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Selected Possibilities of the FSW and FSSW Methods in the Removal of Material Defects and Welding Imperfections

Abstract: The article describes unconventional applications of friction stir welding (FSW; linear) and friction stir spot welding (FSSW) processes including the possibility of removing material defects and welding imperfections. The article presents results of tests involving aluminium alloys and demonstrates various repair methods in relation to types of material defects and welding imperfections.

Keywords: friction stir welding (FSW), friction stir spot welding (FSSW), welding imperfection.

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For decades, friction welding has belonged to the most reliable, cheapest and most versatile methods of thermal joining. Numerous advantages of the process include the possibility of joining dissimilar materials, the course of the welding process independent of the thermal conductivity of elements being joined, the high strength and stability of joints, high technological reliability-joint strength ratio and high process efficiency.

For a long period of several decades, friction welding involved the setting of one or both elements into rotational motion. This approach significantly limited the development of the method also known today and, depending on its variant, referred to as conventional, inertial or radial welding [1]. Despite the existence of adequate technological potential, between the 1850s and the early 1990s, the utilisation of friction generated between a tool and workpieces to make a joint of workpieces was not subjected to verification. In the above-named period, tools were solely used for cutting, drilling or milling, i.e. machining. The idea to employ a tool inserted between elements to join instead of separating them was both bold and contrary to previous experience, yet the FSW method (Friction Stir Welding) and its further variants, i.e. the FSSW (Friction Stir Spot Welding) and FSP (Friction Stir Processing) methods were born.

The friction welding method involves the insertion of a (usually axisymmetric) rotating tool into the metallic environment and the generation of friction around it (Fig. 1). If the tool rotates and moves, e.g. longitudinally, a linear weld is obtained (FSW, i.e. friction stir welding). If the tool inserted in metal only rotates, spot welds are obtained (FSSW – friction stir spot welding). The use of a divided tool and appropriate deformation sequence enable the filling of an opening left after the removal of the probe from the material (RFSSW - Refill Friction Stir Spot Welding). The method where

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a moving and rotating tool constitutes the surface through friction and a filler metal present on the surface is known as friction stir processing (FSP) [2-5].

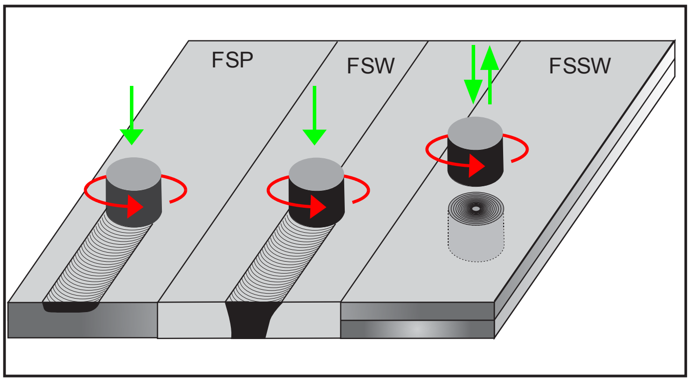

Fig. 1. Friction stir welding variants

Since the mid-1990s, the friction stir welding method has been developing very intensely leading to the invention of different FSW variants as well as extending the range of joinable materials, types of joints, material configurations and industrial applications [6]. An interesting FSW implementation enables the removal of various material defects and welding imperfections, the removal of technological openings as well as the repair or replacement of riveted or bolted joints. In cases of small imperfections it is possible to stir metals in the area of such imperfections and, as a result, eliminate the so-called contraction cavities (Fig. 2).

