

MODELLING OF FRICTION WELDING

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Abstract

Welding technique is a method used in order to joint various materials in manufacturing methods. Friction welding in the technique is one of the various application methods. The method has widespread use since 1950. The most important advantages of the method are the easy application, the material save and the energy save. In the process, heat is generated by conversion of mechanical energy into thermal energy at the interfaces of the components during rotation under pressure. In this study, relation between mechanic and heat energy was carried out mathematically. AISI 1040 medium carbon steel which is the example material was used in the experiments and the models. The examination was made using Quick-Field program due to the harmony with the experimental results and the easy application. As a result, different data were evaluated for obtained material properties and operating conditions, and obtained results were compared with previous studies.

Then, the most suitable conditions for time, material and energy were acknowledged on the future applications of friction welding.

Keywords: Friction Welding, Modeling, Heat.

INTRODUCTION

In general, any of the machine parts can be produced by one of the various manufacturing methods such as 'forging, machining and welding'. The determination of the methods depends on the production cost of the alternatives for the individual parts. Friction welding is one of the most popular methods among other welding methods.

In the process, heat is generated by the conversion of mechanical energy into thermal energy at the interface of the work pieces during rotation under pressure. Some advantages of friction welding are that is economical as regards material, it requires low production time and it offers greater possibilities when it comes to the welding of different metals or alloys. Friction welding can also be used in order to join components that have circular or non circular cross-sections.

The most interesting parameters in friction welding are friction time, friction pressure, upset time, upset pressure and rotation speed.

In general, friction welding is divided into two methods: continuous drive friction welding and inertia friction welding.

In the continuous drive method, one of the components is rotated at constant speed (s), while the other is pushed towards the rotated part by a sliding action under a predetermined pressure-friction pressure (P_1). Friction pressure (P_1) is applied for a certain friction time (t_1). Then, the drive is released and the rotary component is quickly stopped while axial pressure is increased to a higher predetermined upset pressure (P_2) for a predetermined time (t_4). The layout of the welding method is shown in figure 1. Parameters of the method are shown in figure 2.

