joint. The second peak of the power versus vibration curve shows the optimum parameter. After the second the peak power starts to decrease. Figure 9 explains the relationship between power versus vibration as a consequence of displacement for 0.5mm ED and 0.25 mm ED (Palardy, 2017).

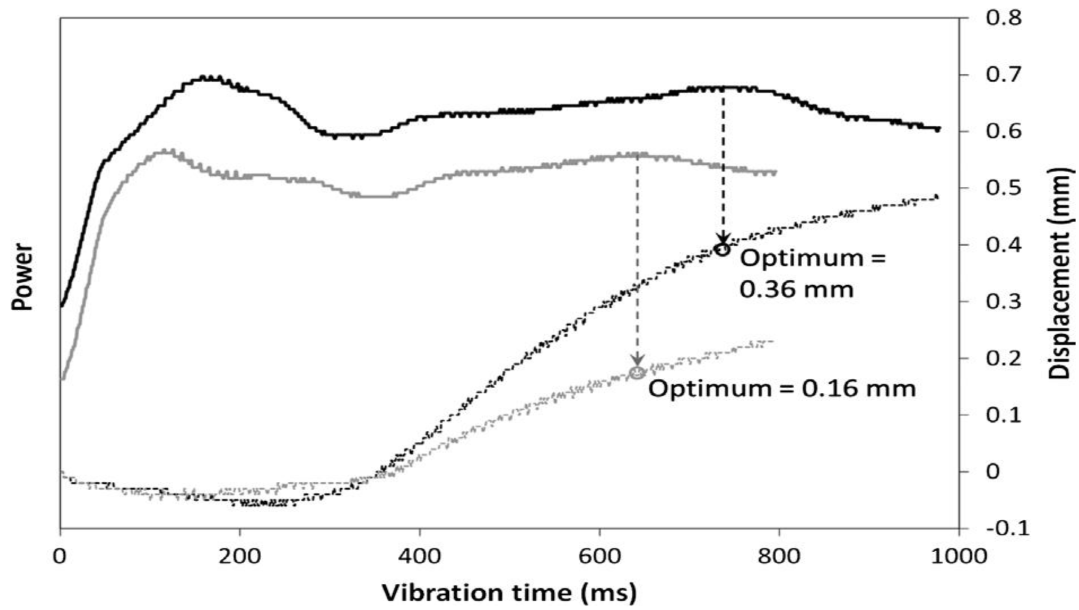

Figure 9:

Optimum displacement (Palardy, 2017)

0.16mm and 0.36mm are optimum displacement for 0.25mm ED and 0.5 ED, respectively.

The welding power is a result of the vibration conjunction and pressure of the sonotrode. The energy consumption of process can be calculated with time merging of the power. The triangular ED is widely used on UW; however, it has some disadvantages such as dimensional stability. The shape and size of ED are hard to mold without encountering shrinkage or concentric. To minimize these disadvantages, flat ED (FED) is used in the process. The welded parts consist of polyamide 6 (PA6) and twill woven CF. PA6 and CF were consolidated via heat and pressure, and lamination were conducted as cross layered woven. To better understand the effect of the FED, specimens were welded with FED and without FED. The parameters of the UW were kept constant, and the welded area and conjugation were compared in two processes. The four welding energies were applied during the experiment such as 200W, 450W,600W and 800W respectively. However, it has been found that 200W was not enough to join the parts especially without FED joining. Figure 10 shows the lap shear strength (LSS) versus welding energy (Goto, 2019).

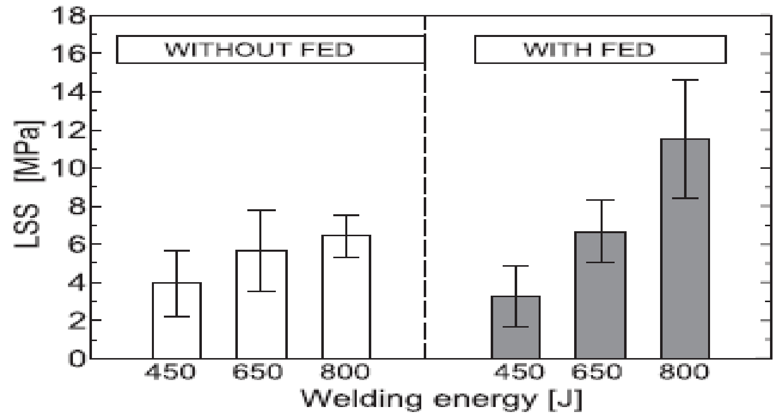

Figure 10:
LSS versus Welding Energy (Goto, 2019)

As a result of the experiment, it was observed that increasing the weld energy has positive effects on LSS for both designs (Goto, 2019).

