International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 1, January - 2014

A Review of Different Methods for Joining of Bi-Metallic Materials by Friction Welding

Mohamed Harraz[1a], Mustafa Awd[1b], Adham Al-Sayyad[1c]

[1]*Faculty of Engineering and Materials Science, German University in Cairo, New Cairo, Egypt*

Abstract

The hybrid joining between different bi-metallic materials has become extremely important in many industrial applications especially where the combination of strength and weight reduction is needed. High temperature materials such as high strength steels and Ti alloys combined with lightweight materials such as aluminium are widely being used in many industrial applications and particularly in the automotive and aerospace industries. Traditional fusion welding processes introduce significant amount of heat into the material and frequently lead to property deterioration, such as cracking and porosity during solidification. On the other hand the hybrid joining between different bi-metallic materials using conventional welding techniques are not possible. These problems could be overcome by the use of the recently developed solid state friction welding approaches. This review paper focuses on aspects of rotary friction welding of high performance and high-temperature materials combined with lightweight alloys, and introduce a new realization for friction welding of incompatible bi-metals.

1. Introduction

In technical practice, welding technologies remains the most widely applied approach for joining and fusion of metallic components in the fabrication industries. Progressive firms in this industrial sector dedicate significant portions of their quality control investments to ensure that joined parts are realized using the best joining techniques and that the structural integrity of these parts are not prematurely compromised while in operation. Conventional fusion welding processes such as arc welding and quite recently laser welding require enormous heat inputs which often times results in the deterioration of key material properties such as strength due to the formation of cracks and pores induced during solidification. Solid state welding techniques such as friction welding markedly minimize the heat related problems inherent to fusion welding [1]. With its varieties friction welding has been used for more than 50 years to eliminate the problems of melting, excessive heat input and shrinkage during cooling. Rotary friction welding and linear friction welding as shown in Figure 1 are examples of solid state welding which are widely used in many manufacturing and fabrication applications because they are economical, highly productive, easy to operate and environment friendly. Rotary friction welding utilizes frictional heat of the pressure applied by forging force generated between a stationary work piece and a rotating one to produce a metallurgical bond with minimum preparation needed and as almost no melting occurs at the interface. This proves to be effective in joining similar and dissimilar materials which were said to be difficult by other conventional welding methods. [2-4].

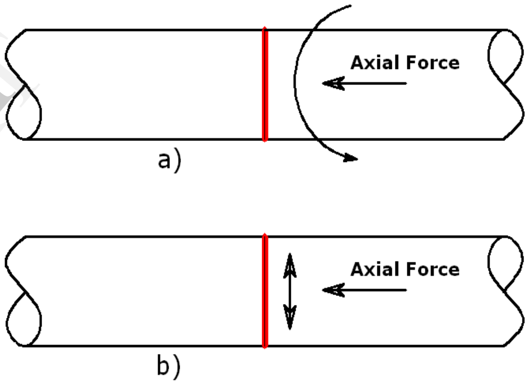

Figure 1. Schematic drawing of rotary friction welding a), and linear friction welding b)

Unlike conventional welding that primarily uses high temperature diffusion to achieve a metallurgical bond, friction welding experiences a mechanical mixing of thin layer of molecules on each side of the interface [5]. Other approaches investigated the methods of energy input to the system and at what rate this energy should be delivered to the work piece. These approaches have led to two main varieties of friction welding; continuous drive friction welding and inertia friction welding. In continuous drive the rotating part is continuously driven by an energy source such as an electric motor running at fixed speed or preset varying speed in which the rate of energy is constant and can be supplied for as long as necessary. On the contrary, in inertia friction welding only a finite amount of energy is available to make the weld which is stored in the form of a flywheel. The flywheel is run up to a set speed at which its input power is cut off and the weld cycle is initiated after which energy stored is dissipated into the weld. The work piece is then decelerated to zero speed in which a progressive reduction in the rate of energy input is possible [6]. A schematic drawing of the two varieties of friction welding is shown in Figure 2.

