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"RESEARCH AND DEVELOPMENT IN MECHANICAL INDUSTRY"

RaDMI 2010

In Memoriam of Prof. dr Georgios Petropoulos

PROCEEDINGS

Volume 1

Editor:
Predrag V. Dašić

1

16-19. September 2010.
Donji Milanovac, Serbia

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P R E F A C E

The First Conference ″Research and Development in Chemical and Mechanical Industry″ - **RaDMI 2001** was held upon the initiative of Predrag Dašić and prof. dr Miroslav Radovanović in Kruševac from October 22-24, 2001.
Until now, 9 conferences were realized. The conference accepted and published over 1.500 papers, from which 1.100 were from abroad from 40 various countries of the world. Total number of authors and coauthors is over 2.000. Papers of the 8th conferences were published in 16 proceedings in hard copy and 8 proceedings in electronic form (CD-ROM). Amount of printed material was approximately 11.000 pages. Some papers from the 8th International conference RaDMI 2008 will be printed in special issue of international journal from SCI-E paper ″Strojniški Vestnik – Journal of Mechanical Engineering″ Vol. 55, no. 2 (2009) (Web site: http://en.sv-jme.eu/).

Tenth International Conference ″Research and Development in Mechanical Industry″ **RaDMI 2010** will be held on 16–19th September 2010 in Donji Milanovac, Serbia.

Topics of the Conference RaDMI 2010 are:

- **Plenary Session:** Invitation papers, with 18 papers;
- **Session A:** Research and development of manufacturing systems, tools and technologies, new materials and production design, with 52 papers;
- **Session B:** Transport systems and logistics, with 9 papers;
- **Session C:** Application of information technologies in mechanical engineering, with 23 papers;
- **Session D:** Quality management, ISO 9000, ISO 14000, TQM and management in mechanical engineering, with 49 papers;
- **Session E:** Application of mechanical engineering in other industrial fields, with 50 papers.

The aim of organizing the Conference is: animating scientists from the faculties and institutes and experts from the industry and their connecting and collaboration, and exchanging the experiences and knowledge of domestic and foreign scientists and experts.
On behalf of the organizers, we would like to extend our thanks to all organizations and institutions that have supported the initiative to have this anniversary gathering organized. We would also like to extend our thanks to all authors and participants from abroad and from the country for contribution to this conference.

This Tenth International Conference RaDMI is entirely dedicated to the late Prof. dr Georgios Petropoulos, our friend and active participant in all the previous conferences.

Donji Milanovac, September 2010.

CHAIRMAN OF ORGANIZING COMMITTEE

Predrag Dašić, prof.

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HEAT GENERATION – TEMPERATURE PHASES OF THE FSW PROCESS

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Summary: *Friction Stir Welding has appeared in the early 1990s and since numerous scientists work on mathematical explanation of it. Operational phases of the process, geometry of the welding tool, optimal technological parameters of the process and many other physical facts are the goal of researches around the world. Friction Stir Welding is a process where temperature has significant influence on weld creation. Temperature is one of the main reasons why some welds are qualitative and some are not. Just like during any other welding process, Friction Stir Welding has temperature phases which, if properly described and explained before application of welding, can help in definition of the parameters needed for adequate welding procedure. This paper gives an overview on these phases.*

Keywords: *Friction Stir Welding, Heat Generation, Temperature.*

1. INTRODUCTION

Friction stir welding (FSW) is a solid – state welding process (metal of the welding pieces and/or filler metal are not melted during the welding process), and is used mostly for applications on sheet or plate shaped parts, usually on large parts which cannot be easily heat treated post weld to recover temper characteristics. FSW is used where the nominal metal characteristics should remain unchanged or minimally changed during the welding process.
FSW was invented and experimentally proven by Wayne Thomas and its team at The Welding Institute UK in December 1991 and this institute holds numerous patents on the process [1].
This process is primarily used on:

- 2000, 5000, 6000, 7000 series aluminum,
- Aluminum based metal matrix composites,
- Copper and its alloys,
- Titanium and its alloys,
- Zinc, stainless steel and nickel alloys,
- Lead, Plastic,
- Some combinations on previously mentioned materials (for example, welding of bronze and aluminum).

