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Study of the technology of vbration jointing of thermoplastic materials used in the automotive sector

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Abstract. Plastics have a wide use in almost all economic areas, their appearance and use has emerged as a necessity to reduce the consumption of natural products and thus decrease the impact on the environment. In the automotive field, a wide range of plastic products are used due to the additional advantage of weight saving and the production rate of large parts, but which in the assembly process requires joint operations with each other respectively with other objects. An important factor in the studied theme was the challenge of combining 2 different PPMA and ABS materials, taking into account the advantages of each one, namely the PMMA polymer plastic material ensuring the transparency property and the ABS polymer plastic material ensuring the strength and stability of the jointed part. The study presents a part used in the automotive industry for which the process of combining the component materials was detailed

Keywords: *welding, plastics, ABS, PMMA, automotive*

Introduction

The need for joining components arises in situations where the whole part is difficult to manufacture in a single stage of manufacture due to the involvement of different materials and geometric constraints and complexities.

Components can be joined by mechanical fixation (with nuts and screws), chemical bonding (with adhesives) or by physical bonding (welding). The method used depends on the material to be joined, the size of the part, the geometric details in the joining region, the production rate of the parts, the service conditions and performance requirements of the assembly, cost constraints and aesthetic requirements.

Welding is the recommended option if an assembly of parts requires a permanent bonding. There are many welding technologies suitable for thermoplastics such as: centrifugal welding, hot plate welding, infrared welding, ultrasonic welding, or friction welding with/without filler material.

Friction welding and vibratory friction, also called vibration welding, provides a robust method for joining thermoplastics to manufacture complex gap assemblies from simplified injection molded items without using an external heat source, adhesives, or mechanical fasteners. Using only the heat resulting from the inner friction of the joined parts creates precise, hermetically sealed joints between the plastic components, which once glued can become airtight and maintain pressure if necessary.

In the automotive industry this technique is used for welding headlights, instrument panel assemblies, acrylic-acetal gasoline tanks, nylon brake fluid tanks, access doors to the welded polypropylene compartment in 2 planes, etc.

2. Presentation of the process

Vibration welding of plastics uses the energy resulting from the transformation of the mechanical friction energy between the welding components into heat that damages the melting of the material in the joint area [STAS 12147-85] [8].

The work will present the way of joining 2 pieces having as base material PMMA polymer (upper part) and ABS polymer (lower part) resulting in an assembly whose joint must ensure resistance and tightness to air and water, being used on the outside of a car.

The vibration welding method will be used due to its advantages that fall within the previously exposed desideratum of using material and methods that ensure good productivity, lower costs, low energy consumption (vibration welding not needing outside heat) and with low impact on the environment (without smoke).

PMMA (polymethylmethacrylate) is a thermoplastic polymer, obtained by polymerization of methylmethacrylate monomer. It is transparent that is why it is also called "acrylic glass" and good mechanical resistance to scratching makes it to be used in the automotive field in parts that are located outside cars in the outside environment and require transparency, [11].

Acrylonitrile Butadiene Styrene (ABS) is an amorphous polymer produced by emulsion or by mass polymerization of acrylonitrile with styrene in the presence of polybutadiene. The most important properties of ABS are impact resistance and hardness, [11].

The process of welding by linear vibrations is based on a relative oscillating frictional movement of the parts that reach melting (semicrystalline) or softening (amorphous) of polymers due to the compression of particles during movement according to the amplitude and frictional force.

Advantages of the vibration welding process

Polymer

- melted polymers are not openly exposed to air, so there is no risk of oxidation of the polymer.
- no foreign material is introduced, so the welding interface is created from the same material as the welding parts.
- the transparency of the material and the wall thickness do not impose limitations on the welding process as in the case of laser welding.
- heating is largely localized so it is much less likely that material degradation from overheating will occur.

Process

- the process is cost-effective having short cycles and involves the use of simple equipment.
- welding processes are suitable for mass production.
- no smoke is emitted during welding.
- the process works well for a variety of applications.

Aspect

- The weld burrow is formed at the edges of the welded kitties during the process. If this leads to an unacceptable appearance, then a hidden joint is used.

2.1. Welding of thermoplastics

Thermoplastic polymers are composed of molecules in which there are repeated monomeric units attached together in long chains. An important property of thermoplastic polymers is that they soften and melt after heating and harden when further cooling. When two products made of a thermoplastic material are welded, the polymer chains diffuse over the interface and a bond is formed by combining the chains, as shown in Figure 1. This applies to all welding processes for thermoplastics.

In the joints of usual polymers, the flow of molten polymer is not required; the link is formed by diffusion.