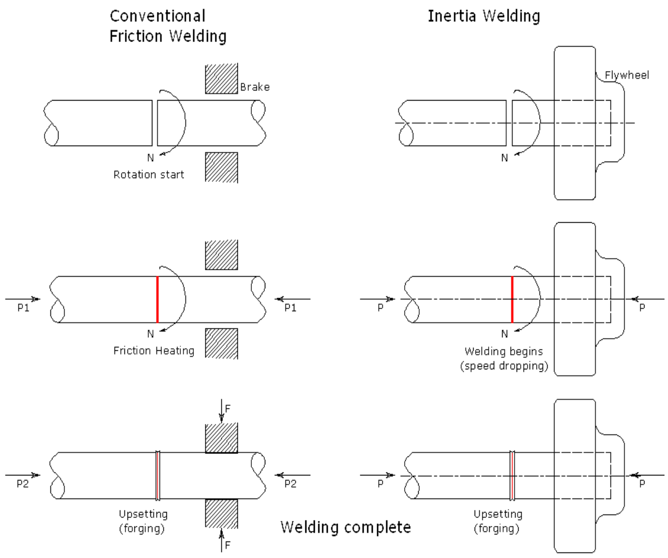

Figure 2. Schematic layout of conventional rotary friction welding and inertia friction welding.

2. Classification of materials combinations for friction welding

Joining of dissimilar materials became very important for many industrial applications; especially for the automotive, aerospace and marine industries where joining of dissimilar materials is a strategy for the implementation of robust and lightweight structures [7]. This section summarizes the most widely joined dissimilar materials in industry and highlights many challenges for joining dissimilar materials such as differences in melting points and cast structure at the interface, inclusions and micro segregation. Also joining of some similar materials that are considered non-weldable using conventional welding techniques are done by friction welding. Nevertheless in most of the friction welding applications of similar and dissimilar materials, the strength obtained exceeded that of the weaker material. This made friction welding the preferred method whenever size and geometry of the work piece permits [8].

2.1 Aluminium and carbon steel

Friction welding of dissimilar metals such as aluminium and steel is very difficult to achieve efficiently and to obtain a sound weld because of the formation of a brittle phase known as intermetallic compound (IC). The formation of such IC dramatically reduces the mechanical strength of the joint between aluminium alloy and steel and usually causes brittle fraction [10-12]. As one of the solutions to such problem a sound friction welding of aluminium alloy and steel can be obtained by the use of an insert metal as shown in Figure 3, friction welding of 2017 aluminium alloy and S45C carbon steel for example is carried out using a thin layer of insert metal of A1050-H14 that is friction welded first to the carbon steel by brake-type friction welding. Afterwards the insert-metal side is welded to the aluminium part using brake-type friction welding. The use of such technique has shown an increase in the mechanical strength of joints produced from aluminium alloys such as A2017 and carbon steel S45C by using an insert metal of both A1050 and aluminium alloy composed of Al-3%Mg [13].

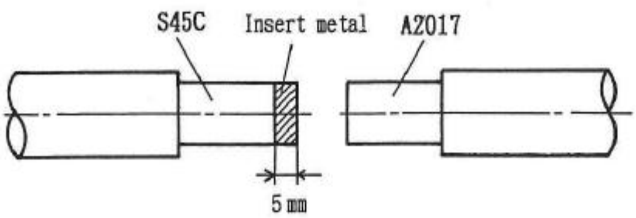

Figure 3. Welding design with a 5mm insert metal [13]

2.2 Aluminum and mild steel

In continuous drive friction welding of mild steel the rotational shear takes place over a wider area. This means that this rotational shear represents the bulk shear strength of mild steel at elevated temperature. Experiments showed a strong linear relation between equilibrium torque and burn off rate on one side and the applied pressure on the other side while other factors such as initial operating speed and workpiece size do influence the torque and burn off rate, the applied pressure accounts for the highest influence [14]. Higher welding pressure results in a narrower double cone shaped or pinched HAZ thus a fine weld interface grain structure is attainable. On the other hand if cold drawn mild steel refinement of the material across the HAZ and interface regions was applied, it will result in lower hardness than the parent metal which increases with pressure at a given speed although lower hardness was obtained for higher speeds at the same pressure [15].

2.3 Steel to ceramic by an interlayer

Due to the big differences in the thermal and mechanical properties and in the crystallographic structures of ceramic and steel, it is not directly possible to make a sound and strong bond between a ceramic material and steel using conventional friction welding. Most joints break at the interface or in the adjacent area in the ceramic material during the cooling down phase [16]. Attempting to join a ceramic material such as alumina (Al_2O_3) to mild steel is very difficult to achieve by direct friction welding because of the big difference in thermal expansion. Alumina has much lower thermal coefficient expansion and therefore when the two joined parts cool down thermal stresses at the weld interface are induced which usually cause cracking. A solution for such challenging problem makes it possible to friction weld a ceramic material such as alumina to mild steel by introducing a 1mm thick aluminium sheet as a soft interlayer between the two materials. The compatible interlayer metal (aluminum) acts as stress-relieving medium absorbing the stresses induced during the cooling phase. The aluminium sheet is welded first to the mild steel using the same method used to weld aluminium to carbon steel [13]. Afterwards the mild steel together with the interlayer is friction welded at 900 rpm to the ceramic material [17].

