Joining Of Metal-Plastic Composites With Advanced Welding Processes

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Abstract: Due to the growing environmental concern and the increasing demand for more ecological methods of transportation, composite materials that combine low weight and high resistance have raised the interest of several industrial sectors. Among these materials, the metal-plastic composites (MPCs) can be highlighted, who combine a low weight and a relatively high mechanical resistance. Such materials are used in advertising signs, building panels, motor shielding, etc. Mechanical joining of MPC materials is to be avoided when protrusions are not allowed or because of aesthetical reasons. Welding is therefore considered as an interesting alternative. However, qualitative joining using welding of the MPC materials to other MPC materials or to metallic plates is a real challenge. Due to their special features (layer structure, material mix, etc.), conventional manufacturing processes are therefore only of limited or no use at all. In particular, the polymer core layer is a barrier for the use of conventional joining methods. This contribution presents a novel joining approach for MPCs. The basic approach is the local melting of the polymer layer by ultrasonic waves and displacement of the molten plastic material by pressure on the cover sheets. This work proposes the investigation of the use of non-conventional solid-state welding processes, such as ultrasonic welding (USW) and refill friction stir spot welding (RFSSW), for joining MPCs with aluminium sheets. Prior to the application of the joining processes, the intermediate plastic core of the MPC materials is displaced using ultrasonic vibrations, so that the materials can be joined as monolithical materials. These joining concepts are validated experimentally. The obtained weld quality is assessed based on destructive and non-destructive testing methods.

Keywords: adhesive bonding; EN-AW-5182; EN-AW-6082; refill friction stir spot welding; ultrasonic welding; mechanical joining; MPC materials.

1. INTRODUCTION

Today, there is a large demand for efficient and sustainable energy use since the climate is evolving at a rapid pace, mainly caused by greenhouse gasses emitted by human activities. To address the increasing ecological concerns, the implementation of high strength lightweight materials with high performance in several industrial branches is the key factor to success. This weight reduction is necessary and involves approaches from different engineering disciplines. Weight reduction is generally defined as an integrative construction technique, using all available means from the field of design, material science and manufacturing in a combined way to reduce the mass of a structure and its single elements, while at the same time the functional quality is increased [1].

MPCs are used in a growing range of technical applications in various industrial sectors due to their excellent stiffness to weight ratio. In addition to the weight, the MPC's outstanding stiffness and damping properties are a major advantage. A challenge that connects all the different applications is the necessity to process the MPCs efficiently with high quality and to join them with other materials, using suitable joining techniques. From a technological point of view, the problem arises from the layered structure and the material mix of the MPCs, which is characteristic for these materials. This can detrimentally affect the quality when processing the sheets using forming or joining manufacturing processes. Regarding joining, the conventional processes which have been used for many years for monolithic sheets are unsuitable for joining of MPCs. The consequences can be a poor surface quality due to cracking of the metallic surface layers or a local failure of the metal-plastic structure. Considering these difficulties, an investigation must be undertaken to develop suitable joining techniques capable of joining sandwich-structured sheets with other adjoining (metallic) components.

2. Experimental Procedure

Numerous application fields and many product variants with different technical production conditions and requirements are possible. Up to now, the presented MPCs are mainly joined using mechanical fasteners or bonding methods, such as bolts, rivets or chemical reagents. However, (some of) these techniques do not contribute to a weight reduction, require preparations of the sheets with chemicals and/or are generally not ecological at all. Therefore, several innovative joining concepts are developed in order to apply modified conventional joining technologies for joining MPCs with monolithic sheets.

One concept that will be explored is the two-step approach (see Figure 1), which involves pre-treatment of the MPCs by local liquefication of the polymer interlayer near the future joint area. The outer metal skin layers of the MPC material are compressed after the core has been displaced, in order to be able to treat them as a monolithical material. Liquefication and displacement of the polymer interlayer could be accomplished in several ways. Each of them is based on the efficient use of frictional heat, provided by the RFSSW-process, ultrasonic-stimulated forming tools or a shoulderless, un-grooved flat FSW-tool mounted on a milling machine.

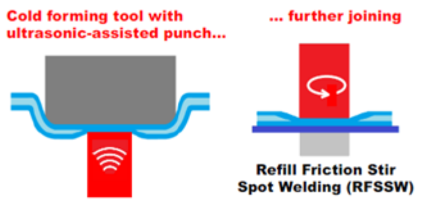

Figure 1: Visualization of the two-step approach [2].

