Modeling heat input when friction stir welding

V Statsenko¹, A Sukhorada² and V Lelyukhin²

¹Senior Production Editor, FEFU, Vladivostok, RU; ²Production Assistant, FEFU, Vladivostok, RU
E-mail: vladsta@mail.ru, alexeyman_09@mail.ru, lelv0@mail.ru

Abstract. An important element of friction stir welding technology is the determination of the temperature of the material in the mixing zone, which can be determined by calculating the amount of heat introduced into the welding zone. To determine this value, experimental studies were carried out on a stand in which the material to be welded (aluminum alloy AMg5) is modeled as an experimental tube with a diameter of 20 mm, and the tool (from tool steel P6M5) is modeled as a working plate. On the stand, studies of the dependence of the friction moment and heat-liberation value were performed. According to the obtained experimental data, the heat-liberation dissipation and heat power on the working tool are calculated, the dependences of these values on the radius of the working tool are obtained.

To increase the amount of heat input in the center of the contact area, a tool with a drive with two concentrically located (one inside the other) shafts is proposed, while the inner shaft rotates at a higher speed than the outer one. According to the obtained experimental data, the dependences of heat release for each shaft and the total heat release for a tool with two shafts at an external shaft rotation speed $\omega = 63 \, \text{s}^{-1}$ and different rotation speeds of the internal shaft are calculated. In total, for the external and internal shafts, the total heat release value is about 2 times higher than the total heat release value using a single shaft.

The purpose of this work is to find the values of heat release in friction stir spot welding, as well as the development of friction spot welding tools with higher heat release.

1. Description of the technical solution and experimental technique

Friction stir welding (STD) refers to hardphase welding methods, so it is important to know the temperature conditions. Experimental measurement of temperature in the heating zone is associated with certain difficulties, since the tool at this moment rotates and closes the heating zone with a flat end surface. In most publications [1-3], devoted to the calculation of the temperature distribution in the process of SST, they are based on solving the heat-transfer equation and offer numerical calculation methods. But for calculations, the main necessary parameter is the amount of heat energy supplied to the heating zone (heat release).

The distribution of heat release over the radius of the contact area of the tool with the workpiece during classical friction welding has a parabolic shape [7]. This is due to the uneven distribution of the linear speed of rotation of the tool face over the radius of the heating area; it varies from zero in the center to a maximum at the outer radius. The change in frictional moment is not considered.

To study the dependence of the moment of friction and heat release along the radius of a rotating tool, a laboratory stand was designed and manufactured [4].

Its main element is a cylindrical working tube made of aluminum alloy AMg5, which outer diameter is 20 mm, wall thickness is 2 mm, length is 40 mm. This tube simulates the material of the plates being welded. It rotates on the surface of the working plate of tool high-speed steel R6M5,
which simulates a tool for friction stir spot welding. Due to the change in the speed of rotation of the working tube, it is possible to set different linear speeds of rotation of the end surface of the tool relative to the surface of the steel plate, corresponding to the speeds of rotation of the real tool at different radii.

A working plate of R6M5 tool high-speed steel is fixed on the desktop of the stand through the gasket. The worktable is fixed on the movable part of the pressure ball bearing, its fixed part is fixed on the base. When the working tube is rotated and pressed with a certain force to the working plate, the frictional moment is determined by the force measured by the electronic dynamometer and the length of the rod (shoulder).

The experiments on heat release were carried out on a VM127 universal vertical milling machine. When measuring the frictional moment, the compression force of the tube relative to the plate is set, which maintains the temperature of the contact point in all modes.

During the experiments were determined the heat losses by thermal conductivity along the rod, on which the working tube is fixed, as well as from the working plate through the gasket to the working table, and losses due to convection from the surface of the rotating working tube into the environment. After the necessary measurements were made, the results of calculations of these heat losses showed that in different modes the heat conduction losses along the tool stem are 8–10%, to the work table it does not exceed 9–15%, heat abstraction by convection from the cylindrical surface of the experimental tube is 2.5–4.5%. These losses are considered in the calculations of heat release.

2. Results of experiments and calculations

Experiments on measuring heat release were carried out at the speed of rotation of the spindle of the milling machine in the range of 400–1600 rpm (42–167 s⁻¹). At the same time, by regulating the pressing force of the working tube and the working plate, the temperature of the contact place in all modes was kept constant - 335 ± 15.

As a result of the experiments performed, the dependence of the frictional moment change with an increase in the speed of rotation of the working tube was obtained Figure 1a.

These data made it possible to calculate the volume power of heat release during friction, which is directly proportional to the rotational moment Mₚ and the speed of rotation ω and inversely proportional to the contact area of the working tube and plate Figure 1b. The data presented on this graph were obtained considering heat losses.

