Orbital friction welding of metallic materials and dissimilar material joints on non-rotationally symmetrical joining cross-sections

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Keywords

Orbital friction welding, metallic material, dissimilar material joints, non rotationally symmetrically cross-sections

1. Introduction

Orbital friction welding is a new process for the joining of metallic materials and dissimilar material joints with nearly any (non-rotationally symmetrical) geometry, Figure 1, e.g. joints between flat strips or box sections, joints on non-rotatable parts (oblique pipe connections or pipelines), angular bonding (aluminium window frames) as well as the economically viable series fabrication of several parts or joints in one operation. A new machine concept for orbital friction welding is opening up the entrance to this new technology with concrete production applications, Figure 2. Within the framework of a research project, orbital friction welding was investigated as a new joining technology for metallic materials and dissimilar material joints on non-rotationally symmetrical joining cross-sections.

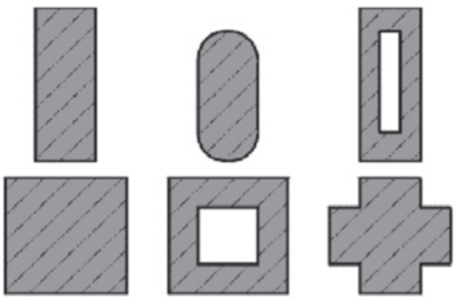

Figure 1. Possible joining cross-sections for orbital friction welding.

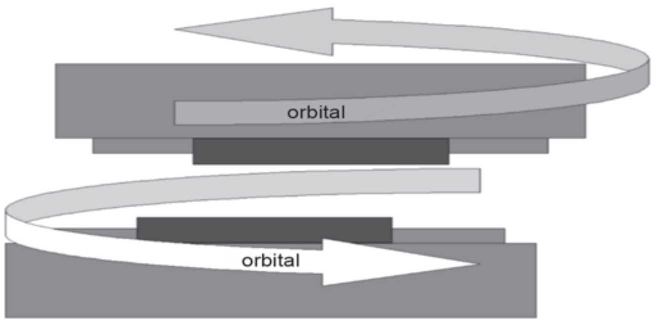

Figure 2. Schematic representation of the multi-orbital friction welding process.

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2. Procedure and experiments

The welding tests were performed on an orbital friction welding machine which was newly developed for metallic materials and works with a synchronised double oscillating head driver ("multi-orbital friction welding"), Figure 3. This drive technology permits a frictional movement with circular oscillation (comparable with an orbital sander) at an effective oscillating frequency up to 2 x 100 Hz, with an oscillating circle diameter up to 1.5 mm as well as with positioned deceleration and centre resetting for a precise final dimension of the welded parts. The relative speed between the joining faces with the maximum oscillating circle diameter and at the maximum oscillating frequency is 0.94 m/s. Because of the orbital frictional movement, a standardised friction speed exists at every point on the joining plane and at all times. This results in standardised friction conditions for a uniform heat input across the entire joining cross-section [2].

Figure 3. Multi-orbital friction welder of the MOSYS RSM100 type with a pressing-on force up to 100 kN.

The material behaviour, suitable working conditions and attainable joint properties were investigated on similar joints and material combinations with mild steels (S355 and S235), alloyed steel (X6CrNiMoTi17-12-2), aluminium alloys (AlMgSi and AlMg4) and brass (CuZn39Pb2). This also results in generalisable statements which are applicable to other alloys in the frequently used material groups. Rectangular joining cross-sections in the dimension range of a (5 ÷ 20 mm) x b (10 ÷ 40 mm) and hollow section variants with different wall

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thicknesses (20 mm x 20 mm x 2 mm to 40 mm x 40 mm x 3 mm) were chosen as typical joining geometries. Such cross-sections cannot be joined with conventional rotational friction welding and therefore constitute an essential extension to the applications for the friction welding of metallic materials.

3. Results

As a result of the principle, orbital friction welding may lead to cyclic deformations which are caused by the alternating friction direction and the acting friction shear forces and exert an effect not only on the friction speed in particular (oscillation losses are reflected in reduced oscillating circle diameters depending on the load) but also, in part, on the distribution of the pressing-on pressure. Therefore, special attention must be paid to a sufficient stiffness of the welding peripherals [3], e.g. by utilising highly stable clamping tools, by consistently minimising the component unclamping length, by using component cross-sections which have adequately thick walls or are reinforced as well as by giving preference to the utilisation of materials with a high strength and the lowest possible thermally induced softening. The friction shear forces should be reduced by means of suitable process management particularly in phases of intensive friction (initial friction phase and braking/resetting phases), e.g. by limiting the pressing-on force or by setting a higher friction speed (higher frequency or larger oscillating width) in order to produce sliding effects (depending on the material).