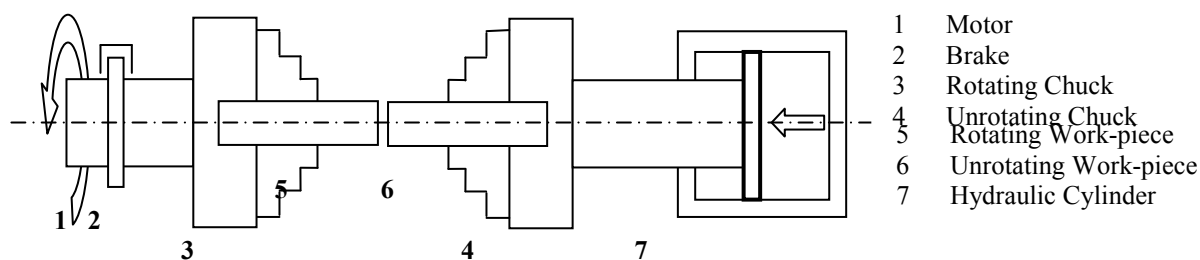


Fig. 1. Layout of Continuous Drive Friction Welding

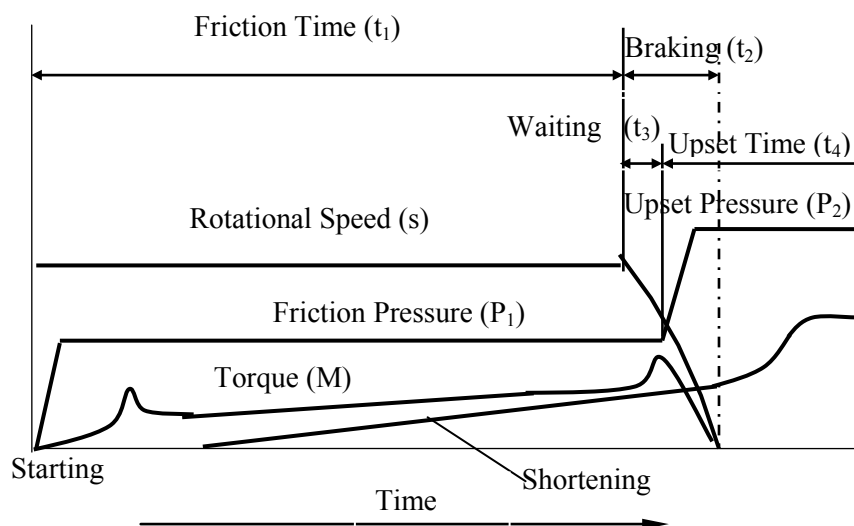


Fig. 2. Parameters on Continuous Drive Friction Welding

Various research papers have been published in this area, and these were given below. Vill, V. I. [1] made a study on the friction welding of metals. An analytical temperature solution was presented in an article based upon a finite weld piece and ambient temperature chuck ends by Rich, T. and Roberts, R.[2]. They discussed the establishment of boundary conditions. They used continuous drive method to join AISI 4140 steel tubes. Imshennik, K. P. and Kragel' Skii[3] examined heating properties in the friction welding. Healy, J. et al. [4] made analysis of frictional phenomena in friction welding of mild steel. Kinley, W.[5] made a study on the friction welding set-up. Murti, K.G.K. and Sundaresan, S.[6] directed a study about parameter optimisation in friction welding of dissimilar materials. Sluzalec, A.[7] developed a finite element model to simulate the temperature process. Nentwig, A.W.E. et al. [8] investigated the effect cross section differences of the components upon the

joint quality of friction welding and offered that friction pressure, upset pressure and rotation speed must be changed in friction welding of different cross-sections. Bendzsak, G. J. et al. [9] investigated numerical model in friction welding. Fu, By L. and Duan, L.[10] carried out the analysis of the coupled thermo-mechanical problem during friction welding by using finite element method, according to the constitutive relation of large elasto-plastic deformation and the principle of virtual work in their studies. Then, the heat flow and stress-strain process at the heating stage of friction welding were simulated, and the law of variation of temperature, stress and strain fields during friction welding were systematically investigated by authors. Balasubramanian, V., et al. [11] made a study about application of friction welding to 1045 steel welds. Sahin, M.[12] investigated effects of work-piece dimensions and plastic deformation on friction welding method. Then, Sahin, M and Akata, H. E.[13] examined an

experimental study on application of friction welding for parts with different diameters and width. Investigations on the effect of dimensional differences in friction welding of AISI 1040 specimens were directed by same authors [18]. D'Alvise, L. et al. [17] studied finite element modelling of the inertia friction welding process between dissimilar materials.

In this study, it is aimed to support the development of the method and the new knowledge supplement to literature by the friction welding, which is a manufacturing method. Therefore, proper conditions on work-pieces, which are not produced on other manufacturing methods, are selected for material and energy use. Then, conditions for more results than material properties and production quality were determined using new knowledge and technologies.

THE EXPERIMENTAL PROCEDURE

The Experiment Set-up

In the present study, an experimental set – up was designed and constructed as continuous drive method. The experiment set-up is given in figure 3.