The shear joint geometry is mostly suitable for semi-crystalline materials such as high-performance polyamide (HPPA), PA6, PA66, Polyphenylene Sulfide (PPS) etc. Also, the near field welding is recommended for the same thermoplastic family (Yeh, 2013). HPPA is the common material, if the thermal resistance is necessary. But, as mentioned before the geometry is the biggest problem for the application area. 50% GF reinforced PA6T/6I was chosen as HPPA and the effect of the welding time was investigated. The hold pressure and amplitude were constant for all experiments and the adjusted parameters are 400N and 100%, respectively. Table 4 shows the properties of PA6T/6I (Kumar, 2020).

Table 4. The Properties of PA6T/6I (Kumar, 2020)

Property	Value
Density (g/cm³)	1.55
Young’s Modulus (MPa)	17500
Tensile Strength (MPa)	235
Melting Temperature °C)	330
Service Temperature (°C)	250 (Max.)

The welding depth as a result of the welding time was inspected according to the peak forces. It was found that the peak load increases by increasing the welding time. Also, the increased peak load boosted the weld depth (Kumar, 2020).

2.2. The Vibration Welding (VW)

The effect of the orientation of the reinforcement such as CF or GF in the thermoplastic matrix has not been provided yet. However, a lot of research has been proceeded about it. The gate location of injection mold is the common way to determine filler orientation direction, longitudinal or transverse, in the matrix, especially in the vicinity of welding surface (Kenig, 1986). However, changing the gate location is not feasible for the researchers and in their studies. Therefore, cutting direction of the material is chosen as the most convenient way. The parts were cut in the direction of injection and transverse direction. This process makes it possible to investigate GF orientation’s effect on the vibration welding. Figure 11 shows the cut process scheme. The length of GF has a significant effect on the mechanical properties of the composite (Silverman, 1987). The filler orientation in the polymer matrix has a certain effect on mechanical properties of the composite and according to this hypotesis. This change should be seen on the mechanical properties of the welded polymers (Kagan, 2004; Kagan, 1999; Bright, 1981). 30% GF reinforced PA6 (PA6-GF30), %30 GF reinforced high viscosity PA6 (PA6-GF30EF), 30% short GF reinforced PP (PP-30GF) and 30% long GF reinforced PP (PP-30LGF) have been investigated. The GF size and its orientation in the matrix have been investigated in three phases. One of them is cutting the parts according to the flow direction (longitudinal), the second is cutting the part transverse direction of the flow direction (transverse) and the last one is injection molded parts without cutting (injection-molded/gate position). The vibration weld parameters were kept the same for all parts. The parameters of the vibration welding process namely amplitude, weld pressure and depth are selected as 0.5µm, 0.5MPa and 1.4mm, repectively (Fiebig, 2018).

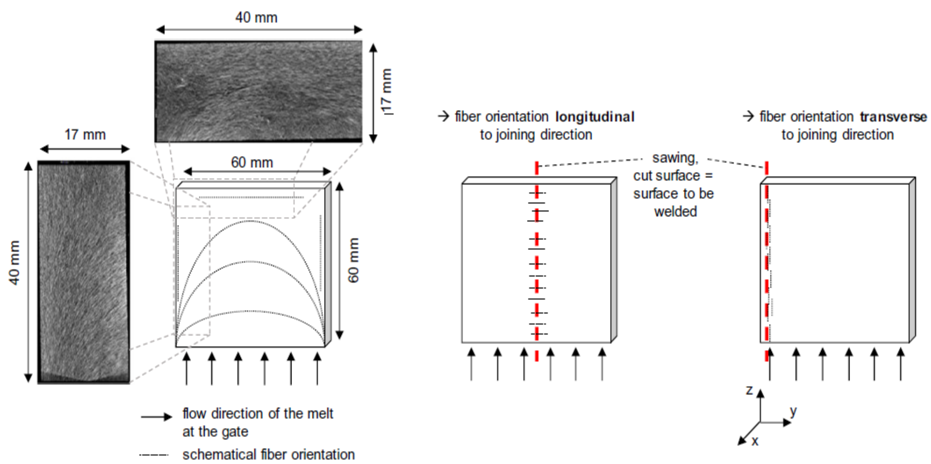

Figure 11:
Cutting Process of the Parts (Fiebig , 2018)

The weld strength of the welded both composites have not significantly been changed by fiber orientation. Figure 12 shows the weld strength of the composites (Fiebig, 2018).