Analysis of these graphs shows that with a uniform increase in the rotational speed, the intensity of the friction moment is different - more significantly reduced at low speeds (up to 100 s⁻¹) and less significantly at speeds of rotation more than 100 s⁻¹. The calculated dependence of the volume power of heat release at the same time has a complex appearance with an increase of this value at rotational speeds in the ranges of 40-83 s⁻¹ and 105-167 s⁻¹ and its decrease at rotational speeds of 83-105 s⁻¹. This dependence is determined by the fact that with increasing rotation speed, the friction moment decreases with different intensities, the contact area remains constant.
According to these data, for the friction stir spot welding tool, the specific and total heat release calculations for each ring section 2 mm wide were made, and then the total heat release on the tool. The results of the calculation of the dependence of the total thermal power (heat release) on the entire contact area on the tool radius are presented in Figure 2. These data allow us to estimate the dimensions (diameter) of a tool for a given heat power and its rotational speed. So, on a tool with a radius of 8 mm, at a rotation speed of 63 s\(^{-1}\), heat release of 0.4 kW can be obtained, and at a speed of s\(^{-1}\) - 0.6 kW.

The obtained data confirm the literature data [1-3] on the minimum heat release in the central part of the heating spot.

To increase the amount of heat input in the center of the contact area, it is proposed to use a tool with a drive with two concentrically located (one inside the other) shafts, while the inner shaft rotates at a higher speed than the outer shaft Figure 3 [9].
Figure 3. Tool for friction stir spot welding.

The tool for friction stir spot welding has an outer shaft 1, an inner shaft 2, radial bearings 3, thrust bearings 4, gears 5, 6, 7, 8, shaft 9, input shaft section 10, top cover 11, body 12, glass 13, the bottom cover 14, the compression device 15.

Under the action of the rotational moment of the $M_{tw}$ shaft 9 using the gears 7 and 8, as well as the gears 5 and 6 drives the shafts 1 and 2. Since these gears have different diameters, this ensures the rotation of the inner shaft is about 2 times larger than outer. Due to this, a higher heat abstraction occurs on the internal shaft. The compression device 15 ensures the pressing of the shafts 1 and 2 to the welding point.
Figure 4. Dependence of heat release for each shaft (a) and total heat release (b) for a tool with two shafts at the speed of rotation of the external shaft 1 - $\omega = 63$ s$^{-1}$; rotation speed of the inner shaft:

2 - $\omega = 105$ s$^{-1}$, 3 - $\omega = 157$ s$^{-1}$ and 4 - $\omega = 209$ s$^{-1}$

According to the obtained experimental data, the dependences of heat release for each shaft and the total heat release for a tool with two shafts at an external shaft rotation speed $\omega = 63$ s$^{-1}$ and different rotation speeds of the internal shaft are calculated, the results of calculations are presented in figure 4.

Analysis of these graphs shows that the total heat release from the tool has a more uniform distribution, and in total for the external and internal shafts the value of the total heat release is higher than the value of the total heat release using a single shaft. So, at the speed of rotation of the external shaft - 63 s$^{-1}$, and the internal one - 209 s$^{-1}$ for a working tool with a radius of 9 mm, the total heat release is 2 times more than for one shaft at the same rotational speed.

3. Conclusion

Thus, in friction stir spot welding of AMg5 aluminum alloy using an R6M5 high-speed steel tool at its rotational speed of 167 s$^{-1}$, in order to bring heat power of 0.7 kW, it is necessary to use a tool with a diameter of 18 mm, for heat power of 0.4 kW enough to choose a tool with a diameter of 12 mm. Similar data can be obtained for other speeds of rotation of the working tool. When using a tool with two shafts rotating at different speeds, you can get an increase in heat release by 2 times with a constant contact area.

References

[1] Kotlyshev R.R., Shuchev K.G., Kramskoy A.V. Calculation of temperatures for friction stir welding of aluminum alloys, Bulletin of the DGTU (2010) 693-699.
[2] Medvedev A.Yu., Pavlinich S.P., Atroshchenko V.V., Markelova N.I. Modeling of the temperature field for linear friction welding, Bulletin of the USATU (2010). 76-81.
[3] Statsenko V.N., Negoda E.N., Suhorada A.E., Polutsky K.A. Analysis of technology by friction stir welding, Vestnik of the engineering school of the FEFU. (2017).
[4] Rzaev R.A., Chularis A.A., Dzhalmukhambetov A.U., Atuev Sh.M. Dynamic model of temperature distribution in the metal for friction stir welding, Fundamental research. (2016) 47-55.
[5] Grujicic M., Arakere G., Yalavarthy H.V. He T., Yen C.F. and Cheeseman B.A. Modeling of AA5083 Material Microstructure Evolution During Butt Friction-Stir Welding, Journal of Materials Engineering and Performance. (2010) 672–684.
[6] Martin J. Pushing the boundaries – friction stir goes deeper than before, TWI Connect. January/February. P. (2006).

[7] Vill V.I. Svarka metallov treniem, Mashinostroenie, Leningr, otd-nie, Russian, 1970.

[8] Thomas W. M., Nicholas E. D., Needham J. C., Murch M. G., Temple-Smith P., and Dawes C. J., International Patent Application No. PCT/GB92/02203; GB Patent Application No. 9125978.8; U.S Patent No. 5,460,317. 1991.

[9] Statsenko V.N., Sukhorada A.E., Romanova V.V., Tool for friction stir welding. Patent for utility model No. 186699, application No. 2018118628, priority of the invention 05.22.2018, registration date 01.29.2019