It is suggested that solid-state welding processes will be the most suitable for the second phase of this two-step approach, more specifically the welding stage. Solid-state welding implies that the temperature during the welding process is not exceeding the melting point of the materials to be joined. This avoids many defects associated with melting and solidification, such as gas porosities, hot cracking, and non-metallic inclusions [2,3]. The principles of the investigated and tested (joining) approaches are discussed more in depth in the following paragraph.

A. Refill friction stir spot welding (RFSSW)

RFSSW is highly suitable for welding aluminium alloys, especially for welding advanced high-strength aluminium alloys (2xxx–7xxx), which are not weldable or at least difficult to weld using the conventional well-known strategies [4]. The RFSSW approach results in a spot connection with considerably fewer material losses, the absence of a weld crater and a noticeably flatter surface, in contrast to friction stir spot welding (the non-refill variant). The interfacial metallurgical bond is made through frictional heat and plastic deformation, both leading to softening of the materials [5,6]. The complete welding process consists of 4 different stages as visualized in Figure 2.

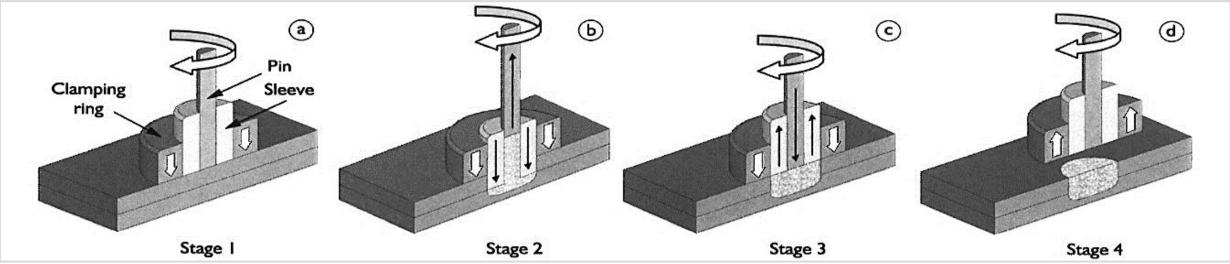

Figure 2: Schematic presentation of the RFSSW-process sequence [7].

In the first stage, the clamping ring, sleeve and pin are lowered simultaneously until the tool shoulder has reached the top level of the upper metal sheet. The clamping ring fixates the adjoining components between the welding head and the anvil by applying a surface force, while the pin and sleeve start rotating with an equal speed, in touch with the upper metal layer. Initial frictional pre-heating is initiated. When this kind of friction occurs, the temperature of the upper metal sheet is rising, increasing the plasticisation rate of the adjoining materials. In the second phase, the sleeve (or pin) is plunged into the adjoining materials under a high rotational pre-set velocity while the pin (of sleeve) is retracted. Because of these movements, a round-shaped space is created underneath the pin (or sleeve) in order to contain the previously plasticised and softened material. Described as the third stage, the movement of the sleeve (or pin) is reversed when a pre-determined plunge depth is reached. The residual plasticised material, accumulated underneath the pin (or sleeve), is pushed down in the created weld crater in order to refill it. The last stage represents the retrieval of the welding head [5, 6, 8].

The process itself is characterized by determination of its parameters, which is mainly done by experimental work (trial-and-error) by observing the joint behaviour, the microstructural and the mechanical properties of the weld. The total duration of the friction phase, named as the joining time (JT), is the sum of the plunge time (PT), dwell time (DT) and retraction time (RT), as depicted in Figure 3.

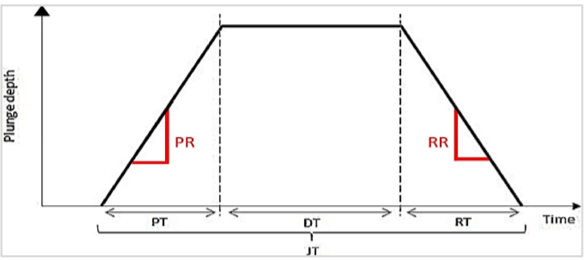

Figure 3: Time-related parameters, proper to RFSSW [5].

The slope of the curve, i.e. the rate at which the plunge depth increases, or the retraction is performed, is defined as the plunge and retraction rate respectively (PR, RR). The JT controls the amount of heat generated during the welding cycle. The PT refers to the actual time it takes to reach the pre-determined plunge depth (PD) by the plunging part of the tool. This PD is described as the penetrating distance of the plunging element of the RFSSW-tool during the plunging phase, mainly restricted by the thickness of the workpieces to be welded. This is in contrast with the RT which is equal to the duration of the retraction phase of the plunging element at the end of the weld cycle. Both plunge and retraction time lead to plastic deformation of the weld zone. Accordingly, the time the plunging element remains stationary at the PD whilst rotating with a certain rotational speed (RS) is defined as the dwell time (DT). The clamping force used to fix both workpieces in the overlap configuration is set based on empirical rules of thumb: the clamping must be rigid enough to avoid relative movement of the workpieces during welding whilst ensuring complete refilling, but may also be limited to avoid excessive plastic deformation of the joining parts.