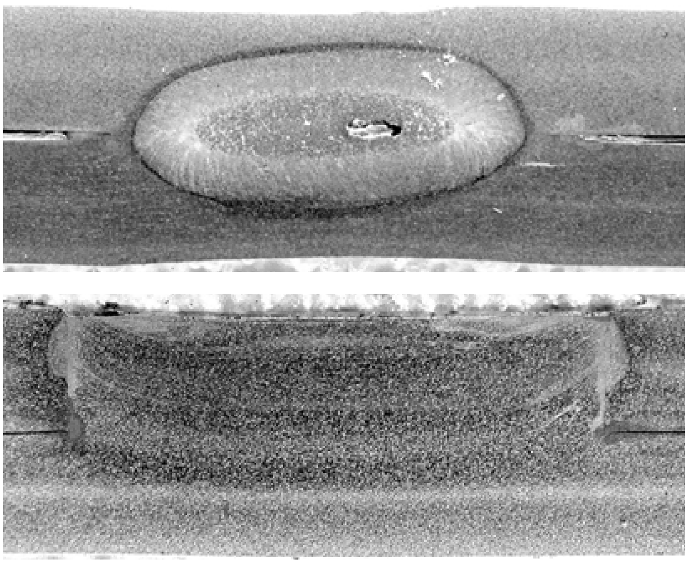

Fig. 2. a) Weld made using the resistance method – alloy PA4; b) repair weld made in the spot weld area – alloy PA4.

Point-like, linear or spatial material defects as well as welding imperfections left by previous operations can be removed by adapting the following approaches:

- direct, i.e. where a related repair tool is placed near a welding imperfection and is set into rotational motion penetrating the welding area;
- indirect, i.e. where inserts made of materials corresponding to base materials are placed into elements being repaired and the entire zone is subjected to plasticisation by being set into rotational and plane motion so that it can reach the volume greater than that of the insert (Fig. 3).

It should be emphasized that the above-presented operation is a relatively new and innovative technological idea.

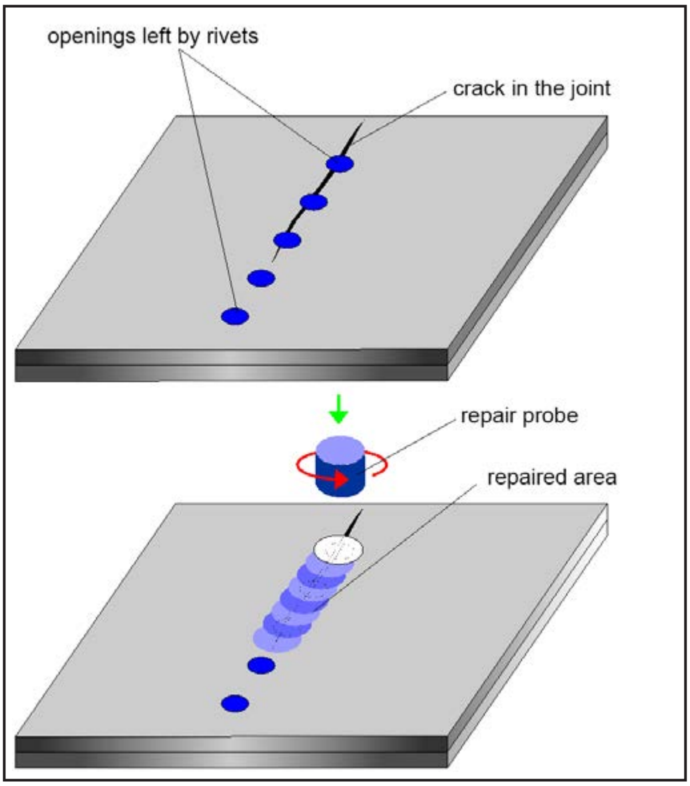

Fig. 3. Repair of riveted joints using friction stir welding

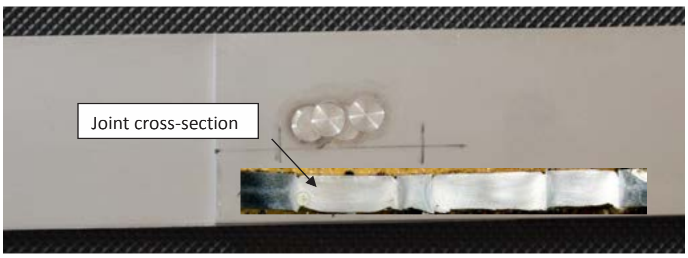

Fig. 4. Crack filled with four overlapping spot welds made using the RFSSW method

Procedure 1

The repair procedure (Fig. 5) described below involves the use of a repair element having the form of a probe with the conical work part. The cylindrical (gripped) part of the probe is placed in the rotating head of the device. Afterwards, the probe is set in a rotational motion and moved towards the opening of sheets to be joined. Friction generated at the contact area between the side surface of the conical part of the probe and the opening leads to the emission of heat and the plasticisation of metal. The process of repair is continued until the plasticised metal flow out above the upper surface of elements being joined.