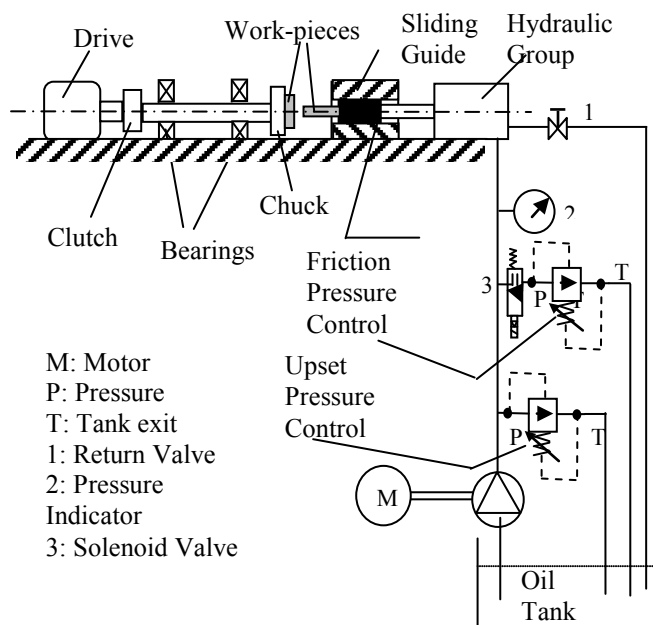


Fig. 3. Continuous drive friction welding set-up

Material

Composition of AISI 1040 steel is given in Table 1.

Table 1. Chemical compositions of test material used in the experiment [14]

Material	% C	% P	% S	% Mn	% Si	% Ni	% Cr
AISI 1040	0.35 0.44	< 0.04	< 0.05	0.75	0.20	-	-

Geometry of Parts

The experiment specimens were machined from AISI 1040 steel on geometry below. Geometry of parts is given in figure 4.

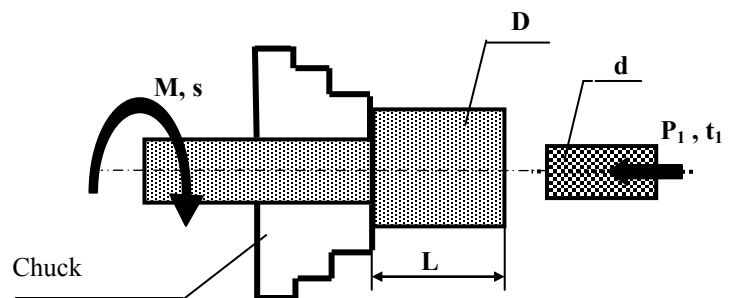


Fig. 4. Part dimensions used in the experiments.

The Experimental Study

The experiments were carried out at laboratory by designed and constructed continuous drive friction welding set-up. Motor power of set-up is 4kW, and revolution speed of motor is 1410rpm.

Then, upset pressure and upset time were kept constant. But, friction time and friction pressures were changed in the experiments. First, tests were conducted to determine the optimum parameters for a convenient joint. The optimum parameters were determined with 10mm's specimens having equal diameter [18]. Welding experiments were directed to obtain optimum friction time and friction pressures using upset time (20 sec) and upset pressure (110 MPa). Hence, the optimum parameters were found (30 MPa) for friction pressure and (5 sec) for friction time. Then, these parameters obtained were used to join parts having different diameters and widths [18]. Parameters used in the friction welding experiments are given in Table 2.

Table 2. Parameters used in the friction welding experiments [18]

Length of rotating work-piece (L)mm	Diameter of rotating work-piece (D)mm	Diameter of axially sliding work-piece d(mm)	Friction Time t_1 (sec)	Friction Pressure P_1 (MPa)	Upset Time t_4 (sec)	Upset Pressure P_2 (MPa)
15	10	10	5	30	20	110
	15					
	20					
	30					
	40					

Temperature measurement is of great importance at interfaces of parts because of friction in friction welding. But, it is hard to predict measurements according to time of the temperatures. In this study, AISI 1040 material was used considering the similar properties of AISI 1045 material in the experiments. And, Quick-Field simulation program was used in this study. Because, it is easy to make study with the program, and it is suitable to compare obtained knowledge from welding methods with the program, and the program gives close results for real values [15, 16].

Temperature Dependent Properties of Material

In this study, AISI 1040 material was used considering the similar properties of AISI 1045 material in the experiments [11].