A classic cross-sectional view of a RFSSW-weld is shown in Figure 4, revealing its typical geometrical zones, characterized by their own metallurgical (grain size, orientations, etc.) and mechanical properties.

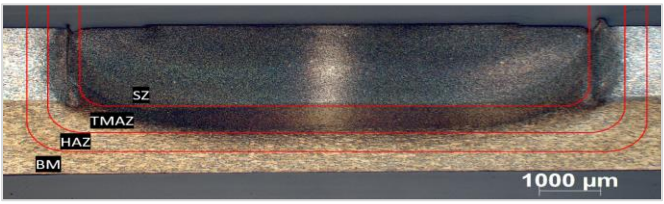

Figure 4: Geometric zones in RFSSW-specimen [9].

The stir zone (SZ), which has the same area of the tool's plunging elements, is typically found in the middle of the nugget and features equiaxed refined grains formed due to dynamic recrystallization. Therefore, this area can be further divided in the pin (P-SZ) and sleeve stir zone (S-SZ), referring to the individual plunging parts of the welding tool assembly. These refined grain distributions are usually associated with a zone having superior characteristics compared to the base metal (BM), which did not undergo microstructural changes. Next, the thermo-mechanically affected zone (TMAZ) is defined as a transition layer which surrounds the SZ. This area is mainly caused by elevated temperatures, provided by rotation of the welding tool, and high plastic deformation rates, both resulting in larger grains. The HAZ is the intermediate area between the weld nugget and the unaffected materials and does not experience plastic deformation. The microstructural changes within the HAZ are due to frictional heat. The transition from the HAZ to the base material (BM) cannot be specified exactly but the coarsening of the grains usually provides an indication [10,11].

B. Ultrasonic welding (USW)

USW is an industrial welding technique where high-frequency ultrasonic acoustic vibrations are locally applied to workpieces being held together under pressure to create a solid-state weld. Practical application of this process is already known from the late 1960s and is nowadays mainly used for plastics, metals and especially for joining dissimilar materials, such as electric contacts (aluminium-copper), or battery connections (copper-nickel) as shown in Figure 5 [12].

The bond formation is based on energy transfer (vibrations) between the materials to be joined which avoids the necessity for connective bolts, nails, soldering materials, or adhesives thus contributes to weight reduction [14].

Figure 5: Dissimilar USW, illustrating its versatility [15].

A typical USW-assembly is shown in Figure 6, left. Before welding, the adjoining workpieces are fixed between the so-called anvil and the sonotrode. This coupling system transmits the low-amplitude acoustic vibrations (1 - 25 µm) which are generated by the piezo-electrical transducer, i.e. the emitter of the ultrasonic vibration waves. The sonotrode tip is the component that directly makes contact under static loads between one of the workpieces and ensures penetration of the waves inside the materials, along with transmitting the ultrasonic energy. Next, the sonotrode and the upper joining sheet start vibrating as a result of constant expanding and contracting of the sonotrode along its length. This must be done with the same amplitude and (resonance) frequency in order to plasticise the materials due to frictional slippage at the weld interface and thus finally creating the welding joint (see Figure 6, right) [16,17].

The US-parameters must be optimised in order to achieve good quality welds. For each application or material to be processed, the variables are established experimentally. First, the frequency (f) is adjusted by the converter that is implemented in the machine and must be finetuned in order to achieve the desired weld quality. Therefore, the maximum frequency level is limited by the used welding tool, also named the welding horn or sonotrode. This component is custom-made to meet the desired application requirements, and its shape determines the maximum achievable amplitude that can be used to perform the weld. If necessary, the tool must be changed in order to reach higher frequency levels, which may lead to shorter welding times (WT). The latter is described as the amount of time for the ultrasonic waves being applied to the workpieces. This parameter is directly related with the total energy input and takes about 5.0 ms to 1.0 s for workpieces with larger thicknesses, much lower compared to the previous discussed RFSSW-technique. Next, there are two different ways on how the energy setting (E) may be chosen. This could be in terms of high-frequency power input to the transducer, or the power dissipated between the assembly consisting of the transducer, sonotrode and the workpiece itself. Logically the power requirement will depend on the workpiece material and its thickness. Next, the amplitude (A) of the vibration, usually expressed in a percentage, is related to the melting temperature of the material: workpieces with higher melt temperatures may require an increased amplitude. Further, the workpieces are held together by a longitudinal applied clamping force (F), straight to the backing anvil. Choosing this parameter too high will lead to unnecessary deformation of the workpieces to be welded, in combination with the need for higher ultrasonic power rates. This contrasts with a low clamping force, which causes tip slippage and leads to surface damage or exaggerated heating. [18]. Usually, the parameters for a given application should not be changed once they are determined, unless the welding result is influenced by wear of the equipment, such as a sonotrode tip change, slippage or adjustments of the workpiece environment. Also, manual use of this application is not recommended (but not excluded) since the processing parameters are accurately determined, so deviations can lead to a decrease of the weld quality.