Similar joints consisting of mild steel were friction-welded as a flat strip joining cross-section of 30 mm x 10 mm and as a square cross-section of 20 mm x 20 mm with a centre borehole with a diameter of 10 mm. With friction times between 2 s and 6 s as well as friction/upsetting pressures of 10 ÷ 40 N/mm^2 and 60 ÷ 80 N/mm^2 respectively, the work was carried out in the range of the maximum oscillating frequency (2 x 87 Hz) and oscillating width (1.5 mm). An optimised process sequence is not achieved with these welding parameters. Moreover, the strength of the joints (R_m up to max. 472 N/mm^2) is still approx. 10% below the characteristic values of the base material. The main cause is the current upper limit of 0.94 m/s on the relative speed which is stipulated by the setting ranges of the frequency and oscillating width of the available installation. The orbital friction welding of mild steels necessitates higher relative speeds which are presumably in the range of 1 ÷ 2 m/s.

Similar orbital-friction-welded joints consisting of the high-alloyed, stainless and acid-resisting steel X6CrNiMoTi17-12-2 and of the aluminium alloys AlMg4, Figure 4, and AlMgSi can be joined with comparatively large joining cross-sections and a good joint quality. The required process conditions can be represented in the working range of the machine. Particularly in the case of aluminium materials, oscillating widths over 1.5 mm exert an advantageous effect [4]. In the tensile test on optimised welded specimens, the fracture occurs outside the joining zone in the base material.

The symmetrical formation of the heat-affected zone over the friction cross-section with a nearly uniform width is shown to be a positive aspect of the cross-section-related standardised relative speed during orbital friction welding. The influence of the temperature on the base material is uniformly narrow not only in the centre of the joining plane but also at the edge of it. Thus, it differs from typical rotational-friction-welded joints with which the extent of the heat-affected zone increases from the centre to the edge in most cases. With regard to the investigated joining cross-sections up to 400 mm^2, the final positioning accuracy (axial misalignment or edge misalignment) is less than 0.2 mm.

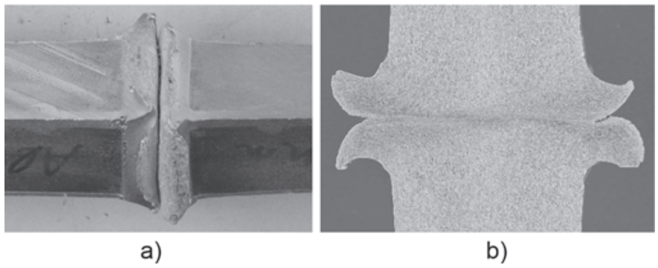

Figure 4. Accurate-position and defect-free orbital-friction-welded joint on the 20 mm x 20 mm cross-section consisting of AlMg4 (oscillating frequency: 2 x 87 Hz, oscillating width: 1.5 mm, friction pressure: p_R = 60 N/mm^2, forge pressure: p_{St} = 180 N/mm^2, friction time: t_R = 2.4 s, total length loss: s_{ges} = 6.8 mm, tensile strength: R_m = 278 N/mm^2, fracture location: base material); a) overview, b) transverse section (etchant: Alu-macro).

As well as similar joints, the orbital friction welding of dissimilar material joints was investigated in particular. Orbital friction welding provides a wide variety of possibilities to this end. Beyond the restriction to circular cross-sections in the case of rotational friction welding, orbital friction welding also makes it possible to apply another fabrication spectrum covering non-circular joining cross-sections.

With regard to the orbital friction welding of steel-aluminium joints (S355/AlMgSi), the required friction/upsetting pressures of 60/120 N/mm^2 are comparable with those in the case of conventional rotational friction welding. The heat is input very quickly with friction times below 0.5 s in order to limit the heat dissipation, the softening and the length shortening (approx. 5 mm) on the aluminium side. As far as the orbital friction welding of the S355/AlMgSi material combination is concerned, the tensile strength of the joint reaches almost 90% of the tensile strength of the base material - an already nearly optimum result taking account of the slight softening in the joining zone which arises in the case of rotational friction welding too. Here, the process-integrated facing of the steel specimens might improve the process conditions with regard to an increase in the quality and to the repeat accuracy.

