Numerical Modeling of Friction Welding Process

Ali. Moarrefzadeh

***Abstract*— Friction welding is a solid state joining process which can be used to join a number of different metals. Friction welding achieves 100 per cent metal-to-metal joints, giving parent metal properties. It is the only joining process to do this. No addition material or fillers are required and there are no emissions from the process. The thermal effect of friction welding that specially depends on the friction type and temperature field of it in workpiece, is the main key of analysis and optimization of this process, from which the main goal of this paper has been defined. Numerical simulation of welding process in SIMPELC method and by ANSYS software for gaining the temperature field of carbon steel, the effect of parameter variation on temperature field and process optimization for different cases of electrode done.**

***Keywords*–** Numerical Simulation, Friction, Weld, SIMPLEC, ANSYS, Temperature Field and Carbon Steel

I. INTRODUCTION

Friction welding is a solid state joining process which can be used to join a number of different metals. Friction welding achieves 100 per cent metal-to-metal joints, giving parent metal properties. It is the only joining process to do this. No addition material or fillers are required and there are no emissions from the process.

The process involves making welds in which one component is moved relative to, and in pressure contact, with the mating component to produce heat at the faying surfaces. Softened material begins to extrude in response to the applied pressure, creating an annular upset. Heat is conducted away from the interfacial area for forging to take place. The weld is completed by the application of a forge force during or after the cessation of relative motion. The joint undergoes hot working to form a homogenous, full surface, high-integrity weld. Metals are made up of positive ions 'floating' in a 'sea' of electrons (Fig. 1).

However, in a practical situation metal pieces do not spontaneously bond to each other and form 1 piece. This is because even polished metal surfaces have a layer of oxide and surface contamination. They are also not smooth enough for the atoms to be brought close enough to bond.

In friction welding, the surfaces are rubbed together to burn off the oxide and surface contamination layers and bring the atoms in close enough proximity to bond.

A. Types of Friction Welding Rotary

Rotary friction welding is the most common form of friction welding and has become the industry standard for a number of processes including welding API drill pipes and drill rods, joining of axle cases and spindles and welding of piston rods.

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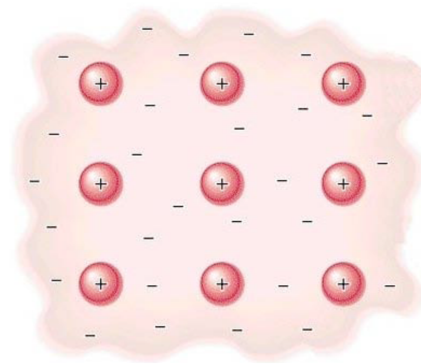
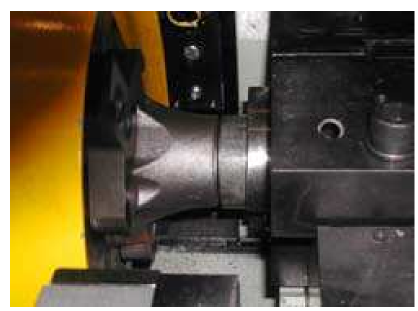


Fig. 1. Friction Welding Process

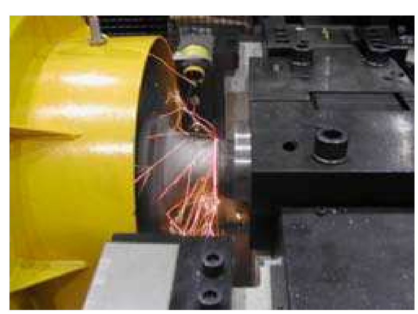
Rotary friction welding involves holding one component still while spinning the other component and brining the two together. Thompson Friction Welding is the world leaders in rotary friction welding having supplied over 500 machines and has over 45 years experience. In order for a join to be successful the following processes must take place (Fig. 2):

a) Pre-Contact: One part is held stationary in a fixed clamp. The other part is held in a rotating chuck.



(a)

b) First Friction: The chuck is accelerated to speed and the parts brought into contact under a light force.



(b)

c) Second Friction: The force is increased – plastic material starts to extrude from the weld interface.

(c)

d) Second Friction: The second friction phase continues until sufficient material has been extruded.

(d)

e) Forge: Rotation is stopped – the force increased and the parts forged together.