A typical cross-sectional view of an US-welded specimen is recognisable by its alternating sawtooth pattern as shown in Figure 7(b), which is the result of the local indentation by the knurled pattern of both the sonotrode and the backing anvil. Several regions (see Figure 7 (a)), can be defined with the same terminology as RFSSW since the tool-material behaviour relationship is almost equal compared to friction welding processes.

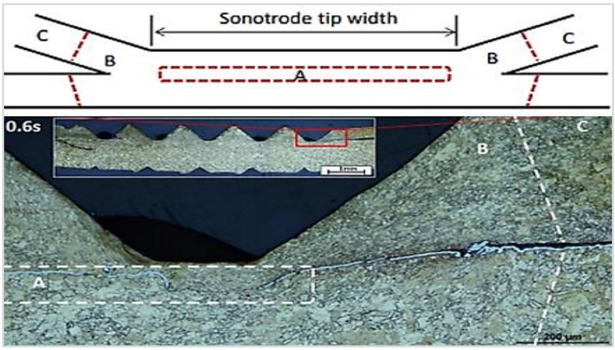

Figure 7: Typical USW cross-section, including the visualisation of its geometrical zones [19].

The weld nugget, similar to the stir zone in RFSSW and typically having the same width as the sonotrode, is the region characterized by the greatest adhesion and effective interfacial bonding between the adjoining surfaces. Here, the components are experiencing a combination of increased temperature by the ultrasonic vibrations and thus frictional heat due to the horn movement, followed by plastic deformation as a result of the sonotrode force, both leading to dynamic recrystallization and thus grain refinement. Next to the zone where the sonotrode acted on, the thermo-mechanically affected zone (TMAZ) forms the transition layer to the unaffected base metal (BM). The area of the TMAZ shows elongated grain shapes parallel to the vibration direction, which are slightly coarser compared to those of the weld nugget [19].

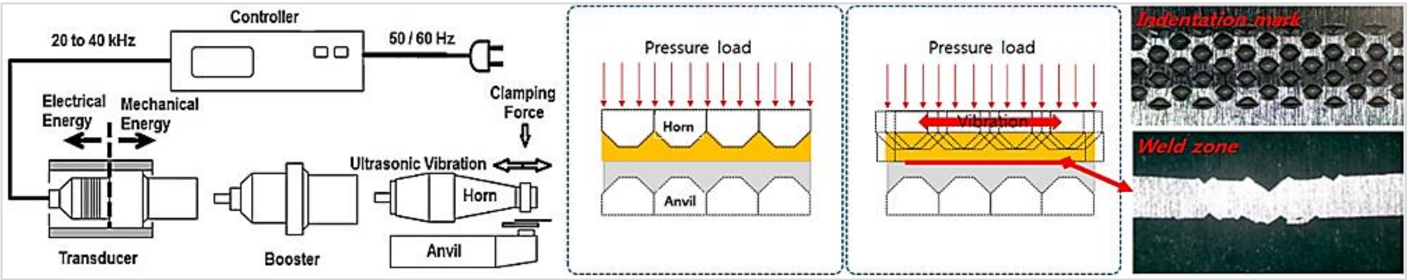

Figure 6: Built-up of an ultrasonic welding system (left), including the interfacial joint development [13].

3. Material selection

The selected materials can be divided in two main categories, the MPC components and the aluminium alloys respectively. The Hylite® (Highly Versatile Composites) MPC materials, manufactured by 3A-Composites, were used for the experiments as the lower joining component. The material itself consists of polypropylene (PP) with a thickness of 0.8 mm, surrounded by two solid aluminium skins (EN AW-5182) each having a thickness of 0.2 mm, resulting in an overall thickness of 1.2 mm.