Orbital friction welding tests on the material combinations consisting of AlMg4 with X6CrNiMoTi17-12-2, Figures 5 and 6, and S355 with X6CrNiMoTi17-12-2, Figure 7, also show the great potential of orbital friction welding. In the investigated cross-section range (300 ÷ 400 mm^2), both material combinations are weldable with very good joint properties.

The joining plane of the steel-aluminium joint executed by means of orbital friction welding is defect-free in the metallographic investigation. In the tensile test, the fracture occurs outside the friction-welded joint in the base material of the aluminium alloy at Rm = 240 N/mm^2. A longer clamping length and larger clamping area of the friction-welded specimens might not only lead to a further improvement in the positional accuracy but also decrease the clamping imprints in soft materials such as aluminium which are caused by the pulsating clamping pressure with an oscillating frictional movement.

The friction pressures used for the unalloyed / high alloyed steel joints, Figure 7, are low in comparison with those in rotational friction welding. Even at a friction pressure level of 20 N/mm^2, both steel materials are already plastified sufficiently quickly while friction pressures in the range between 40 N/mm^2 and 100 N/mm^2 depending on the material and the cross-section are required for this purpose in the case of rotational friction welding. The "homogeneous" energy input across the whole area to be joined exerts a positive effect here. At 180 N/mm^2, the upsetting pressures are relatively high compared with rotational friction welding.

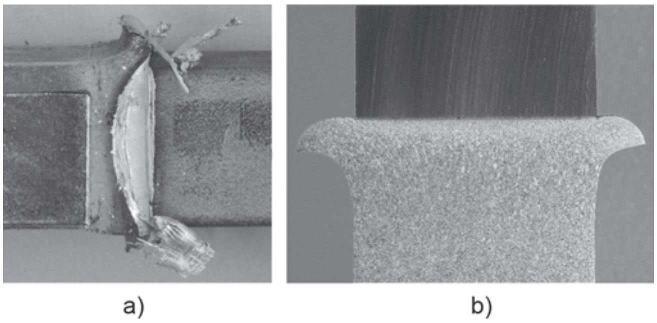

Figure 5. Orbital-friction-welded joint on the material combination consisting of AlMg4 with X6CrNiMoTi17-12-2 on the 20 mm x 20 mm cross-section (oscillating width: 1,5 mm, oscillating frequency: 2 x 75 Hz, friction path: s_R = 2.0 mm, friction pressure: pR = 60 N/mm^2, forge pressure: p_{St} = 120 N/mm^2, total length loss : s_{ges} = 3.6 mm, friction time: t_R = 0.79 s, tensile strength: R_m = 240 N/mm^2, fracture location: base material); a) overview, b) transverse section (etchant: Alu-macro).

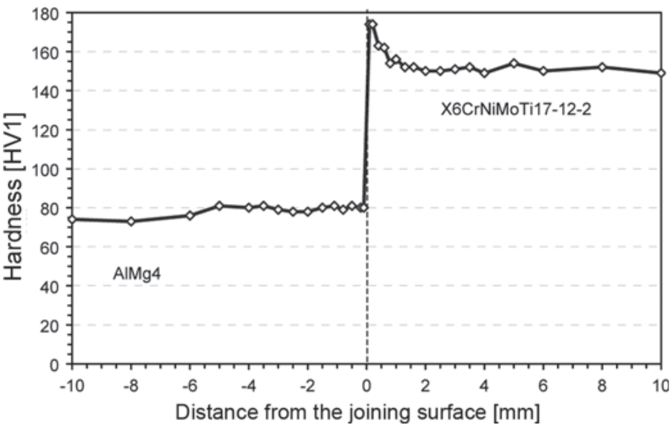

Figure 6. Influence of the orbital friction welding process on the hardness in the material combination consisting of AlMg4 and X6CrNiMoTi17-12-2 on the 20 mm x 20 mm joining cross-section (oscillating width: 1.5 mm, oscillating frequency: 2 x 75 Hz, friction path: s_R = 2.0 mm, friction pressure: p_R = 60 N/mm^2, forge pressure: p_{St} = 120 N/mm^2, total length loss: s_{ge}s = 3.6 mm, friction time: t_R = 0.79 s).

The optimised unalloyed / high alloyed steel joints investigated metallographically is defect-free over the entire joining cross-section. In the tensile test, the fracture occurs outside the joining zone in the base material of the mild steel S355 (R_m = 537 N/mm^2). The good joint properties are not even affected if, as an alternative, the friction areas are prepared by means of a saw cut instead of by means of rectangular milling.