To ensure the proper process of repair, the length of the conical part of the probe should, by approximately 30%, be longer than the total thickness of the sheets in the overall joint, whereas the apex angle of the cone of the probe should be smaller than the flare angle of the opening. Research-related experimental tests revealed that the distance between the above-named angles should be not less than 5° [7]. During the tests, the primary time of repair in riveted joints made of aluminium alloy AW7075 did not exceed 1 s (in relation to a single repaired opening left by a rivet in an overlap joint having a thickness restricted within the range of 2,5+2,5 mm).

To increase the strength of the joint it is possible to remove the excess of material left after the repair both from the upper and lower surface of the external sheets. Such an approach will lead to the reduction of stress concentration in the interface area, increasing (at the same time) the fatigue strength of the joint.

Procedure 2

The second procedure involves the use of a cylindrical repair probe (Fig. 6). The primary advantage in comparison with the previously presented repair is the simple probe design and the easier making of an opening for repair. However, it is necessary to use an additional element, e.g. having the form of a strip or stamp, providing resistance to the above-named probe. A high rotation rate of the probe combined with pressure trigger friction between the butting face of the probe and the strip plasticising the face of the probe. Further pressure against the already plasticised metal is exerted by an increase in metal pressure under the solid part of the probe and its expansion both in the longitudinal and transverse direction. Similar to procedure 1, the process is performed until the plasticised metal flows outside the upper surface of elements being joined. Depending on the operating conditions of the riveted joint, the removal of the strip may but does not have to prove necessary. However, the strip should be removed in cases of structures which might be exposed to crevice corrosion.

The proposed procedure involves the use of removable or multiple-use strips. If there is no necessity of leaving the strip in the joint following the repair process, the strip can be made of materials having similar physicochemical properties. However, if the strip cannot be left in the joint, it is necessary to use cooled strips of high thermal conductivity or strips

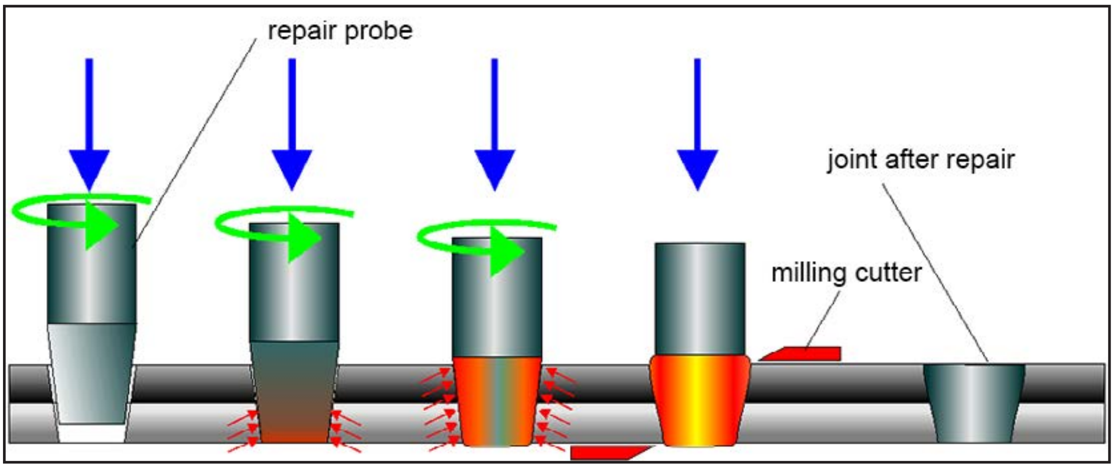

Fig. 5. Repair of riveted joints using conical repair probes

made of high-melting materials of appropriately high thermal capacity. The aim of the above-presented solution is to prevent the joining of the strip with the probe.