The MPCs represent a smooth and flat surface with low roughness, provided by its applied polyester finish layer based on fluoropolymers. These coatings are characterized by tight molecular structures with great solid content and have outstanding properties of chemical resistance, thermal stability, low friction coefficients and dielectric constants [20]. However, it is fundamental to generate frictional heat on the outer skins of the MPC sheet to create the welding nugget, based on heat conduction through the various material layers, in order to apply friction welding techniques. Therefore, it is expected that this coating may increase the vulnerability to welding defects.

EN AW-6082-T6 aluminium with thicknesses varying from 1.0 to 1.5 mm is used for the upper joining sheet, to be joined with the Hylite® materials.

4. Experimental data, work and discussion

The main objective of these experiments was to gather the necessary insights into the joint formation using thermal and mechanical joining techniques of the Hylite® MPCs and aluminium sheets in EN AW-6082-T6. Subject of investigation was the metallurgical bond creation between the thin aluminium skin sheets of the MPCs and the aluminiumsheets and the intermediate plastic layer behaviour under the influence of (frictional) heat. The following experiments are discussed.

- Application of conventional joining techniques (bolting, adhesive bonding) or application of joining processes without adoption of the two-step approach (RFSSW, FSW)
- Displacement of the polymer core (by RFSSW, US-forming tools and frictional heat provided by a shoulderless and un-grooved FSW-tool)
- Joining experiments using RFSSW and USW (with both displaced and un-displaced polymer core).

The executed test series are examined by visual, macroscopic and metallographic investigation methods, lap shear testing and hardness measurements as well as the influence of the RFSSW-parameters (PD, RS) are investigated.

4.1. Application of mechanical joining techniques

Some conventional joining techniques were used to join the MPC sheet and aluminium sheets, to serve as a benchmark for the joints executed according to the new joining concepts.

A. <u>Joining by bolting</u>

Bolt connections are well known in most industrial sectors and are available in many different sizes. Therefore, the adopted metric sizes (M6 → M12) are chosen to resemble the size of the welding tool used at a later stage in this work.

The obtained lap shear strength (LSS) is graphically shown in Figure 8 and ranges from ±3.0 kN for the smaller, up to ±7.0 kN for the larger bolt sizes. This finding is comparable with RFSSW, where using the sleeve plunge method tends to lead to larger bonding areas and thus better mechanical performance [21].

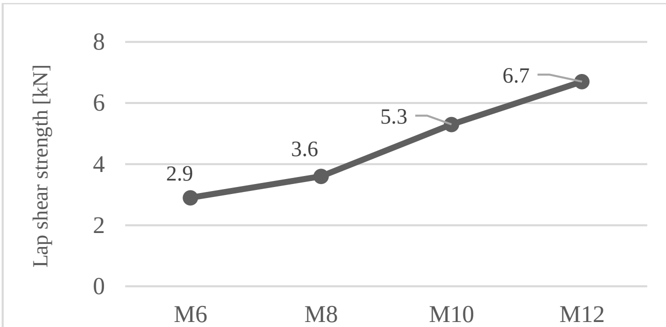

Figure 8: Obtained LSS – joining by bolting.

B. <u>Adhesive bonding</u>

Chemical fastening technologies are preferred over mechanical joining when high stiffness assemblies are desired. In many cases, it offers an alternative to welding making it interesting to experiment with. In total, 4 compositions were made: the bonding agent was applied in 2 different ways; spot-wise (with reference to the used welding technique) and uniformly spread over the entire overlap area, both on MPCs with and without removed coating. The results of the tensile tests are visualized in Figure 9.

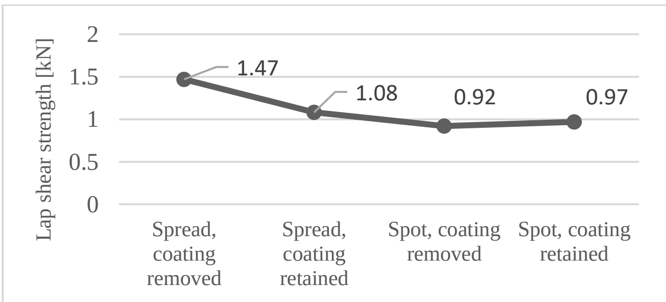

Figure 9: Obtained LSS - joining by adhesive bonding.