2. PRINCIPLE OF WORK AND OPERATIONAL PHASES OF FSW

During FSW process (1 and *2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line*
Figure 1), a cylindrical – shouldered tool, with a profiled threaded/unthreaded probe (1 and *2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line*
Figure 1, 5) and flat or coned shoulder (1 and *2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line*

Figure 1, 4) is rotated at a constant speed and fed at a constant traverse rate into the start point of the joint line (1 and *2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line*

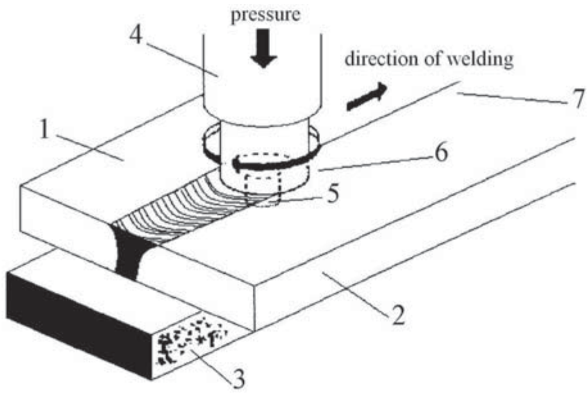
Figure 1, 7) between two plates (1 and *2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line*

Figure 1, 1 and 2). Welding plates are butted together and clamped rigidly onto a backing plate (1 and *2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line*

Figure 1, 3) in a manner that prevents the abutting joint faces from being forced apart. The height of the probe is slightly less than the weld depth required (height of the welding plates) and the shoulder tip (1 and *2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line*

Figure 1, 6) is in intimate contact with top surfaces of the welding plates.

Friction stir welding uses two types of physical – mechanical processes, that happen with materials, to create weld: friction processes and deformation processes (as the most dominant – stirring). Friction processes result with generation of heat [3]. Frictional heat is generated between the welding tool's active surfaces - probe side, probe tip, shoulder tip and the material of the work pieces. This heat generated during sliding and sticking of welding tool and welding material [5, 6], along with the adiabatic heat within the material, cause the stirred materials to soften without reaching the melting point allowing the traversing of the tool along the weld line in a plasticised tubular shaft of metal.



1 and 2-welding plates; 3-backing plate; 4-shoulder; 5-probe; 6-shoulder tip; 7-weld joint line

Figure 1: Principle of the FSW

There are various shapes and design of welding tool, backing plate etc, but that does not affect basic friction stir welding process, without any concern on technology varieties, friction stir welding process can be separated to five phases: a) plunging, b) dwelling, c) welding, d) dwelling, and e) pulling out.