Diffusion is not related to viscosity.

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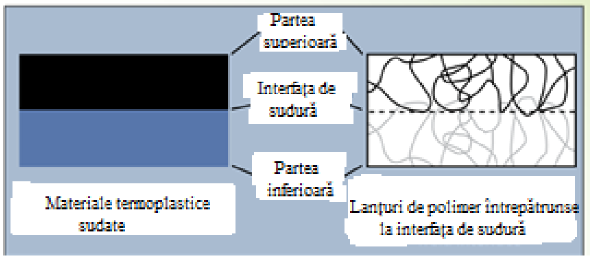

Figure 1. Molecular diffusion and combination due to welding, [9]

The low thermal conductivity of thermoplasts maintains the cooling speed after melting low enough for the formation of strong bonds.

The behavior of thermoplastics is different and advantageous compared to metals where heat is easily transported away from the welding area. Almost any thermoplastic can be welded by vibration: crystalline, amorphous, filled, foamed and hardened.

In the case of welds involving different polymers, the weld strengths are governed by the mutual affinity of the two polymers, so if the two polymers are not compatible, the resistance factors at the welded joint may be substantially less than 1,0, relative to the less potent polymer; for example, pairs of polymers such as PMMA-PBT, ABS-PPO, ABS – PEI, PPO – PC, PPO – PPO / PA (mixture of PPO and PA) and PPO/PA – PC develop significantly lower vibration welding resistances than the resistance of the weaker polymer, [2].

For compatible pairs of polymers, the resistance of the weld under optimal processing conditions can be as high as the resistance value of the weakest of the two polymers in the case of different pairs such as: PC-PEI, PMMA-PPO, PC-PBT, PC–PC/PBT (PBT and PC mixture), and PBT– PEI [2].

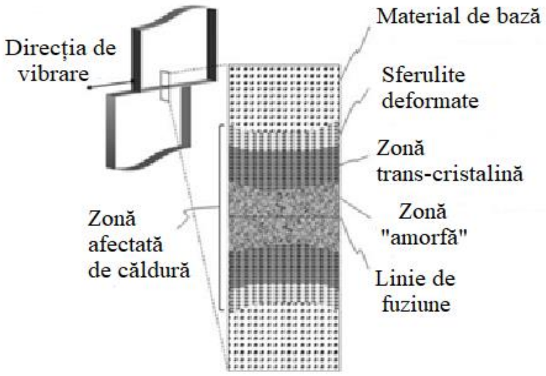

Figure 2. Typical microstructure detail of the vibration welding area of a semi-crystalline polymer [2].

For semi-crystalline polymers, Schlarb and Ehrenstein [5], Chung and Kamal [3, 4] and Varga et al. [7] concluded that the typical microstructures in the heat-affected area of the welds with the best resistance consist of four regions, as shown in the simplified way in Figure 2 (taking into account the observations of microscopic studies reported in [3, 4, 5] the various fillers used in this scheme only serve to differentiate the different regions and are not representative of the actual microstructural characteristics observed):
- the "amorphous" region – located in the immediate vicinity of the welding line, being a region without any visible crystallineness (indication of rapid extinguishing),
- region "trans-crystalline line" - is a recrystallized area with spherulites of various sizes (indicative of melting, flowing and re-solidification).
- 'deformed spherulite transition zone" - ahead of the basic material.
- the microstructure region of the basic material.

2.2. Phases of the vibration welding process

The process takes place over 4 successive phases shown in Figures 3,[2]:

- Phase I – solid friction – the penetration of the weld is not recorded in the friction process. This indicates that normal pressure does not lead to the collapse of any interface as long as the material is solid.

The first signs of displacement that are recorded on the linear displacement of the transducer indicate the onset of melting at the interface, thus marking the end of the first phase.

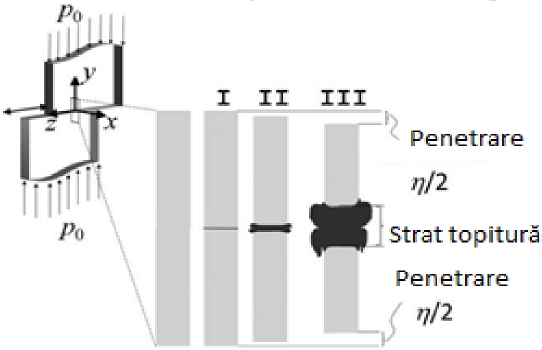

Figure 3. The evolution of the macroscopic appearance that occurs in the area of the weld seam during vibration welding. The scheme shows the cross-section of the weld area in plane x – y with the vibration carried out in the direction z, [2].