As shown in Figure 9, no clear relationship between the LSS and the used configuration was obtained. Even when the best result (±1.5 kN) is achieved with larger contact areas and with removed coating, the deviation in strength (±0.4 kN) is proportionally quite large which indicates uncontrolled circumstances and thus difficult to make comparisons. Various factors could be the cause of this, such as curing temperatures, curing pressure or surface contaminations.

4.2. Application of thermal joining approaches

A. Weldability of thick to thin sheets using RFSSW

The purpose of these experiments was to investigate if it is possible to join thick (EN AW-6082, 1.5 mm) to thin (EN AW-5182, 0.3 mm) sheets using RFSSW, where the thickness of the latter has been chosen equal to the thickness of the MPC's cover sheets.

The combination of using thin materials and a (relatively) high clamping force, to ensure adequate material coupling and complete refilling of the welding zone, results in bending of the workpieces. This deformation was prevented by using a steel backing plate, leading to joints which could withstand tensile shear loads up to ±2.0 kN. A typical cross-section is shown in Figure 10.

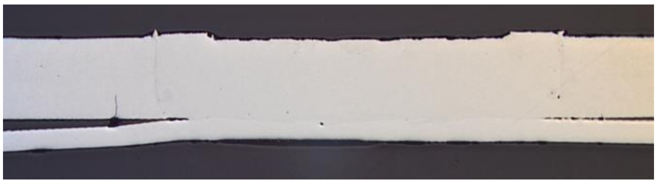

Figure 10: RFSSW of thick to thin aluminium sheets.

B. Preliminary experiments with friction stir spot welding

Experiments were carried out using friction stir spot welding (FSSW; the non-refill variant) for welding MPCs and aluminium sheets, reaching LSS values up to ±1.50 kN. The created metallurgical bond is characterized by absence of voids, cracks or other harmful welding defects related to FSSW, whilst the top sheet is highly deformed, as shown in Figure 11.

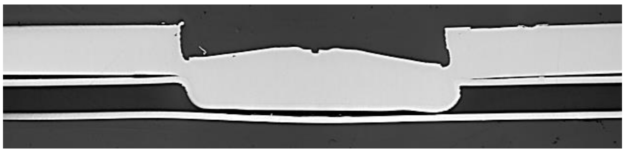

Figure 11: Preliminary trials using FSW.

Although, the top sheet did not always remained intact, resulting in tops sheet plug-outs (=perforations), surely affecting the tensile load capacity of the weld, which decreases on average by ±0.50 kN. Further, it seems that the polypropylene interlayer of the MPC is not entirely molten and displaced. One reason for this may be the polyester coating of the Hylite® MPC, offering a thermal stability to the material, and complicating the heat conduction through the multiple workpiece layers.

4.3. Displacement of the polymer core

A. Displacement by RFSSW

The aim of these experiments is to investigate the effectiveness of locally displacing the polymer core of the MPC under the influence of frictional heat, provided by the combination of the rotational tool movement, the frictional resistance the RFSSW-tool experiences during its movement and the exerted clamping force to expel the liquefied polymer from the future joint area. The Hylite® MPC served as bottom joining partner, on top of which an EN AW-6082 (1.50 mm) sheet was placed.

Various approaches (pin/sleeve/pin-sleeve/etc.) can be used based on the tool segment plunging into the workpieces, whereby the plunge depth (PD) and the joining time (JT) are the most decisive parameters. However, using the pin plunge method directly led to perforation of both workpieces. Therefore, it was suggested to adapt the sleeve plunge variant since using multiple plunge cycles (e.g. pin-sleeve) highly increases the heat input, and would cause both joining partners to be welded together, rendering the MPC useless for further (welding) experiments. The most valuable result, using the sleeve plunge variant of RFSSW, is visualized in Figure 12.

Figure 12: MPC with locally displaced plastic core.

B. Displacement by US-vibrations

The approach relies on locally injecting ultrasonic energy on the outer metal cover sheets of the MPCs by an ultrasonically stimulated forming tool. Due to the frictional resistance between the bottom surface of the sonotrode and the faying material, sufficient frictional heat is generated to liquefy the polymer interlayer, followed by squeezing it out of the future joining area by manually increasing the clamping force.

During these experiments, a rectangular-shaped, 36 kHz sonotrode was used, mounted on a manually operated welding gun where the force can be regulated by the foreseen lever. However, using an unrounded sonotrode face is not optimal since the skin sheets may become vulnerable to tearing and its sharp edges are likely to introduce additional material stresses.