Procedure 3

The repair presented below involves the use of a well-known technology for the spot welding of sheets involving the RFSSW method and a divided tool (Fig. 7). The repair of a riveted joint involves the insertion of a repair probe into an opening (originally prepared for a rivet) or, if necessary, into an opening drilled to reach a diameter subjected to repair (imperfection to be removed). The filler metal (probe) should tightly match the opening; the height of the probe should slightly exceed (by approximately 5-15%) the total thickness of elements being joined. To prevent the probe from moving it is necessary to use a strip (as in procedure 2).

The first stage of repair involves the connection of the upper and lower sheets with the repair probe by the external rotating sleeve at a depth exceeding the interface of elements being joined. The deformed metal is pushed towards the centre of the tool and fills the space between the sleeve and the receding probe. The subsequent stage involves the backward motion of the sleeve and the probe, leading to the complete connection of the probe with the sheets at a previously assumed depth. The next phase involves the performance of repair on the opposite side of the elements, after the previous removal of the strip. The repair is performed in a manner similar to that described above or can be performed in one step, i.e. where the strip is removed as described in procedure 2 (Fig. 6).

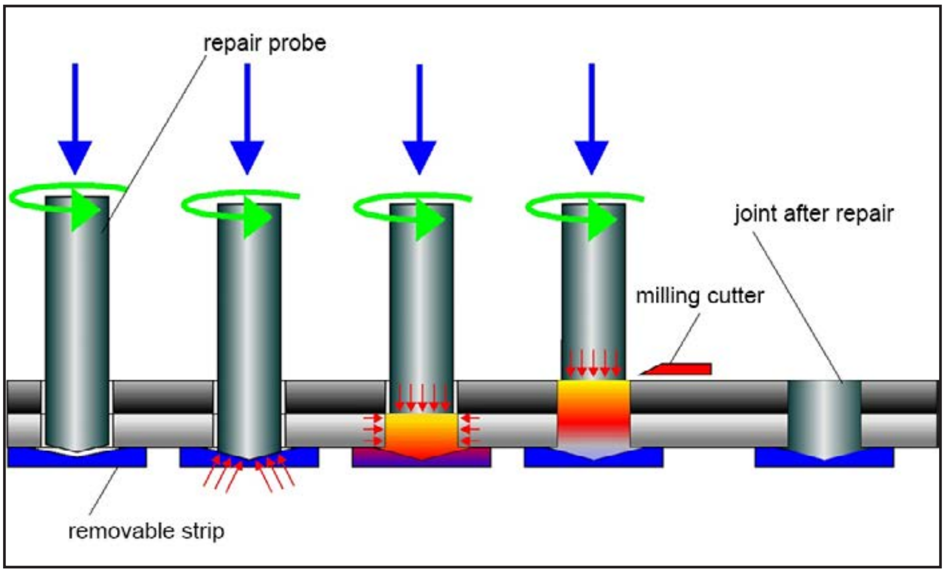

Fig. 6. Repair of riveted joints using cylindrical repair probes

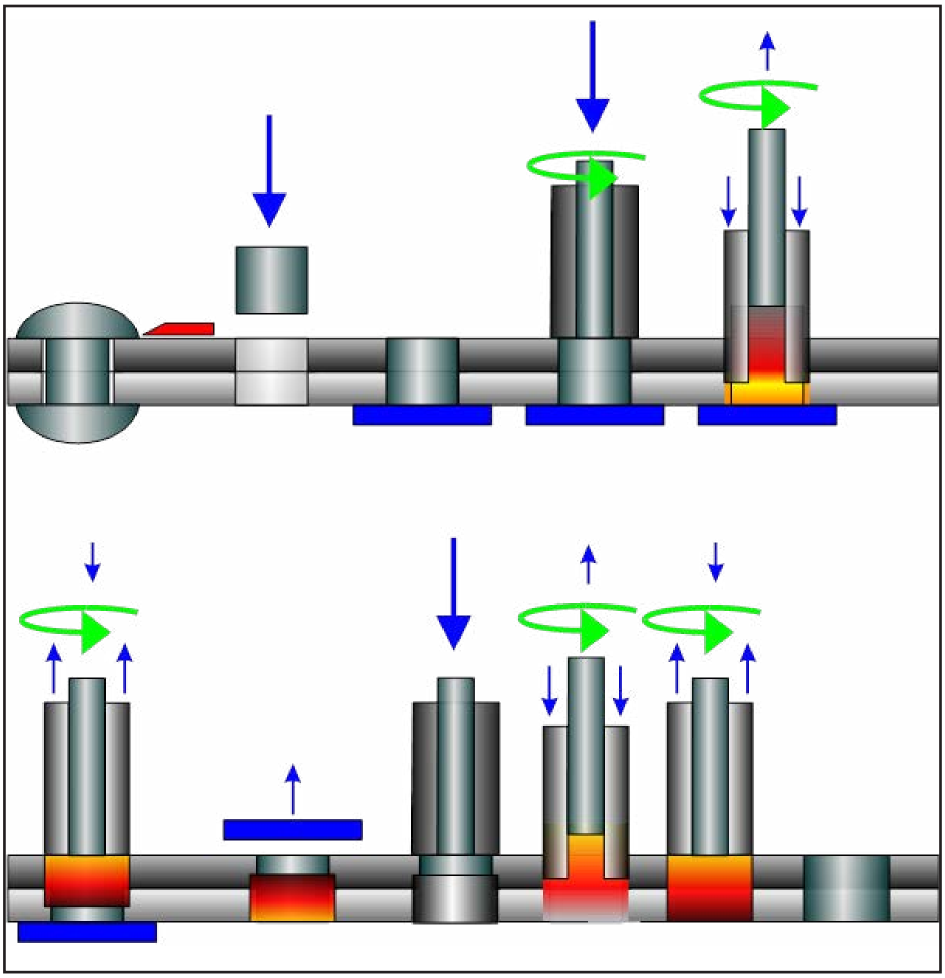

Fig. 7. Repair of riveted joints using the RFSSW technology

Conclusions