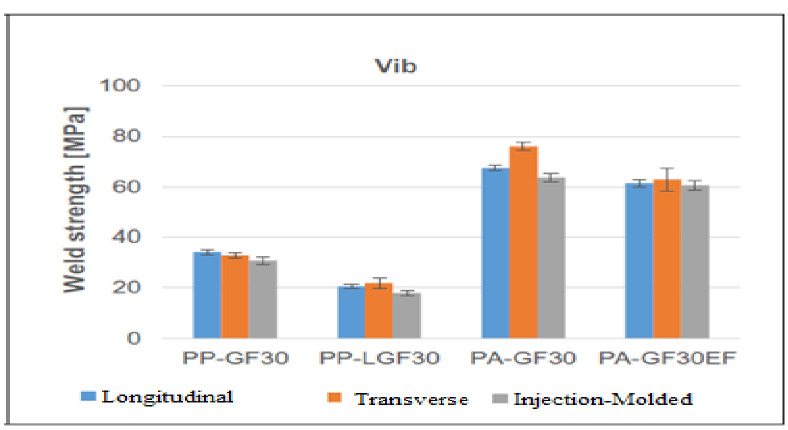

Figure 12:
The Weld Strength of Polymer Composites (Fiebig, 2018)

In the VW process has a specific dimension that can be defined as a shell. For instance, if the parts have a thickness of 3.2mm, 0.2mm the shell blocks the welding process for a while and decreases welding efficiency (Klimkeit, 2011). To better understand the effect of non-effective thickness, the parts have been machined and compared with the parts injection molded. Also, GF orientation has been added to the equation. Figure 13 shows the parts manufacturing scheme (Showaib, 2020).

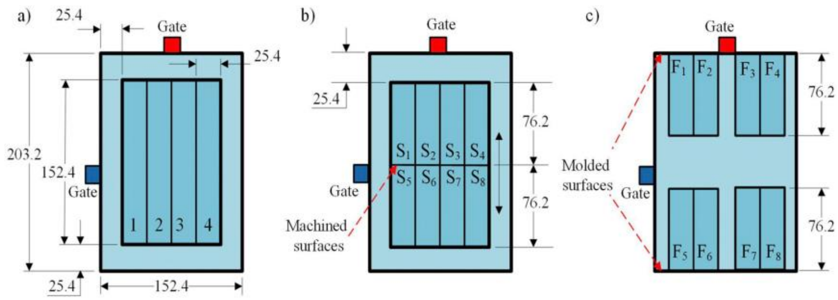

Figure 13:
Sample Preparation Scheme (Showaib, 2020)
(a)Tensile Test Bars, (b)Machined Samples (c)Injection Molded Samples

The GF orientation was adjusted by gate position of the mold. The red colored gates represent perpendicular GF orientation, and the samples are named P-Flow, blue colored gates represent longitudinal GF orientation, and the samples are named X-Flow. To simplify the sample manufacturing methods, the abbreviations of these welding methods according to the samples manufacturing are named WMF (Welded Molded Face) and WMS (Welded Machined Surface). 30% GF reinforced PBT (Polybutadiene Terephthalate) has been chosen for VW processing and the parameters of the VW, the frequency and the amplitude, are selected as 120 Hz and 1.59mm, respectively. The welding depth is an adjusted parameter for both welded samples. Figure 14 shows the welding process according to the welding depth versus the welding time for WMS and WMF samples (Showaib, 2020).

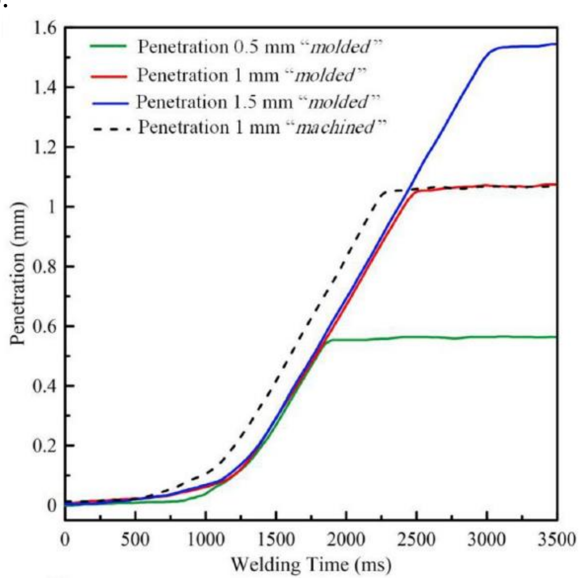

Figure 14:
Penetration/Welding Depth versus Welding Time (Showaib, 2020)

Lower welding pressure is recommended in order to increase welding strength for the welding process (Bernasconi, 2007). The relative tensile strength of WMF is compared by changing welding pressure. The gate position was chosen by using the color red in Figure 13b, and Figure 15 shows the welding pressure and relative strength chart (Showaib, 2020).