NUMERIC SIMULATION

Quick-Field Finite Element Analysis Program

In more engineering situations today, it is known that it is necessary to obtain approximate numerical solutions to problems rather than exact close form solution. In recent years, the finite element method has rapidly become a very popular numerical analysis technique for obtaining approximate solution to a wide variety of engineering problems. Finite element method envisions the solution region as built up of many small, interconnected sub-regions or elements. The material properties and governing relationships are considered over these elements and

expressed in terms of unknown values at element corners.

Quick-Field V 4.2T version can be downloaded from the internet free (www.quickfield.com/free.html) used program is limited with 200 nodes. With this program, to find the heat distribution in any section below requirement would be need for two dimensional calculations.

1-First of all drawing is required. This can be taken from other drawing programs such as AutoCAD in DXF format.

2-Thermal conductivity of solid body.

3-Surface boundary conditions (Convection, radiation or heat flux).

Suppositions given below were used in quick field software program.

Table 3. Temperature Dependent Properties of 1045 Steel [11]

Density (7860 kg/m ³)										
Temperature °C	20	150	315	485	650	750	815	1000	1150	1300
Specific Heat j/(kgK)	460	500	586	730	835	1250	840	670	630	630
Thermal Conductivity W/(mK)	52	48	46	43	34	33	32	43	48	60

Suppositions

Suppositions for theoretical approaches were given below:

- 1) Forms of parts were not changed along welding stage.
- 2) Friction pressure was homogeneously spread at welding interface. However, in this welding method, there are two components. While one is unrotated-part, the other one is rotated-part. Torque that is at interface of the parts is not homogeneously spread according to the rotation axis. Friction pressure or friction force which requires for friction is applied to work-pieces by hydraulic piston. Then, friction force was not changed with starting of melting and surface-deformation at friction-surfaces.
- 3) In general, forms of work-pieces were not changed at welding stage.
- 4) Chuck has large-mass. Then, friction welding time occurs such as 5-9 sec. in a short time. So, it was foreseen that temperature was kept constant on cross-section according to surface-axis which is contacted of fixed chuck of rotated-work-piece.
- 5) There are different circumference-torsions and heat fluxes because of friction along rotation-axis at interfaces of work-pieces.
- 6) Friction coefficient was accepted observing similar studies ($\mu=1$) [7].

Correlation between Torque and Heat Energy

Mathematical expression between operating characteristics on friction welding and heat energy produced because of friction welding can be found observing suppositions. It was assumed that friction pressure homogeneously spread on interface of rotated and unrotated parts. Produced heat and its variation can be determined with respect to operating characteristics and dimensions of parts. Produced heat energy can be expressed as

$$d\dot{Q} = \omega \cdot dM \quad (W) \quad (1)$$

where ω is angular velocity, and dM is differential torque of circle at width dr [2].

Then, torque dM can be expressed as

$$dM = r \cdot dF_{\text{fric.}} \quad (Nm) \quad (2)$$

where $dF_{\text{fric.}}$ is friction force over circle at width dr , and r is radius of circle.

Then, it can be defined that friction force $dF_{\text{fric.}}$ equals to friction-coefficient multiplied by axial-force of pressure P over circle at width dr .

$$dF_{\text{fric.}} = r \cdot (\mu \cdot P \cdot 2\pi \cdot dr) \quad (3)$$

By introducing equations (2) and (3) into equation (1), we obtain

$$d\dot{Q} = 2\pi \cdot \mu \cdot \omega \cdot P \cdot r^2 \cdot dr \quad (W) \quad (4)$$

It can be defined that total energy occurred at friction-surfaces is heat occurred over friction-surface with respect to distance r and thickness dr from rotation-axis in figure 5.