- Phase II – unstable evolution of penetration – the beginning of the penetration of the weld marks the beginning of the flow regime and viscous dissipation of the molten material. At first the penetration rate evolves with time, this indicates an unstable state in which the rate of new melt flow within the melt film is not equalled with an output rate in the weld seam, thus indicating an effective accumulation of the melt and the increase of the melt film as shown in Figure 3.

The increase in the width of the joint is actually an increase in the region of the melt flow in the x direction, according to Figure 4, which causes longer periods of stabilization of the flow in that direction.

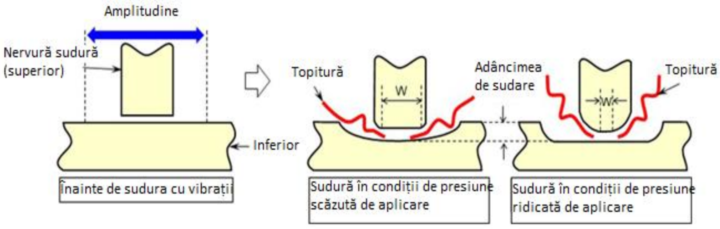

Figure 4. Melting film evolution, [10].

- Phase III – Constant increase in penetration – within this phase, the lateral extrusion to the outside of the material results in the growth of the weld seam.

According to Stokes' measurements for longitudinal vibration welding [6] it is shown that the penetration rates of the equilibrium state increase with increasing weld pressure under the conditions of constant preservation of the weld geometry, amplitude and frequency.

After a certain time, penetration increases linearly with time resulting in a constant penetration rate. Thus, the steady state was established with the rate of formation of the fresh melt corresponding to the rate of melting output in the weld seam, which implies a 0 accumulation rate or a constant thickness of the molten area.

Even from the conception phase of the devices, constructive measures are taken so that in the area of formation of the joint the production of heat by friction is favored. Once the plastic has softened and melted sufficiently, the vibrational movement should be stopped quickly to prevent shearing of the joint area.

Stopping can be achieved either by using a shear pin, which will break when a predetermined shear force value is reached, or by using a clamping device.

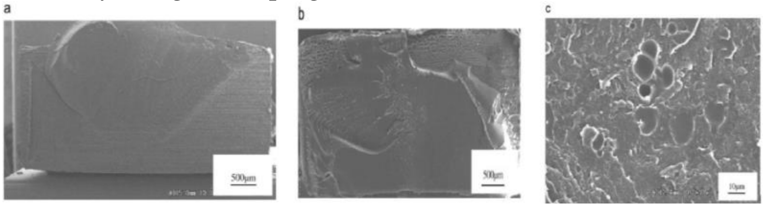

Figure 5. Representation of the breaking surface at the joining interface of a PC material at a welding pressure of 0.3MPa and welding time of 1.5 seconds (a), 3 seconds (b) and 4.5 seconds (c), [1]

The discharge time, unlike the friction time, is not chosen at high values, because when stopping the relative movement, the weld cools at high speed. Figure 5 shows the appearance of broken samples made by welding with different time.

- Phase IV – solidification – after the moment of stopping the vibrational movement causing the friction of the pieces to stop, the previously formed melt begins to cool and then solidify, resulting in the final welded joint. This time is 1 second.

According to research by Stokes it has been observed that the most resistant welded joints are produced when the penetration is at least 0.25 mm [8, 9, 10].

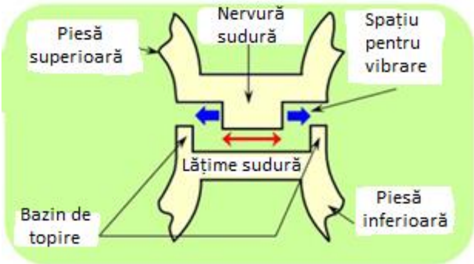

Figure 6. Merging detail of 2 plastics (longitudinal - left) and section (right), [10]

Figure 6 shows a joint detail of 2 plastics in which the cross-section joint is represented, indicating the components of the joint.

The determining factor of the strength of the welded joint is the penetration of the weld. The strength of the joint is equal to the resistance of the polymer of the base material, and this can be achieved when the penetration of the weld exceeds a critical threshold, equal to the penetration that is recorded at the beginning of phase 3 of the equilibrium state.

The resistance of the welded joint decreases for depths less than this value of the critical threshold. The resistance of the welded joint decreases for depths less than this value of the critical threshold. A depth value greater than the critical threshold does not affect the strength of the weld in the case of polymers without reinforcement, or with glass filled, resins or structural foams, but it can increase the strength of the welded joint of various materials [15-16].