In most of the investigated cases, it was possible to prove the fabrication weldability of the selected materials for orbital friction welding. In the case of contours or hollow sections whose walls were too thin, limits on the applicability are recognisable because of the proportional transverse friction and the decreasing transverse stiffness of the joining contours.

The manufacture of a flat strip joint with 40 mm x 5 mm between aluminium and brass was tried out as an example of the application of an orbital-friction-welded material combination with a non-circular joining cross-section. Such joints can be utilised for connection pieces on electrical ground leads [5]. In this respect, the metallic joint between aluminium and brass largely eliminates the problems associated with the contact resistances and contact corrosion of customary cable lug connections.

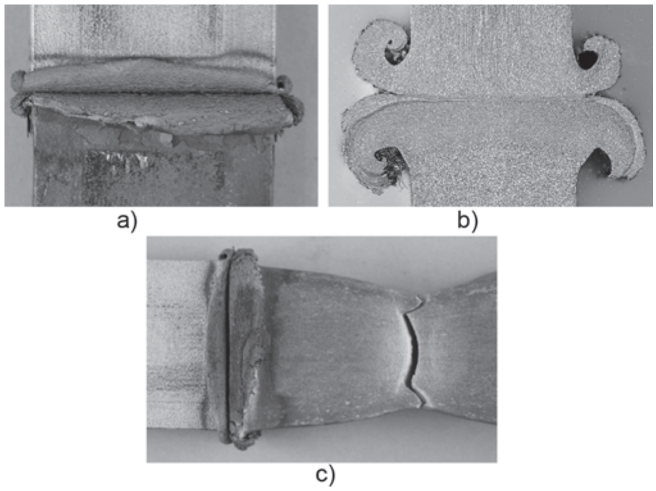

Figure 7. Formation of the welded joint on the 30 mm x 10 mm cross-section consisting of X6CrNiMoTi17-12-2 with S355 (oscillating width: 1.5 mm, oscillating frequency: 2 x 85 Hz, friction path: s_R = 3.0 mm, friction pressure: p_R = 20 N/mm^2, forge pressure: p_{St} = 180 N/mm^2, total length loss: s_{ges} = 6.3 mm, total welding time: t_{ges} = 5.3 s); a) overview, b) transverse section (etchant: Adler), c) tensile test specimen.

In the case of the orbital friction welding of CuZn39Pb2 brass and AlMgSi aluminium at a friction/upsetting pressure of 15/80 N/mm^2 and with a friction time of 3.7 s (including the initial friction phase), the bead formation and the shortening (3.4 mm) which are typical of friction welding arise exclusively on the aluminium while the brass part remains undeformed. The attained tensile strength of the joint is Rm = 162 N/mm^2 or approx. 70% of the tensile strength of the AlMgSi base material. The joint does not have any recognisable imperfections in the joining region and shows the great potential of this new joining technology.

4. Conclusions

The results of the research project indicate the suitability of the orbital friction welding process for metallic materials and dissimilar material joints. These results served to create scientific-technical foundations for the introduction of orbital friction welding for its economically viable utilisation as a new and versatile joining process, however particularly in order to extend the geometrical spectrum in the case of friction welding. The geometrical spectrum is limited to circular joining cross-sections in the case of rotational friction welding and can be extended to diverse geometries and contours by means of orbital friction welding. As far as fabrication-weldable geometries and materials are concerned, one particular aspect of economically viable fabrication is opened up by the possibility of welding several parts together in parallel or simultaneously in one clamping operation.

With regard to other resistance butt welding processes, orbital friction welding results in the distinct delimitation or extension of the utilisation field: Compared with flash butt welding, the clean joining process without any spatter, fumes or radiation facilitates its direct integration and interlinking in production. The heat input and thus the thermal loads on the materials are low and it is emerging that its suitability for diverse dissimilar material joints is similar to that of rotational friction welding. Moreover, it is, in principle, even possible to join non-electrically conductive materials (plastics and ceramic/metal joints). In contrast with the welding process with a magnetically impelled arc butt welding (MIAB), orbital friction welding can also be used in order to weld together full cross-sections and open sections with a wide diversity of materials. Thus, orbital friction welding is opening up new application possibilities as far as the geometry, the material or the production technology is concerned.

Because of the close cooperation with the machine manufacturer, the research work is also resulting in concrete approaches for improving and refining the installation technology. The first steps towards implementing the results in practice on the basis of industrial application trials were already taken during the project period. Already published results as well as other subject-related articles within the framework of the 18th Exchange of Experience with Friction Welding at SLV München on March 18, 2009 are being used for direct technology transfer and are meeting with keen interest from potential users.

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