2.4 Copper alloys by Taguchi method

The main challenging problem of friction welding of non-ferrous alloys such as copper alloys is the low coefficient of friction (0.15) which makes it more difficult to weld compared to ferrous metals. Taguchi method has proven to be an efficient way to obtain a sound and strong weld by using a continuous drive friction welding. The investigation was done on copper alloy specimen Cu Zn28 of size 19 mm diameters and length of 90-100mm. Taguchi method is based on an optimized design of experiment that leads to a successful welding process of copper and brass alloys [18]. Taguchi method depends on applying the axial pressure at two separate phases. The first phase is the frictional pressure, which is followed by a forging pressure which is at least double the value of the frictional pressure. From the Taguchi design of experiment it is observed that the factor that has more effect on the tensile strength is forging pressure, and on the upset, the effect of all the process variables is uniform [18].

2.5 Copper and stainless steel

A reliable joining of both copper and stainless steel offer a very good combination for many industrial applications. Copper in its pure form (~99.99%), is a high conductive material for both heat transfer and electrical applications. Type 384L is a low carbon grade of austenitic stainless steel that exhibits very good corrosion resistance and moderate high temperature strength. The challenging problems in joining copper to stainless steel are the large difference between the yield strength and flow properties of the two materials. On the other hand the increased mass of the copper part and the higher thermal conductivity of copper which is almost 40 times greater than stainless steel, promotes heat flow in copper during welding. In this case successful bonding was realized by considering a smaller diameter stainless steel type 384L that is inertia welded to a bigger diameter (double that of stainless steel) copper sample. Also due to oxidization of the faying surfaced prior to welding this has a detrimental effect on the integrity resulting in various degrees of unbonding near the center of the weld. It was observed that high quality welds could only be produced between copper and stainless steel if both parts were freshly machined prior to welding [19].

3. A new realization for welding dissimilar incompatible metals

Most of the problems and challenges discussed previously are due to incompatibility of the two metals to be joined. The methods presented in this review gives an insight about partial solutions to some of the challenges faced during the friction welding of dissimilar and incompatible metals. However none of presented techniques have tackled the problem of the big heat gradient between the two metals. A new foreseen realization is presented in this section which is based on experimental techniques that are done on similar applications. The technique presented here depends on balancing the heat gradient during welding between the two metals to be joined by friction welding in such a way to reduce the difference in heat conductivity between the two incompatible metals. This approach is realized by the introduction of a controlled amount of heat to the material that is highly conductive in order to concentrate the heat at the interface between the two materials that are friction welded. This can be done by passing a controlled amount of electric DC current through the two metallic parts that are to be welded together prior to and during the friction welding process. This approach also serves as a thermal catalyst to speed up and assist in the plasticization of material with higher melting point in order to assist in the diffusion of the incompatible material and therefore makes it conveniently possible to friction weld metals that are incompatible due to big differences in heat gradients. Figure 4 is a schematic drawing that demonstrates the realization of such technique.

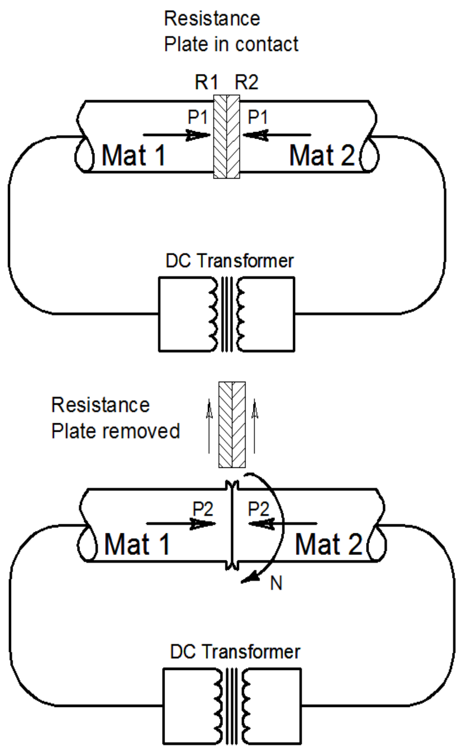

Figure 4. A schematic layout of the concept of the double resistance plate with friction welding process