3. Case Study

3.1. Preparation of parts for welding

The joining of the 2 pieces that will make up the ensemble will be made along the entire length of the outline of the pieces, whose shape is irregular, figure 7.

The assembly will be empty and airtight.

In order to achieve this type of joint, the vibration welding process will be used, so next only the process and the parameters of this process will be presented.

Figure 7. Part contour and direction of welding

The 2 parts made by injection are placed in the devices to be able to allow the welding process. Tools (devices) have the role of centering and fixing the components for welding. These tools must ensure a relatively adjustable position of the elements to be welded. The tools must provide a repeatability of the positioning and fixing of the elements in order to obtain a constancy of the geometry of the assembly of welded parts, which are dimensionally acceptable.

The assembly process must ensure that the scrap due to the welding machine and tools is as low as possible.

The welding tools that will be mounted on the platters of the welding machine must ensure the centering, fixing and detection of the parts that will be welded.

The materials to be used in their construction must provide protection of the parts against scratches and degradations of any kind. They must be designed in such a way as to ensure that it is possible to quickly mount and disassemble in the welding machine in the event of a change of manufacture (welding of the assembly).

3.2. Equipment used

Figure 8 shows an equipment that performs the welding of plastic parts by vibration movement. It is provided with a window that allows the insertion of parts for welding and then closes to ensure the protection of the operator and with a control unit that allows control and adjustment of welding operations and parameters.

The equipment of the vibration systems is electrically operated and consist of 3 main components:

-vibrating assembly (suspended on the springs).

-feeding.

-the pressing mechanism.

The pressing mechanism (which applies the verical pressure to the 2 pieces to be welded) is a hydraulic lifting table, to which the lower fasteners are attached.

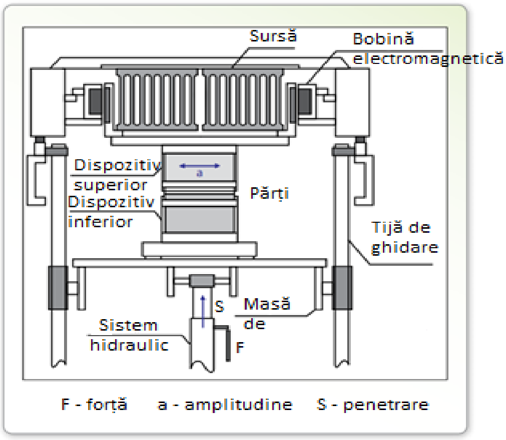

Figure 8. Vibration welding equipment [12].

3.3. Stages of the welding process

The welding process is carried out successively:
1. The parts are cleaned of impurities by blowing with ionized air.
2. The 2 pieces (which will make up the welded assembly at the end) are placed in the welding equipment in the upper and lower fastening device, correspondingly according to the working procedure (WPS) which specifies the way of laying, the control parameters, the loads.
3. The welding jointing equipment closes.
4. The welding process begins by moving the upper and inner devices that drive the movement of the 2 pieces on top of each other to bring the surface joint into contact under continuous pressure.
5. Vibrations which are generated either by a gearbox, by an electric magnet, or by mechanical vibration generators, are transmitted to the devices and through them on articulated surfaces. The movements of the two sides take place in opposite directions, as a result of friction, the temperature rises immediately, reaching the point of plastic melting in less than 1 second.
6. After a predetermined time, an electrical control device stops vibrations while the pressure on the joint is maintained. Simultaneously, the parties are brought into the correct position in relation to each other.
7. The pressure is maintained for a few seconds to allow the molten material to cool and subsequently strengthen creating the welded joint. Then the equipment and devices are opened and the assembly of welded parts can be taken over.

This method is suitable for large parts, parts can be non-circular or irregular in shape, and welded joints can be obtained over lengths of 100 ÷ 150 mm.

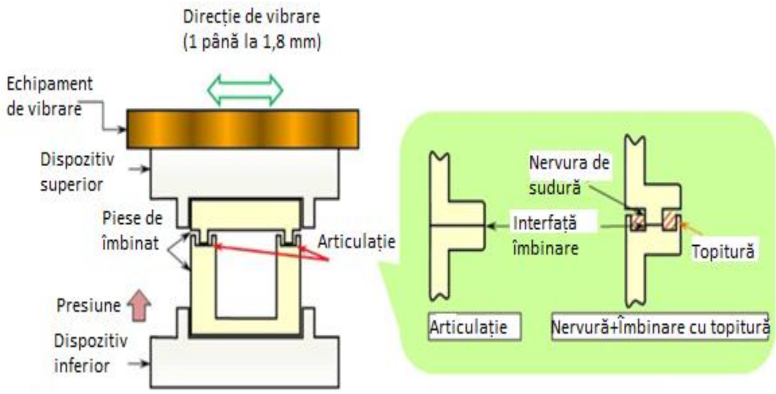

Figure 9 The scheme of the vibration welding process involving sinusoidal oscillations in the longitudinal direction,[10]

Figure 9 shows schematically the vibrating mode of the elements joined in a longitudinal direction, i.e. the parts are vibrated in a direction parallel to the longer edge, being considered "longitudinal vibration".