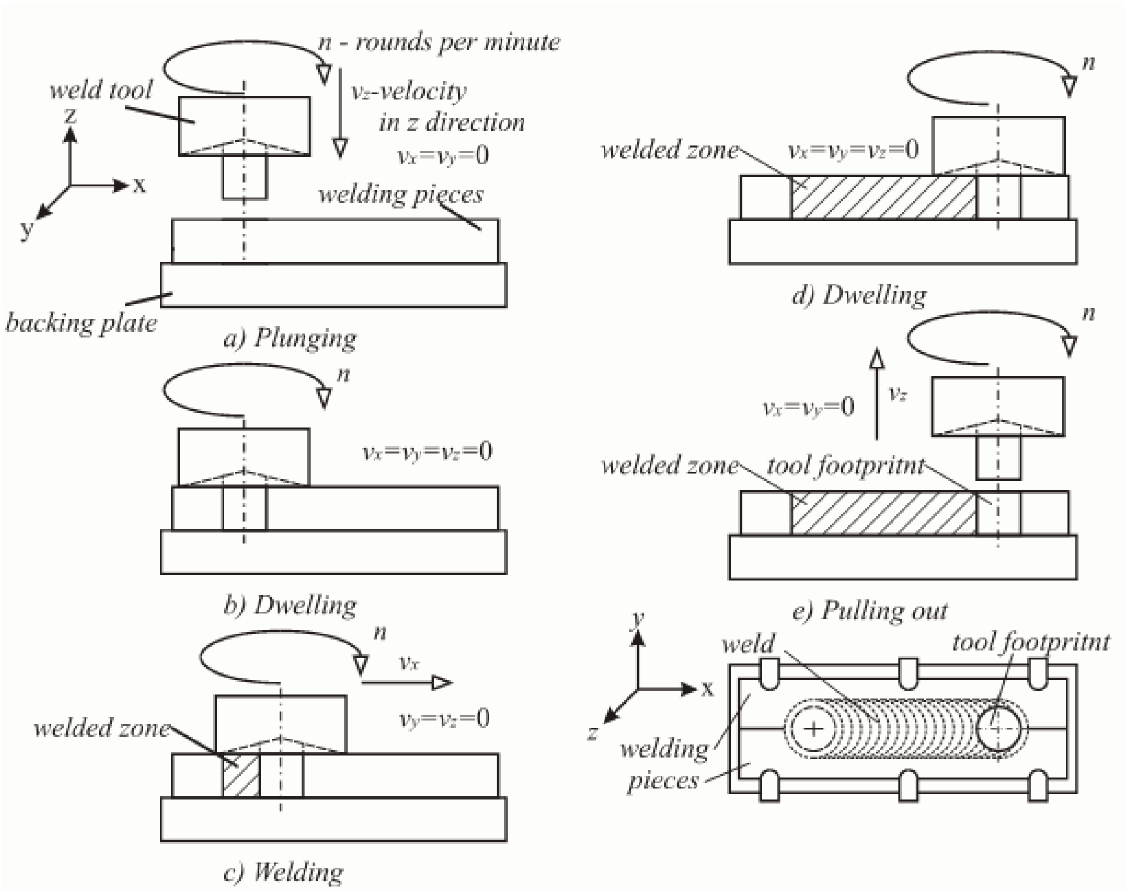


Figure 2: Phases of the friction stir welding process

Figure 2 shows these phases of friction stir welding process. Last two phases are non productive phases and they only finalize the weld but they are unavoidable. During the first phase, the rotating welding tool is plunged vertically into the joint between the weld pieces – into the joint line (Figure 2, a) and it is the classical welding process.
The plunge phase is followed by the dwell phase, where the toll stays steady relatively to the welding pieces but still constantly rotating (Figure 2, b). The mechanical interaction, due to the velocity difference between the rotating tool and the stationary work piece, produces heat by frictional forces. This heat dissipates into the surrounding material – welding pieces, temperature of the material rises and it softens. After these two phases, the welding process is initiated by moving either the tool or the work piece relative to each other, traversal along the joint line (Figure 2, c).
Welding is processed until the welding pieces become connected along the planed weld distance. After welding phase traversal movement between tool and weld pieces stops but welding tool continues its rotation. This is the third phase or the second dwelling phase (Figure 2, d). There is no special need for this phase and if machine used for welding has ability to pull out the tool the same moment when traversal movement along the joint stops, this phase can be avoided. Final phase is pull out of the welding tool from the weld (Figure 2).

3. HEAT GENERATION – TEMPERATURE PHASES OF THE FSW

Analyzing the FSW process it is clear that operational phases of process explain the kinematics of the FSW. On the other hand, temperature rising and heat generation at the contact of welding tool and welding metal show that heat generation phases are not necessarily bonded with operational phases. From the aspect of welded joint heat treatment during welding, FSW can be described in four heat generation or, simple, temperature phases:

1) Dwelling: the material is preheated by a stationary, rotating tool in order to achieve a sufficient temperature ahead of the tool to allow the traverse movement. This period includes the plunging of the tool into the work pieces at one point of the joint line.
2) Transient heating: when the welding tool begins traversal movement along joint line there is a transient period where the heat production and temperature around the tool rises until pseudo steady-state is reached.

3) Pseudo steady – state. Although fluctuations in heat generation will occur the thermal field and temperature around the tool remain effectively constant, at least on the macroscopic scale. Microscopic transformations are present on a high level.
4) Post steady – state. Near the end of the weld heat may "reflect" from the end of the weld pieces and backing plate leading to additional heating around the tool.

Heat generation – temperature phases can not be compared with the existence of operational phases since temperature of the welding plate's changes during the process. In order to show existence of the heat generation phases it was necessary to determine temperature of welding plates. For that purpose, results from the experiment given in [5] were compared to the results of the analytical approach. Estimation of the generated heat by the proposed mathematical model given in [6] is done for the same conditions and welding parameters presented in the paper [5] – dimensions and material properties, technological parameters, welding length etc. Experiment given in [5] is conducted on plates made of aluminum 2024 T3 alloy, height h=3 mm, length L=150 mm and width of a single plate B=60 mm (Figure 3).