Properly performed repairs require the providing of appropriate pressure in the area of a joint subjected to repair. This is because of the fact that during the plasticisation of the repair probe, the filler metal could lift sheets in the area of contact, which, in turn, could result in the formation of a gap between the sheets which could be penetrated by the previously plasticised metal. One of the solutions enabling the elimination of this undesirable situation is the use of an additional external pressure ring connected with the fixed part of the rotating probe column. The above-named issue does not apply to the RFSSW process, where necessary pressure is exerted by the appropriate design of the tool.

An important limitation of the above-presented repairs is the rigidity of applied fixtures.

References

[1] Klimpel A.: *Technologia zgrzewania metali i tworzyw sztucznych*. Gliwice. Wydawnictwo Pol. Śl, 1999.

[2] Węglowski M. St., Hamilton C.: *Investigation into friction stir processing of surface layers*. Biuletyn Instytutu Spawalnictwa, 2013, no. 1, pp. 5-19. http://bulletin.is.gliwice.pl/article/investigation-friction-stir-processing-surface-layers

[3] Iwaszko J., Kudła K., Fila K., Strzelecka M.: *The Effect of Friction Stir Processing (FSP) on the Microstructure and Properties of AM60 Magnesium Alloy*. Archives of Metallurgy and Materials, vol. 61, issue 3, 2016, pp.1209-1214. http://dx.doi.org/10.1515/amm-2016-0254

[4] Iwaszko J., Kudła K., Fila K.: *Friction Stir Processing of the AZ91 Magnesium Alloy with SiC Particles*. Archives of Materials Science and Engineering, vol. 77, issue 2, 2016, pp. 85-92. http://dx.doi.org/10.5604/18972764.1225604

[5] Iwaszko J., Kudła K., Przerada I., Zawada A.: *Structural Aspects of Friction Stir Processing of the Magnesium Alloy with the Use of Cr_2O_3 Particles*. Wydawnictwo Naukowe Akapit. Kraków 2015. p.29.

[6] Ambroziak A.: *Zgrzewanie tarciowe materiałów o różnych właściwościach*. Oficyna Wyd. Pol. Wrocławskiej, 2011.

[7] Kudła K.: *Opracowanie koncepcji sposobu napraw wad materiałowych metodą FSSW*. Research report, Częstochowa 2014.