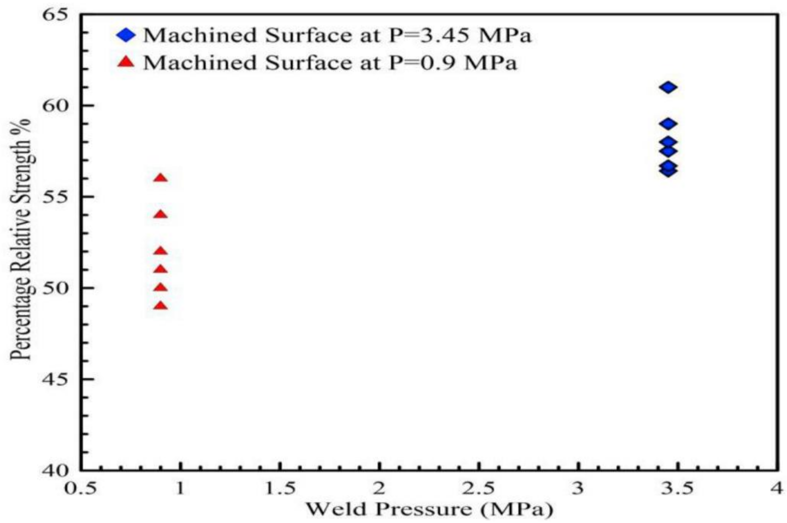

Figure 15:
Effect of The Welding Pressure on Relative Strength (Showaib , 2020)

The maximum tensile strength is another comparison for the samples, tensile bar, and P-Flow samples. Figure 13a and Figure 13c samples are compared and Figure 16 shows the bar chart of the maximum tensile strength (Showaib, 2020).

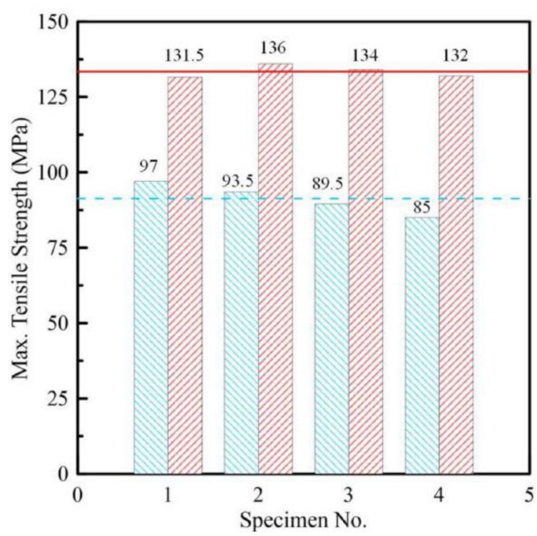

Figure 16:
Maximum Tensile Strength of the Samples (Showaib, 2020)
Blue bars represent the tensile bars and red bars represent the injection molded and welded samples.

It has been found that the relative tensile strength of the parts that welded to machined surface is better than the parts welded to mold surface. Results have shown that welding pressure is an effective parameter for VW process. The gate position, therefore, GF orientation and machining is also effective for the tensile strength of the welded parts. (Showaib, 2020).

The chemical structure of the polymer determines the compatibility and, as a consequence of that, the weldability of the two different polymers. Therefore, the VW between different polymers is not easy and feasible for incompatible polymers without using adherents, surface operations or special geometry etc. Table 5 shows the polymers and their compatible polymers (Yeh, 2013).