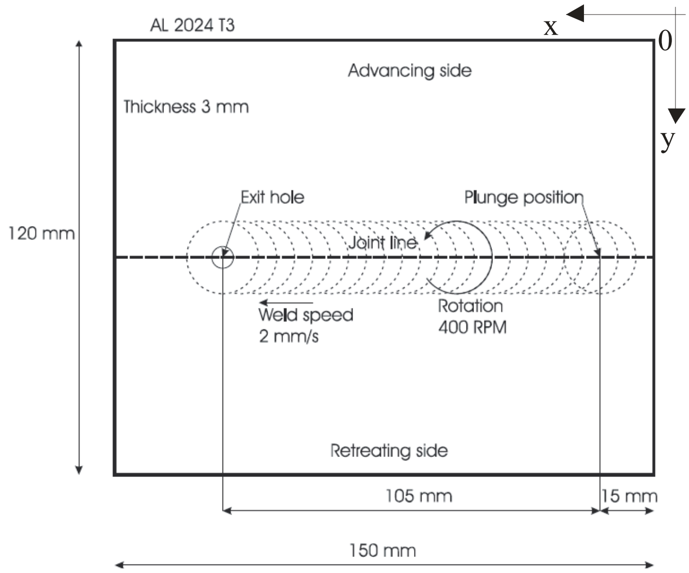


Figure 3: Plates used in experiment [5]

In experiment is used welding tool made of steel. Probe of the tool has left oriented tread (Figure 4), probe diameter is d=6 mm, tread pitch is 0,8 mm and complete height of the probe is H=3,5 mm (H_{max}≈4 mm). Diameter of the shoulder is D=18 mm with cone angle of α=10°. Effective plunging depth of the probe is h_e=2,5 mm.

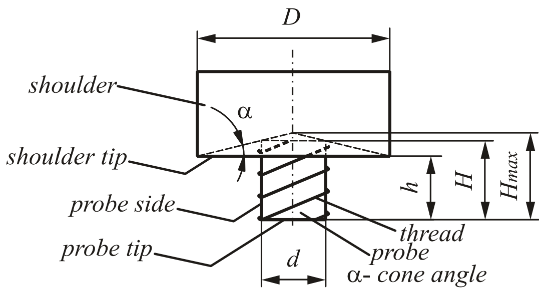


Figure 4: Welding tool used in experiment [5]

Welding tool rotated with n=400 rounds/min, and traveled along joint line with velocity v_x=2 mm/s; rotation axis of the welding tool has been tilted for 1° to the front and shoulder tip has plunged approximately 0,2 mm to the welding plates in every moment of welding. Welding plates had no technological hole (d_0=0 mm).

Plunging/Pressing force and power on the work shaft of the machine were measured during the process of welding. Paper [5] gives graphs representing phases of welding process and timeline of phases:

-plunging phase: t_{pl}=8.7 s,

-first dwelling phase: t_{dw1}=5 s,

-welding phase: $t_w = \frac{l}{v_x} = \frac{105}{2} = 52.5$ s,

where l=105 mm – welding length.

Paper [5] didn't analyze second dwelling and pulling out phases so there is no explicit data to be fully analyzed. The amount of generated heat is necessary for temperature determination. Using mathematical model for heat generation [6] and using the finite differences method, solving adequate temperature "3D heat equation" (Equation 1) for FSW conditions given in [5], temperature of the welding plates is estimated in sufficient number of points in order to get applicable data for further analysis.

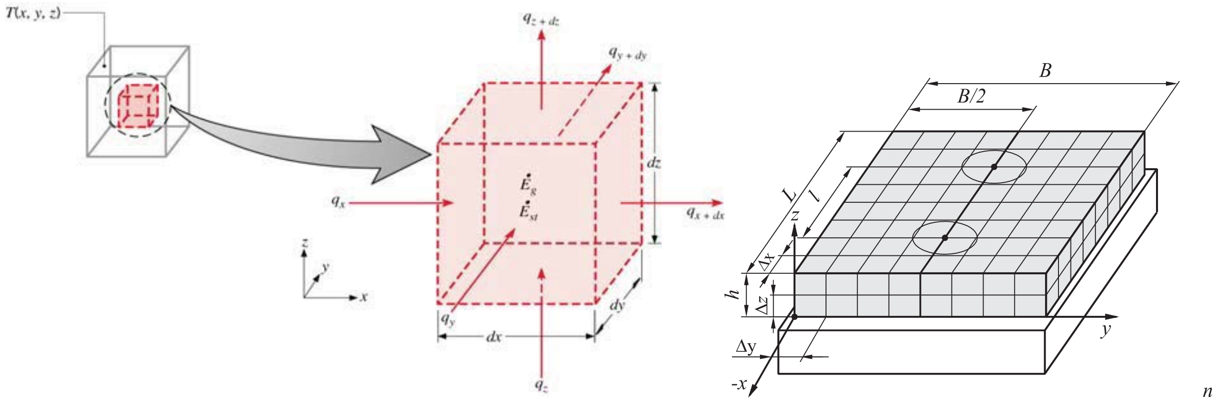


Figure 5: Control volume and element's mesh used in Finite Differences Method application to the FSW temperature determination

$$\rho c \frac{\partial T}{\partial t} = \lambda \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + q_v \qquad \text{Eq. (1)}$$

Figure 6 shows some of the results and temperatures of specific points on welding plates.