If the parts are vibrated in the direction parallel to the short side, welding by "transverse vibration" shall be considered. Together, these processes are called "linear vibration" welding processes because the trajectory of vibrational motion remains linear and constant. If the vibrations are applied in several directions, it is considered welding by "orbital vibration".

3.4. Welding Technology

Parameters of the welding process

In the control panel of the welding equipment where the values of the vibration welding process parameters are entered, and in Table 1 the values of the welding parameters are presented.

Table 1. Parameters of the welding process

Nr.	Parameter name	Value
1	Amplitude oscillation	1.5±0.3 mm
2	Welding Race	0.7±0.3 mm
3	Welding pressure	115 lumena
4	Maintenance time	2±1.5s
5	Pressure Keep	80 lumera
6	Oscillation frequency	100 Hz

The lower tool must be provided with sensors confirming the correct location of the body. The adjustment of the sensors can be made from the front of the welding device. The operator shall be positioned at the mounting position at the vibrating welding machine.

The authorization to start the welding operation is made after the operator performs together with the regulation two sets of welded parts that are checked as follows:
- a set of parts suitable for sealing and 3D measurement.
- a set of parts in which the continuity of the weld joint is verified by the destructive sample.

The operator at the assembly station performs the following operations:
- take the lower part from the stroller, a sulfa with ionized air and place it in the recess of the lower device, taking care that there is no play between the part and the device (press and push the parts);
- takes the upper part from the conveyor belt or from the box and makes it a visual check aimed at not having scratches, cracks, sweeps or black dots (according to the control range) and blows it with ionized air;
- the non-compliant upper parts are deposited in the non-compliant box,
- after blowing it with ionized air, place the upper part over the lower one, taking care that it sits according to the standard, on the fixed centrators;
- starts the welding process;
- at the end of the welding cycle, he extracts from the lower device the assembly consisting of the 2 welded parts, makes them a visual check (according to the control range) following the appearance of the weld seam (by comparison with the model assembly) and puts them on the trolleys that then go to the oven.
- the non-compliant assemblies are identified with the red label and are placed on the palette with parts in analysis.
- non-compliant items shall be recorded.

Identification of special features and important characteristics:
- the appearance of the weld seam.
- dimensional conformity.

Examination

After the jointing of the parts is made to check the quality, a series of measurements are made in several important points.

1. Destructive test:
- the weld seam is good, when the red lens remains in the black housing, or leaves deep print.
- the weld seam is not good, when the weld trace is superficial.

2. Sealing test:

The welded assembly of the parts is given pressure of 100 mbar and the loss must not be more than 0,5 mbar.

The causes that can cause the non-compressive jointing of the parts:
- geometric deformations of the pieces: flatness, burrs due to the surplus of material, deviations of elevations not in accordance with the drawing.
- incompatibility of materials at which the melting temperature is different (example incompatible materials at the housing and lens);
- saturation humidity in the piece.
- unoptimized parameters of the vibration welding process [13-14].

Figure 10 shows 2 unsuccessful examples of joining parts (scrap).

Figure 10. Defects in the joints of parts

4. Conclusion

In the work were present a polymer joint PMMA (upper part) and ABS (lower part) resulting in an assembly whose joint must provide resistance and tightness to air and water, being used on the outside of a car. Although PMMA and ABS are different materials, they are compatible with each other and are frequently merged together.

For the jointing of the two PMMA and ABS materials, the vibration welding process was used due to the advantages:

• good productivity,
• lower costs,
•low energy consumption (vibration welding not needing outside heat)
•low environmental impact (smoke-free).

Analyzing the technology of achieving the welded joint obtained, the conclusion is that if the welding parameters are optimized and the recommended welding technology is observed, the part can be obtained in a relatively short cycle, namely 67 ± 5 sec/ cycle.The determining factor of the strength of the welded joint is the penetration of the weld. The strength of the joint is equal to the resistance of the polymer of the base material, and this can be achieved when the penetration of the weld exceeds a critical threshold, equal to the parttundere that is recorded at the beginning of phase 3 of the equilibrium state.

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