Table 5. Compatibility of the Polymers (Yeh, 2013)

POYLMERS	ABS	PMMA	PA	PET/PBT	PPS	PS	PC	PP
ABS	X							
PMMA		X						
PA			X					
PET/PBT				X				
PPS					X			
PS						X		
PC							X	
PP								X

X: Compatible,
ABS: Acrylonitrile Butadiene Styrene, PMMA: Polymethyl Methacrylate, PA: Polyamide, PET/PBT: Polyethylene Threpthalate/Polybutadiene Threpthalate, PPS: Polyfenilen Sulfide, PS: Polystyrene, PC: Polycarbonate, PP: Polyprophelenye

The welding geometry is the key factor to turn the polymers that are incompatible for VW process to the polymers that are incompatible, but the two parts consolidated with strong bonds. Figure 17 shows the illustration of the process (Wolf, 2019).

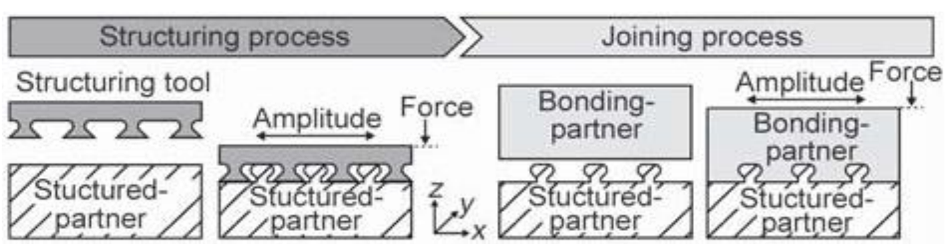

Figure 17:
Form-Fit Geometry and Polymer Welding (Wolf., 2019)

The process consists of two stages. The first is giving the form-fit shape to the structural part by using the structuring tool that is made of steel. The shape has been given by implementing VW process. Then the second is joining the structure part with bonding part via VW process. Three different polymers have been chosen to weld on an incompatible polymer. PA66 was used as a structural part. PMMA, PP and PC were used as a bonding part. To understand the effect of the geometry clearly, the polymers have been welded without fit-form geometry. The VW parameters for two processes were kept constant. The tensile property of the welded parts without form-fit geometry was not measured because of the poor bonding between the polymers. Compatibility of the two polymers is not necessary if the proper weld geometry is chosen. The traditional WV process was not found to be a successful process for the incompatible polymers. Otherwise, the parts with fit form geometry have been shown that they have good bonding properties (Wolf, 2019).

The mechanical properties of the polymers certainly change with increasing or decreasing temperatures (Jia, 1998). The loss of it limits the polymers application area especially in automotive under the hood components, such as water pump, thermostat etc. A significant change in fatigue and tensile strength is inevitable at the conditions of the under the hood component diverse between -40°C and 120°C from application to application. (Lee, 1997). The effect of the increasing or decreasing temperature on the material’s properties is shown on the welded parts, especially for the welded area. 30% GF reinforced PA 6 welded by VW process and the mechanical properties were evaluated at different temperatures. The elevated temperature decreases the mechanical properties of the welded parts. Similar change has been found in fatigue strength of welded and unwelded parts. The temperature change also has similar effects on the welded parts as same polymer composite. (Lockwood, 2014).

3. RESULTS AND DISCUSSION

3.1. The Ultrasonic Welding Process

Results have shown that the ultrasonic welding parameters, amplitude, weld pressure, weld time, and hold time have significant effects on the weld strength. The welding time was found to have the most effective ultrasonic welding parameter, compared to the others, on the ultrasonic welding process between bumper and censor bracket (PP-TD10) parts. The tensile strength was measured 395N. The effect of other parameters on the tensile strength of the welded parts was found to be negligible (Demir, 2019). The same effect on the welding strength was found when the welding time was adjusted to 0.6s or 0.7s in the process. Also, the highest weld quality was found in the same process. For the visual parts, the weld quality and cleanliness are as important as the weld strength. The PTFE film prevented the burr on the welded zone. The comparison between the geometries, ED and without ED, has shown that the average tensile strength of welded parts with ED was higher than the parts that welded without ED (Kiss, 2020). Furthermore, the effect of ED geometry affects the welding properties. The displacement of the welded parts is evaluated for optimizing the ultrasonic welding parameters according to the three different ED sizes. The monitored results have shown that the second peak of the vibration time versus displacement and power curves is the optimum parameter for the selected ED size. 0.25 and 0.5mm EDs created proper bonding between the parts and delamination did not occur at the beginning of the test (Palardy, 2017). The quality can be measured by using the weld area as well. The melted polymers should fill and solidate in weld zone without occurring burr on welded side. The welded area that FED used was found to be smaller than the welded area that FED has not used. Because these parts were welded directly under the sonotrode. The lap shear strength of the designs was clearly affected by the existence of the FED. Especially, with increasing applied welding energy when it reaches 800J, the process with FED is almost twice as more than the process without FED (Goto, 2019). It has been found that increasing of the weld time improves the weld strength. The optimal weld time was discovered as 550ms for HPPA and the maximum force which laminated the two parts was found 3.1kN. The relationship between weld time and weld energy was detected proportionally. The relationship between indentation and force was also detected proportionally for HPPA (Kumar, 2020).