4. Conclusion

This paper describes number of methods that are used for joining of dissimilar materials that are usually non-weldable using conventional welding techniques. The introduction of an interlayer material have proven to be a successful method for solving the problem of incompatibility of different materials by choosing the correct metal that is compatible to both bi-metallic materials. Also samples that are freshly machined prior to welding insure the exclusion of the oxide layer that usually has a detrimental effect on the bonding integrity of the weld. Another realization that is believed to be successful is playing on the heat balance between the two incompatible materials by introducing the different resistance plate that introduce a controlled amount of heat input. The advantage of implementing this foreseen technique is not only balancing the heat flow between the two materials but also facilitating the plasticization at the interface between the two metals and therefore reducing the time and energy needed for performing the welding process. An implementation of such technique is envisaged to have many advantages in the friction welding of bi-metallic materials.

REFERENCES

[1] Moreno and Preto, Welding Defects (1st ed.), Aracne, ISBN 978-88-548-5854-1, 2013.
[2] Hazlett, T. H., Fundamentals of Friction Welding, Metals Engineering Quarterly, ASM, pp. 1-7, Feb 1967.
[3] Quimby, J. A., Friction Welding, Past-Present-Future, ASTME Creative Mfg. Seminar, Technical Paper No. SP65- 90, April 1965.
[4] Vill, V. I., Friction Welding of Metals, translated and published by the American Welding Society, 1962.
[5] Sluetz, E. J., Oberle, T. L. and Brosheer, B. C, "Inertia Welding," American Machinist Special Report No. 621, October 1968.
[6] K. K. Wang, Wen Lin, Flywheel Friction Welding Research, Welding Research Supplement, 1974
[7] Emel Taban, Jerry E. Gould b, John C. Lippold Dissimilar friction welding of 6061-T6 aluminum and AISI 1018 steel: Properties and microstructural characterization
Elsevier Ltd., 2009.
[8] F. Sassani, J. R. Neelam, Friction Welding of Incompatible Materials, Welding Research Supplement, 1988.
[9] K. S. Mortensen, C.G. Jensen, L. C. Conrad, F. Losee, Mechanical Properties and Microstructures of Inertia-Friction-Welded 416 Stainless Steel, Welding Research Supplement, 2001.
[10] G. Sitte: *Weld. Cutting*, 2002, (5), 242.
[11] J. Wilden, J.P. Bergmann, M. Dolles and S. Reich: *Adv. Mater. Res.*, 2005, 6-8, 127.
[12] T. Watanabe, A. Yanagisawa, S. Konuma and Y. Doi:
Quart. J. Jpn. Weld. Soc., 2006, 23(3), 290.
[13] Koichi Ogawa, Hiizu Ochiu, KazukiYasumi, Tadakazu Ohnishi, Friction Welding of Aluminum Alloy and Carbon Steel using Insert Metal, Bulletin of University of Osaka Prefecture, 1994.
[14] C. R. G. Ellis, Continuous Drive Friction Welding of Mild Steel, Welding Research Supplement, 1972.
[15] Emel Taban, Jerry E. Gould b, John C. Lippold Dissimilar friction welding of 6061-T6 aluminum and AISI 1018 steel: Properties and microstructural characterization
Elsevier Ltd., 2009.
[16] Alumina-mild steel friction welded at lower rotational speeds. Mohamad Zaky Noh, Luay BakirHussain, Zainal Arifin Ahmad. 1-3, Malaysia: Elsevier B.V., 2007, Journal of Materials Processing Technology, pp. 279-283.
[17] P. Rombaut, W. De Waele and K. Faes, Friction welding of steel to ceramic, Sustainable Construction and Design, 2011.
[18] P. Shiva Shankar, L. Suresh Kumar, N. Ravinder Reddy, Experimental investigation and statistical analysis of the friction welding parameters for the copper alloy- CU Zn28 using Taguchi method, International Journal of Research in Engineering and Technology, 2009.
[19] R. A. Bell, J.C. Lippold and D.R. Adolphson, An Evaluation of Copper-Stainless Steel Inertia Friction Welds, Welding Journal, Nov 1984.