(e)

f) Weld Complete: The weld is complete – a full area, homogenous bond.

(f)

Fig. 2. Friction welding joints description

The rotary friction welding process is inherently flexible, robust and tolerant to different qualities of materials. The parameters involved are the rotational speed, time and force applied. There are optimum parameters for each particular weld that Thompson Friction Welding has calculated through years of experience. However, as the process is inherently robust and flexible, deviations on these parameters can still give a good weld.

In linear friction welding the same principles apply as rotary. One component is held still while the other is moved at speed and the two are brought together. The difference is that the moving component does not rotate; it is made to oscillate laterally.

The weld times for parts are similar no matter how big the part. Due to the geometry, rotary friction welding does not have any friction in the centre of the rotating part. This portion of the weld must heat up conventionally rather than due to friction. This is not the same for a linear friction weld. Friction occurs throughout the weld surface. This means that weld times are very quick and do not vary hugely from part size to part size. The largest linear friction weld ever produced at Thompson Friction Welding had a weld time of around 4 seconds.

II. NUMERICAL SIMULATION

The differential Equations (1)–(4) are solved iteratively by the SIMPLEC numerical procedure:

Mass continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r)+\frac{\partial}{\partial z}(\rho\upsilon_z)=0 \quad (1)$$

Radial momentum conservation equation:

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r^2)+\frac{\partial}{\partial z}(\rho\upsilon_r\upsilon_z)=\\&-\frac{\partial\rho}{\partial r}-j_zB_\theta+\frac{1}{r}\frac{\partial}{\partial r}(2r\eta\frac{\partial\upsilon_r}{\partial r})+\\&\frac{\partial}{\partial z}(\eta\frac{\partial\upsilon_r}{\partial z}+\eta\frac{\partial\upsilon_z}{\partial r})-2\eta\frac{\upsilon_r}{r^2}\end{aligned} \quad (2)$$

Axial momentum conservation equation:

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r\upsilon_z)+\frac{\partial}{\partial z}(\rho\upsilon_z^2)=\\&-\frac{\partial\rho}{\partial z}+j_rB_\theta+\frac{\partial}{\partial z}(2\eta\frac{\partial\upsilon_z}{\partial z})+\\&\frac{1}{r}\frac{\partial}{\partial r}(r\eta\frac{\partial\upsilon_r}{\partial z}+r\eta\frac{\partial\upsilon_z}{\partial r}).\end{aligned} \quad (3)$$

Energy conservation equation:

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_rh)+\frac{\partial}{\partial z}(\rho\upsilon_zh)=\\&\frac{1}{r}\frac{\partial}{\partial r}(\frac{rk}{c_p}\frac{\partial h}{\partial r})+\frac{\partial}{\partial z}(\frac{k}{c_p}\frac{\partial h}{\partial z})+\\&j_rE_r+j_zE_z-R,\end{aligned} \quad (4)$$

In the solution of Equation (1) – (4), special attention needs to be put on the energy effects on the electrode surface. At the cathode surface, additional energy flux terms should be included in Eq. (4) because of thermionic cooling due to the mission of electrons, ion heating, and radiation cooling [2].

Finite-Element techniques:

1- Finite elements modeling, types and properties for model different parts.
2- The definition of material properties
3- Parameter definition
4- Loading
5- Boundary and initial value definition

III. ADVANTAGES OF FRICTION WELDING

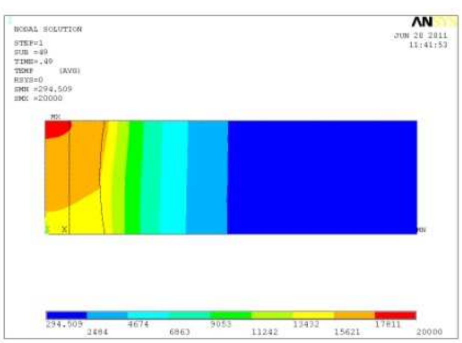
Friction welding has become industry standard in a number of applications. Some of the advantages of the process are detailed below:

- Weld monitoring can insure 100% weld quality
- Friction welding produces a 100% cross sectional weld area
- Far superior weld integrity compared to MIG welding
- Limited operator training require – full automation also possible
- The weld cycle is fully controlled by the machine
- Repeatable results
- Friction welding is a solid state process and does not suffer from inclusions and gas porosity.
- Friction welding required no consumables therefore becomes more cost effective over time
- Friction welding typically will complete a full cross sectional weld in 15% of the time it take MIG welding to produce an 85% cross sectional weld.
- Friction welding requires no special weld interface preparation welding)
- No post machining is needed for friction welded components in many cases
- Dissimilar materials can be joined with no alloying of the material

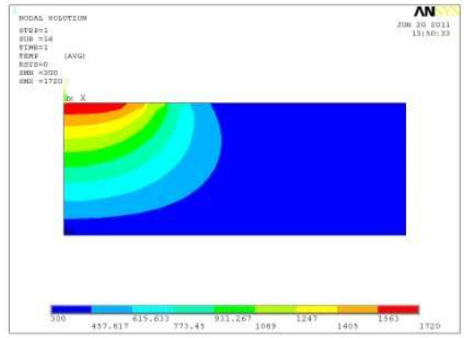
IV. RESULTS AND DISCUSSION

Conclusions for fluid temperature field carbon steel temperature field, completely shown in Fig. 3.

A person acting as Fire Watcher must be standing by with suitable fire extinguishing equipment during and for some time after welding or cutting if Combustibles (including building construction) are within 10 metres. Combustibles are further than 10 metres but can be ignited by sparks. Openings (concealed or visible) in floors or walls within 10 meters may expose combustibles to sparks. Combustibles adjacent to walls, ceilings, roofs, or metal



(a)



(b)

Fig. 3. Conclusions for temperature field: a) temperature field, b) Carbon steel temperature field

partitions can be ignited b radiant or conducted heat.

After work is done, check that area is free of sparks, glowing embers, and flames. Any tank or drum which has contained combustibles can produce flammable vapors when heated. Such a container must never be welded on or cut, unless it has first been cleaned as described in AS.1674-1974, the S.A.A. Cutting and Welding Safety Code. This includes a thorough steam or caustic cleaning (or a solvent or water washing, depending on the combustible's solubility), followed by purging and inerting with nitrogen or carbon dioxide, and using protective equipment as recommended in AS.1674-1974. Water-filling just below working level may substitute for inerting. Hollow castings or containers must be vented before welding or cutting. They can explode. Never weld or cut where the air may contain flammable dust, gas, or liquid vapors.

Exposed conductors or other bare metal in the welding circuit, or ungrounded electrically alive equipment can fatally shock a person whose body becomes a conductor. Ensure that the machine is correctly connected and earthed. If unsure have machine installed by a qualified electrician. On mobile or portable equipment, regularly inspect condition of trailing power leads and connecting plugs. Repair or replace damaged leads. Fully insulated electrode holders should be used. Do not use holders with protruding screws. Fully insulated lock-type connectors should be used to join welding cable lengths. Terminals and other exposed parts of electrical units should have insulated knobs or covers secured before operation.

The output fluid temperature field from nozzle showing heat transfer way between electrical arc and electrode and environment, with related temperatures is completely drawn in Fig. 4. For study the temperature variations in plasma axis and its heat transfer to electrode according to diagram (Fig. 5), the temperature field of electrical arc in its symmetry axis with standoff is drawn.

In this diagram, in each distance from nozzle to workpiece surface, the desired temperature can be derived. Thermal conductivity variation and thermal specific of carbon steel are shown in Fig. 6 and Fig. 7.

Fig. 8 shows a BSE image of the inclusions. White shows the areas where the respective element is found, and black shows a lack of that element. By comparing Fig. 8, it can be seen most of the sulfuris in the inclusions, as expected.