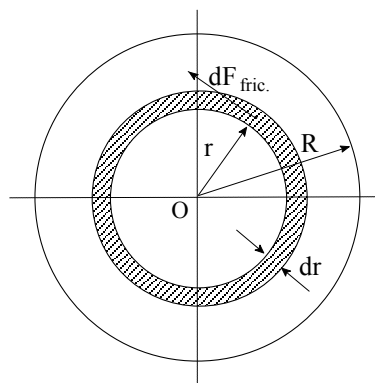


Fig. 5. Friction surface and friction ring (dr)

We obtain heat occurred at welding surface by integrating with R of equation (4) as follows:

$$\int_0^R d\dot{Q} = 2\pi \cdot \mu \cdot P \cdot \omega \cdot r^2 \cdot dr \quad (5)$$

$$\dot{Q} = 2\pi \cdot \mu \cdot P \cdot \omega \cdot \frac{r^3}{3} \Big|_0^R \quad (6)$$

$$\dot{Q} = \frac{2}{3} \cdot \pi \cdot P \cdot \omega \cdot R^3 \quad (W) \quad (7)$$

We obtain total torque by integrating with R of equation (3) as follows:

$$M = \int_0^R 2\pi \cdot \mu \cdot P \cdot r^2 \cdot dr \quad (8)$$

$$M = 2\pi \cdot \mu \cdot P \cdot \frac{R^3}{3} \bigg|_0^R \quad (9)$$

$$M = \frac{2}{3} \cdot \pi \cdot \mu \cdot P \cdot R^3 \quad (\text{Nm}) \quad (10)$$

Then, when equation (7) is compared with equation (10), heat occurred in unit-time over welding surface is equal to total torque multiplied by angular velocity.

$$\dot{Q} = \omega \cdot M \quad (\text{W}) \quad (11)$$

Heat flux occurred over any point at distance r from rotation-axis is equal to circle-area at width dr divided by equation (4).

$$\dot{q} = d\dot{Q} / (2 \cdot \pi \cdot r \cdot dr) = 2 \cdot \pi \cdot \mu \cdot \omega \cdot P \cdot r^2 \cdot dr / (2 \cdot \pi \cdot r \cdot dr) \quad (\text{W/m}^2) \quad (12)$$

As a result, heat flux occurred over any point at distance r from rotation-axis can be expressed as

$$\dot{q} = \pi \cdot \omega \cdot P \cdot r \quad (\text{W/m}^2) \quad (13)$$

RESULTS and DISCUSSION

Both temperature and heat flux variations were theoretically determined on rotated and unrotated parts using starting and finishing of friction time. Therefore, Quick-Field simulation program, which was given properties and principles in use under a special chapter, was used in this study. This work was carried out referring Balasubramanian et al. and Sluzalec [7,11], which are theoretical and experimental. In their studies, temperature over welding surface is 920 – 930 °C for similar material and dimensions using experimental methods in parts having equal diameter. Therefore, obtained 927 °C temperature value using Quick-Field program is an acceptable value. Graphics (figure 7) were found referring the value in this study.

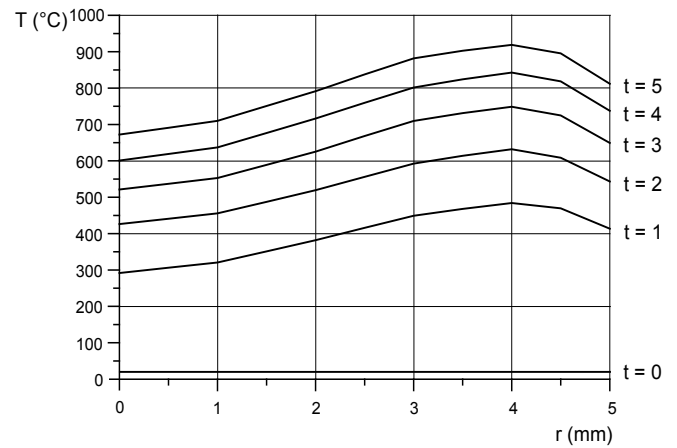


Fig. 7. Temperature variations according to time over friction surfaces (as °C)

As it can be seen in figure 7, temperature variations over the friction surfaces of the parts having equal diameter increase as time is increased. Then, $D=20\text{mm}$. and $d=10\text{mm}$. joints were selected for parts having different diameter as model (figure 8). Mesh points of parts having different diameter (figure 9), temperatures at friction surfaces of the parts, surface temperatures over outer surfaces of parts having big and small diameter and the heat flux vectors and temperature variations at times 1, 2.5 and 5 sec. of the model were investigated using Quick-Field program (figures 10 and 11) [19].