The experiments revealed that it was almost impossible to ensure a complete rearrangement of the polymer interlayer during the pre-treatment, and varying remaining thicknesses were obtained between the samples mutually. In some cases, it was necessary to process the plate twice. The reason may be the applied coating on the Hylite® materials, characterized by its low roughness, obstructing the friction development. It also became clear that once the sonotrode got warmer, the displacement process went easier. After displacement by US-vibrations, the remaining thickness of the MPC was measured as ±0.6 mm.

C. Displacement by frictional heat

For this purpose, the frictional heat was provided by a cylindrical tool (with a diameter of 20 mm) with rounded edges made of hardened steel (42CrMo4), mounted on a vertical milling machine. The process parameters of importance for the operation are the rotation speed, the axial tool displacement velocity and the duration of the axial displacement of the tool, controlled by limiting the allowed axial displacement of the tool pushing against and deforming the aluminium and MPC sheets.

The experiments proved that grooves and/or cracks were observed in the rubbing area of the aluminium sheet when the rotational speed was increased. Also, concerning the properties of the Hylite® material, a plunge depth of 0.6 mm was adopted, leading to suitable results. Increasing this value led to a cracked top skin of the MPC sheet, while a plunge depth equal to 0.5 mm resulted in an insufficient displaced core.

4.4. Joining experiments with US-displaced core

It was confirmed earlier that the applied polyester coating of the MPC is a barrier for applying thermal joining processes. Therefore, a mechanical removal method was applied to the workpieces prior to the joining experiments.

A. RFSSW with the sleeve plunge variant

The influence of the remaining polypropylene core is more remarkable when the sleeve plunge variant is used, when the plunge depth or the welding time is increased. It seems that the residual plastic material becomes very crumbly and accumulates inside the RFSSW-tool. These substances are likely to mix with the plasticized aluminium and therefore become part of the weld nugget, expressed as a black coloured stir groove, clearly visible in Figure 13. Since polypropylene is not greatly adhering to metallics, the mechanical properties of the weld are surely affected.

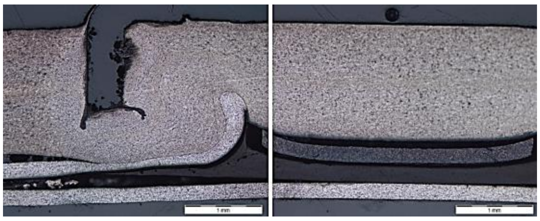

Figure 13: Typical cross-section, sleeve plunge variant of RFSSW.

Further, multiple voids, significant weak interconnections (no bonding ligament zone) and a large hooking-derivative were revealed by metallurgical investigation.

B. RFSSW with the pin plunge variant

The pin plunge variant (see Figure 14) was considered to overcome the weak bonding experienced during the sleeve plunge method. It is expected that this segment of the RFSSW-tool is able to generate more frictional heat due to its larger contact area, highly necessary to liquefy the remaining polypropylene.

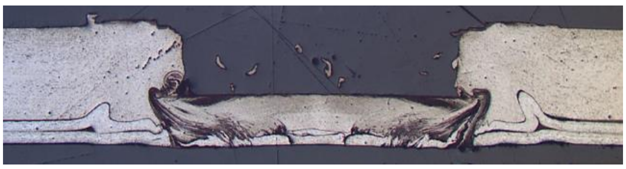

Figure 14: Typical cross-section, pin plunge variant of RFSSW.

The cross-section of such a joint is characterized by an incomplete filling pattern, multiple large hooking-defects, poor mixed spots beneath and around the outer area where the sleeve was supposed to act and a well-bonded region beneath the SZ. Despite that the weld appearance is not optimal, tensile tests were performed and resulted in an average LSS of ±1.0 kN.

4.5. Joining experiments with non-displaced core

A. Refill friction stir spot welding (RFSSW)

During these trials, both displacing the core and performing the weld were done by the RFSSW-equipment, by gradually increasing the PD of the pin-part of the RFSSW-tool. Next, to ensure that no more plastic core material is present near the weld nugget, the pin retracts, after which the sleeve plunges over the same depth whilst the workpieces were (locally) still plasticized. A typical obtained cross-section is shown in Figure 15.

Figure 15: Typical cross-section, RFSSW on non-displaced MPC core.

Subsequently the influence of the rotational speed (Є [1.500-3.000] rpm) and the plunge depth (Є [1,0-1,5]mm) on the LSS was investigated.

I. Influence of the plunge depth (PD)

The LSS as a function of the PD (at 3.000 rpm) is given in Figure 16, proving that the obtained values are approximately equal when the value ranges from 1.0 to 1.3 mm, and reaches a local maximum when a plunge depth of 1.4 mm is used, resulting in a lap shear strength of ±1.56 kN on average. However, when the plunge depth was equal to the thickness of the top joining partner (1.5mm), the LSS dropped rapidly.