3.2. The Vibration Welding Process

The orientation of the GF in the polymer matrix and effects of it on mechanical properties of the composite have been discussed above. The same effect on the weld strength was not found clearly for 30% GF reinforced PA6, 30% GF reinforced PP, 30% LGF reinforced PP and the last 30% GF reinforced high viscosity PA6. The ineffectiveness of the orientation of GF in polymer matrix can be explained by the reorientation when vibration welding process finished. The vibrations reoriented the GF in the polymer matrix independently of the GF orientation in the polymer matrix (Fiebig, 2018). The surface of the parts mostly consists of the neat polymer, approximately 0.3mm inside of the surface consists of the GF and polymer composite. Most of the energy of the vibration welding is spent to melt this thickness, because of the low friction coefficient. It can be suggested that the machining surface will improve the weld strength and more efficient energy transfer can be created on the surface that has high frictional constant. However, this method might not be found feasible for mass production. Although the unfeasibility for the mass production, the effect of machining smooth surface improves the weld strength, and it was found unneglectable. The gate position of the mold determines the GF orientation of the polymer matrix. The weld strength of X-Flow samples was found to be higher than the P-Flow (Showaib, 2020). The GF orientation effect on the weld strength can be different from polymer to polymer and it can be explained with melting behavior of the polymers. The melting behavior of the polymer always changes according to the molecular bonding of the polymer. This difference leads to the adjustable GF orientation during the vibration welding process. The polymer molecular bonding and elemental structure are the key factors for plastic welding process. Each part should be compatible with each other to make appropriate welding process. However, this problem can be solved by using the Fit-Form geometry. It was found that the parts that were welded by traditional vibration welding geometries and process showed insufficient bonding. On the other hand, the parts that are shaped with Fit-Form geometry have made proper and strong bonding, despite the incompatibility (Wolf, 2019). The working temperature of the polymer is the most important factor for choosing the proper polymer according to the application area, especially in automotive engine parts such as thermostat, water pump etc. The elevated temperature affects the mechanical properties of the polymer, inversely (Jandali, 2004). The same effect can be seen on the welded polymers. It has been found that the increasing temperature decreases the weld strength and catastrophic failure cycle (Lockwood, 2014).

4. CONCLUSION

The welding methods discussed above are commonly based on part application. If the welded parts are used as engine cooling parts such as thermostats, water-pumps, oil pumps etc. where the sealing performance of the parts is necessary and have a smooth and comprehensive surface area ultrasonic welding should be used. Also, the process cycle is the biggest factor to determine and reduce the operating cost. Generally ultrasonic welding operation completes between 0,8 second to 1 second. Compared to the ultrasonic welding, the vibration welding of the process cycle time is almost twice times higher than the ultrasonic welding. So, this means the operational cost of the ultrasonic welding is lower than the vibration welding. The part surface area which the vibration transfers from the sonotrote must be comprehended by sonotrode, the lack of the contact between surface and sonotrote, the ultrasonic welding will fail and can not been used. On the other hand, vibration welding has more flexibility about sonotrode, named as vibration source in Figure 3, comprehension on the part surface. If the part geometry does not let the full contact between sonotrode and surface, the vibration welding should be used, because 80% of contact between the sonotrode and surface is enough to perform proper welding, above this value vibration welding can not be performed.

The amplitude and pressure are the most effective parameters for both processes. The weld depth is not adjustable or changeable parameter in both methods. The bead length is already determined in the design phase. It should be constant in both processes and taken equal with measured bead length from the design. On the other hand, the amplitude determines the weld strength and optical properties of the parts. There are some limitations about how much amplitude should be applied on the part such as for the PPS it should be between 28-32 μm and it is proportional with the crystallinity of the polymers. The weld force optimization depends on polymer type because of the applied force and the vibration energy might damage the part. The force will be slightly higher when the crystallinity of the polymers increases.

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CONFLICT OF INTEREST

The author(s) confirm that they do not have any known conflicts of interest or common interests with any institution/organization or person.

AUTHOR CONTRIBUTION

All of the litherature research, editting and article writing were carried out in the study by Onur Kıyılı.

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