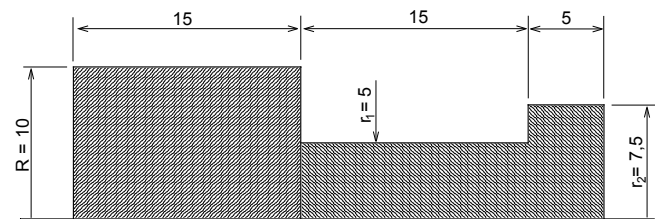


Fig. 8. Welded parts and its' dimensions (Chucks are not shown in this figure)

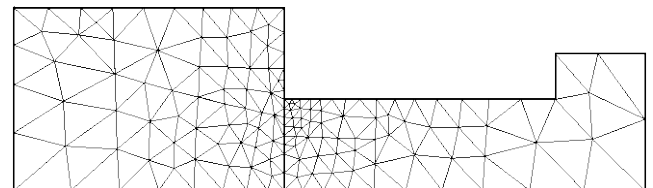


Fig. 9. Mesh points at determined zone of temperature variation

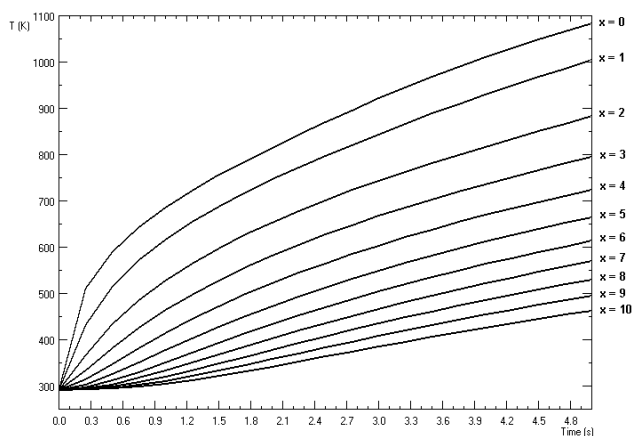


Fig. 10. Temperature variations according to time over outer-surface of small part (as K)

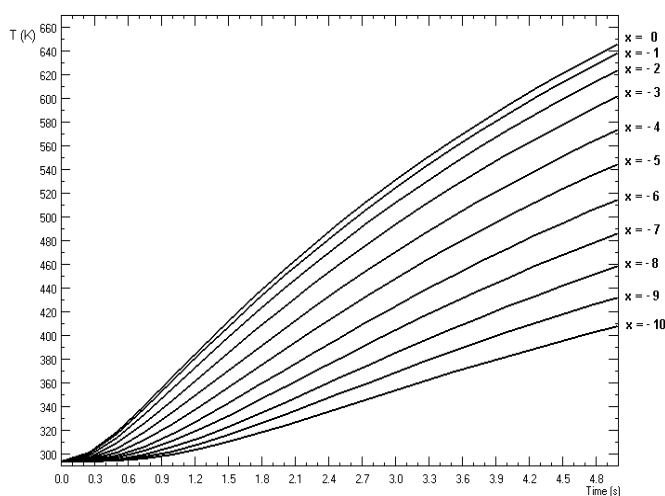
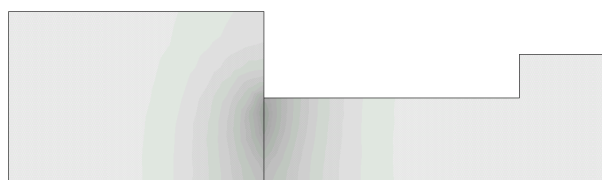
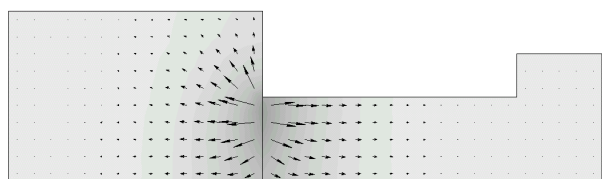