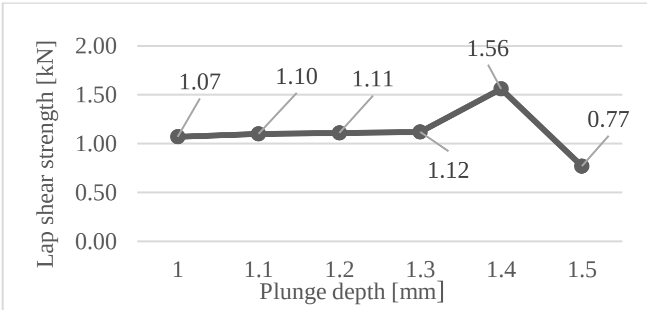

Figure 16: Influence of the PD on LSS.

The reason for this observation may be that using high PD-values increases the weld area and also the heat input, resulting in more mixing of both joining partners as stated by Shen et al. [22].

II. Influence of the rotational speed (RS)

The obtained lap shear strength as a function of the RS when using a plunge depth equal to 1.3 mm is shown in Figure 17. At 2.000 rpm, the highest LSS of ±1.34 kN was achieved. Increasing up to 3.000 rpm, using steps of 500 rpm, leads to a linear decrease of the weld strength (to ±0,91 kN).

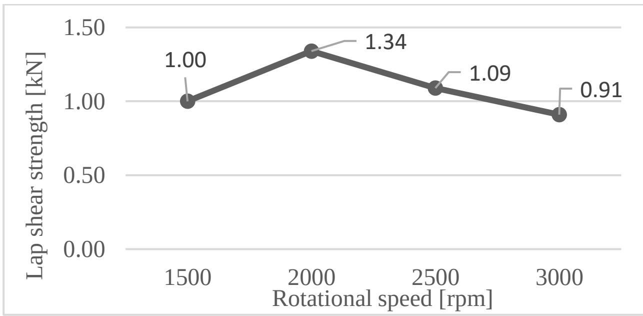

Figure 17: Influence of the RS on LSS.

The latter observations were affirmed by Tier et al. [23], stating that excessive rotational speeds may cause inadequate bonding areas, leading to a lap shear strength reduction.

B. Ultrasonic welding (USW)

As previously acknowledged, a typical USW-cycle ranges between 0.5 – 1.0 s (for pure aluminium compounds). However, it immediately became clear that the welding time had to be greatly increased during these experiments since short welding times directly led to interfacial separation of the joints. Next, it is expected that the welding pressure is directly proportional to the amount of indentation of the workpieces. The size of the latter is of big importance, since after liquefication of the polypropylene layer, a gap of 0.8 mm (i.e. the thickness of the plastic interlayer) should be bridged at the weld interface, in order to firmly make contact between the upper and lower joining sheets.

A typical cross-section is shown in Figure 18, which illustrates the large deformation of the upper joining sheet due to local indentation of the rectangular-shaped sonotrode. The bottom MPC sheet is highly plastically deformed, mainly due to the imprint of the knurled pattern of the backing anvil.

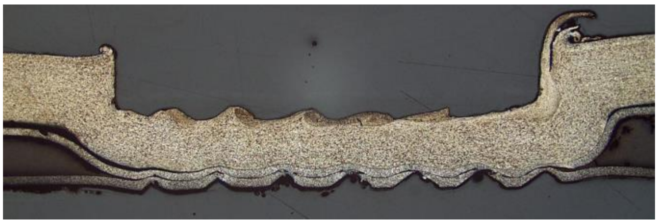

Figure 18: Typical cross-section, observed during USW.

Tensile tests were performed, resulting in an average lap shear strength of ±0.62 kN, which is remarkably lower compared to the previous discussed joining techniques.

5. Conclusion

This paper contains a brief summary of the research regarding the thermal joining of metal-plastic composites (MPCs). Conventional approaches (bolting, adhesive bonding), which are mostly used for this purpose today, were also examined as a benchmark.

Subsequently, the feasibility of the so-called two-step approach was investigated. Several concepts were explored in order to displace the plastic core of the MPC locally, in order to be able to treat the workpieces as monometallic materials. For the second step of this approach, the emphasis was put on joining experiments with MPC sheets using several solid-state welding processes (RFSSW, FSW, USW) to determine their suitability considering the investigated materials.

Accordingly, the lap shear strength of the obtained welds was investigated by tensile testing and the influence of the most decisive welding parameters (PD and RS) was considered.

6. References

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