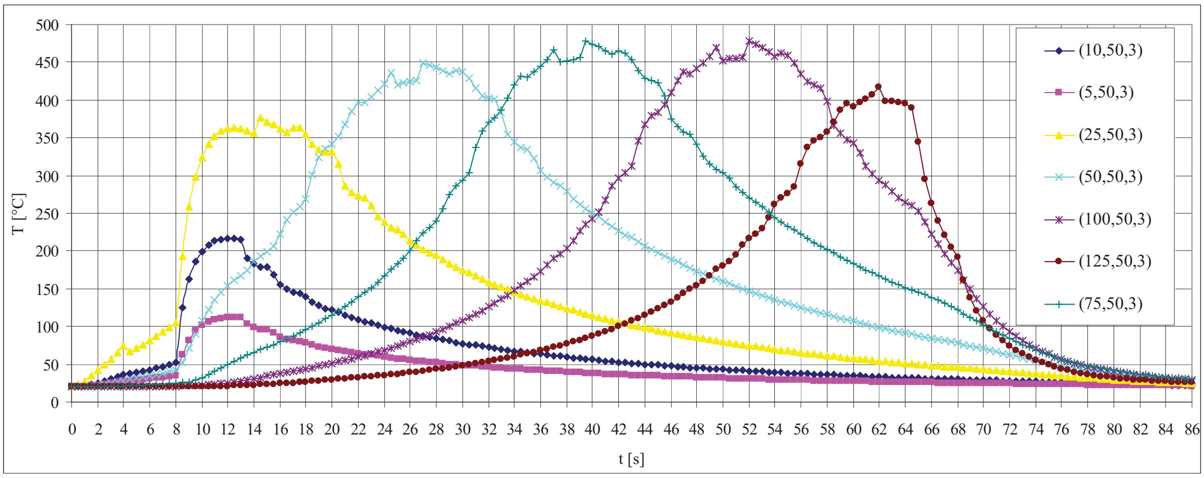


Figure 6: Temperature of some specific points (x,y,z) on the welding plates during FSW process

3. CONCLUSION

It is obvious that heat generation phases or temperature phases do exist for every FSW and they can be analyzed after analysis of the weld plate's temperature. Figure 6 shows that temperatures of different points on plates differ one to another and the temperature changes depending from position and operational phase of the welding tool. But shape of all temperature curves (Figure 6) indicates one common curve that fully describes all heat generation – temperature phases of the FSW (Figure 7).

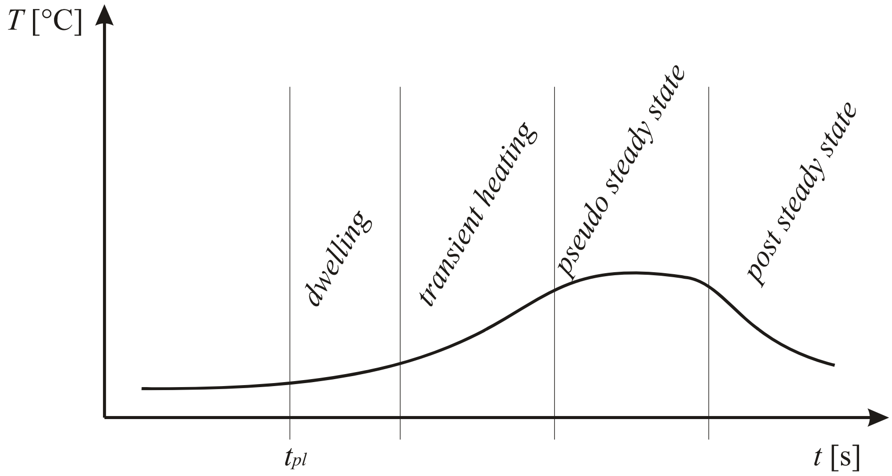


Figure 7: Heat generation – temperature phases of the FSW

Unfortunately, FSW is still not completely investigated process and there is no mathematical model that can describe neither when temperature stages start and finish nor what extreme temperatures can be reached. The only possible opportunity is to conduct an experiment, measure temperature and define phases by experience.

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