Fig. 11. Temperature variations according to time over outer-surface of big part (as K)

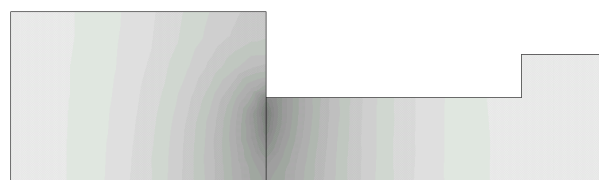
As it can be seen in figures, temperature variations over outer-surface of the small part are bigger than those of the big part.



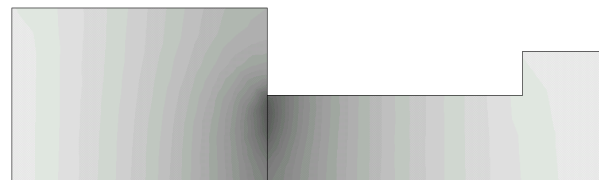
a.) Temperature variation at $t = 1$ sec.



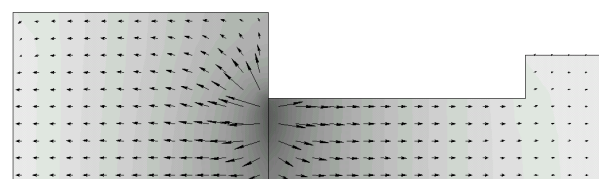
b.) Heat flux vectors and temperature variation at $t = 1$ sec.



c.) Temperature variation at $t = 2.5$ sec.



d.) Temperature variation at $t = 5$ sec.



e.) Heat flux vectors and temperature variation at $t = 5$ sec.

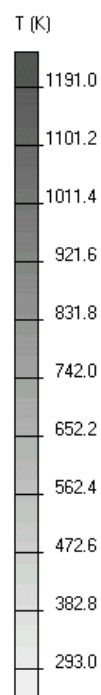


Fig. 12. Heat flux vectors and temperature variations at times 1, 2.5 and 5 sec.

Temperature variations and heat flux vectors of the model part are shown belonging to times 1, 2.5 and 5 sec. in figure 12. Then, the temperature-scale at the upper-right corner can be used to determine the temperatures at various points of the part [19].

CONCLUSIONS

Heat transfer by conduction from welding surface to centre of part in the small work-pieces is much more than that in the big ones. Then, there is high-temperature average over circle of the part. So, heat transfer at surface is higher than other places because of temperature-difference.

While heat variation of work-piece having the small diameter is faster than that of the big one, heat capacity of work-pieces having the small diameter is lower than that of the big one. Therefore, heat transfer of small work-pieces disperses fast. And, more temperature-variation occurs in the small work-pieces.

Then, obtained knowledge from our numerical calculation study is valuable to develop the fundamental theory and engineering application research of friction welding.

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Nomenclature		
$\square$	Thermal Conductivity	W/(mK)
c	Specific Heat	j/(kgK)
T	Temperature	K, °C
$\square$	Specific Mass	kg/m ³
ω	Angular Velocity	rad/sec
s	Rotational Speed	rpm
P	Pressure	MPa
L	Length	mm
r	Radius	mm
D	Diameter	mm
t	Time	sec
F	Force	N
μ	Friction Coefficient	-
V	Linear Velocity	m/sec
M	Torque	Nm
$\dot{q}$	Heat Flux	W/m ²
$\dot{Q}$	Total Heat Flux	W