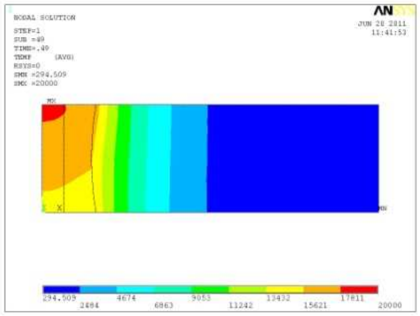


Fig. 4. Electrical arc temperature field

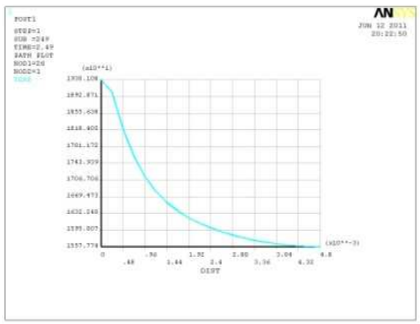


Fig. 5. The temperature field of electrical arc in its symmetry axis by standoff

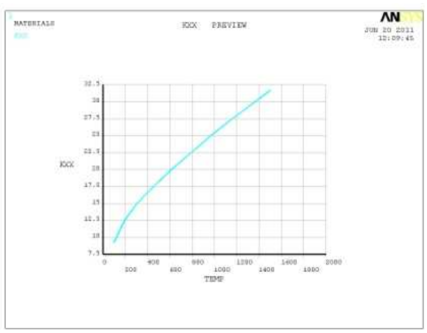


Fig. 6. Thermal conductivity of carbon steel

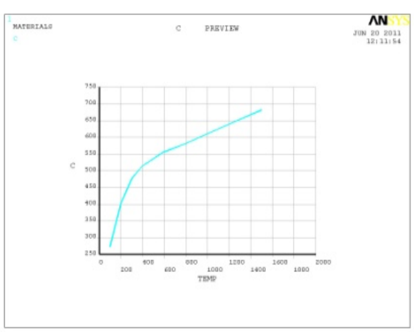


Fig. 7. Thermal specific of carbon steel

V. CONCLUSIONS

Exposed conductors or other bare metal in the welding circuit, or ungrounded electrically alive equipment can fatally shock a person whose body becomes a conductor. Ensure that the machine is correctly connected and earthed. If unsure have machine installed by a qualified electrician. On mobile or portable equipment, regularly inspect

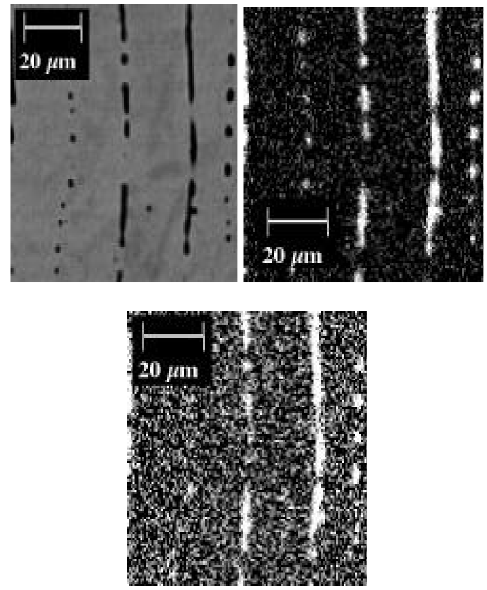


Fig. 8. SEM (BSE) image of inclusions (500X), Location of S (500X), Location of Mn (500X)

inspect condition of trailing power leads and connecting plugs. Repair or replace damaged leads. Fully insulated electrode holders should be used. Do not use holders with protruding screws. Fully insulated lock-type connectors should be used to join welding cable lengths. Terminals and other exposed parts of electrical units should have insulated knobs or covers secured before operation.

A 3D mathematical model for the metal transfer process in FRICTION WELDING was formulated in this article. A complete model describing the FRICTION WELDING welding process is developed, however, the computation of the transient solution of the complete model was prohibitively time-consuming and beyond the capability of the current PCs. In order to study the plasma arc interaction with metal during the metal transfer process, some simplifications have been made. A case of an axisymmetric arc was studied first using this 3D model for the verification purpose. The numerical results agreed well with the previous two-dimensional studies. A case of a moving arc was then computed to demonstrate the 3D capability of the model. The results revealed that the time-invariant Gaussian assumption for the distributions of the arc pressure, heat flux, and current density on the workpiece surface did not represent of the real situation. The calculated distributions for the moving arc were non-axisymmetric and the peaks shifted to the arc moving direction.

The brittle nature of the welded part was investigated using tensile tests, impact tests, and SEM photographs. Several heat treatments were investigated in an attempt to restore the ductility of the samples. No heat treatment could be found that restored the ductility and impact strength. The 416 can be friction welded with adequate tensile strength, but there was a severe loss of ductility and impact strength due to the reorientation of the sulfide inclusions.

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