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PROCEEDINGS

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RESEARCH AND DEVELOPMENT OF MECHANICAL ELEMENTS AND SYSTEMS

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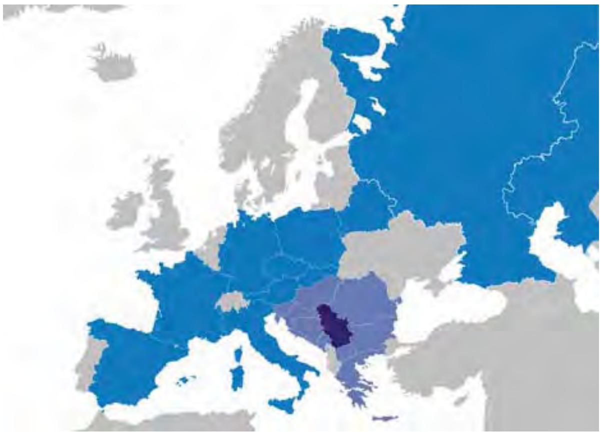
All the publications in this Proceedings have the authorship, whereas the authors of the papers carry entire responsibility for originality and content.

Preface

New technologies, globalization and individualization of customer demands, as well as high quality of modern products, are forcing industrial enterprises to improve their processes of product development. This implies the support of enterprise processes throughout the product lifecycle, from the product idea through product development, manufacturing, improvement and quality assurance to maintenance during operation. Processes of product development are more than just usual engineering. A product portfolio must be analyzed and product concept must be examined from the aspect of its realization. This requires linking internal domain with external teams. New products must be introduced to market with high quality and low development costs. The prerequisite for development of high quality products and high productivity manufacturing is to master the knowledge, which is a result of research in science and technology.

The aim the 7th International Scientific Conference "Research and Development of Mechanical Elements and Systems" 2011 in Zlatibor is:

- to gather experts and researchers in the field of scientific research and industrial product development;
- to present new design solutions related to energy efficiency, application of available resources, product price reduction, …
- to exchange knowledge and experience, through presentations of research results and expert information, with the aim of stimulating industrial activities in the region.



Participant countries

The best 114 abstracts were selected among 154 submitted by authors from Europe und Asia. The lectures came from Austria, Bosnia and Herzegovina, Belorus, Bulgaria, France, Germany, Greece, Croatia, Czech Republic, Hungary, Italy, Kazakhstan, Macedonia, Montenegro, Poland, Romania, Russia, Serbia, Slovakia, Slovenia and Spain. The presentations emphasize future trends in area research and development of mechanical elements and systems and cover the following topics:

- Industrial Product Development
- Computer Added Product Development - CAPD
- Mechatronics and Automatic Control
- Safety, Quality and Reliability
- Materials, Technology and Tribology
- Vibration and Noise, Testing and Monitoring
- Mechanical Systems and Components

The conference offers the possibility for participants to discuss the presented results in detail and share their experience.

Conference President
Prof.Dr.-Ing. Vojislav Miltenović, Full Professor, Machines Development and Construction Centre (CERP), University of Niš, Faculty of Mechanical Engineering, Niš, Serbia

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THE 7TH INTERNATIONAL CONFERENCE RESEARCH AND DEVELOPMENT OF MECHANICAL ELEMENTS AND SYSTEMS

INFLUENCE OF THE TECHNOLOGICAL HOLE IN WELDING PLATES ON WELD CREATION AND HEAT GENERATION DURING FRICTION STIR WELDING

Miroslav MIJAJLOVIĆ
Dragan MILČIĆ
Aleksandar IVKOVIĆ
oban ANĐELKOVIĆ

Abstract: *Friction Stir Welding consists of several physical phases where plunging phase of the welding tool is the first one. During plunging phase, welding tool and welding plates initiate contact between their surfaces what results in change of numerous parameters of materials and contact conditions: welding speed, angular speed, yield strength of material, contact pressure, temperature, dilatation etc. One of interesting and very important parameters is plunging force. Plunging force reaches great values at the beginning of the welding process and this can result with unwanted deformations of welding plates and applied tools. Possible solution for decrease of the plunging force might be application of the technological hole in the welding plates. This paper gives detailed geometrical analysis of the plunging phase, influence of the plunging force on the weld creation with implementation of the technological hole into mathematical model for generated heat estimation.*

Key words*: Friction Stir Welding, Technological hole, eat generation*

1. INTRODUCTION

Friction Stir Welding (FSW) is a solid state welding process predominantly used for welding of plate – shaped parts made of soft metals and alloys – aluminium, copper, bronze, brass etc. Its name or label – Friction Stir Welding, comes from the main physical phenomena that appear during welding process: friction and deformation (stirring). Specialized welding tool (Figure 1), made of material of greater strength and wearing capabilities than material of welding plates, is mounted into the rotating head on a welding machine (usually it is milling machine) and inserted into the "stat point" on joint line, on welding plates. Welding plates are rigidly clamped and fixed on work table of a machine over a backing plate between welding plates and work table. Joint line between welding plates is a path where weld should be created and for FSW it is mostly straight line, along side of the welding plate.

Welding process starts when rotating welding tool firstly touches top surface of welding plates after smooth translation downwards or, in other solution, while work table and welding plates smoothly translate upwards (Figure 2). Intimate contact between welding tool and plates results with appearance of friction, wearing, thermal, electrical, mechanical and other physical processes.

Pushed by the plunging force and constantly rotating around its rotation axle, welding tool plunges into the material of welding plates, deforms material of welding plates around the contact area and most of the mechanical energy given to the welding tool transforms into heat. Heat dissipates into the material of welding tool, welding plates, backing plate and surrounding but most of it delivered to the material of welding plates. This results in increase of heat of welding plates, what changes mechanical properties of welding plates – e.g. yield strength.

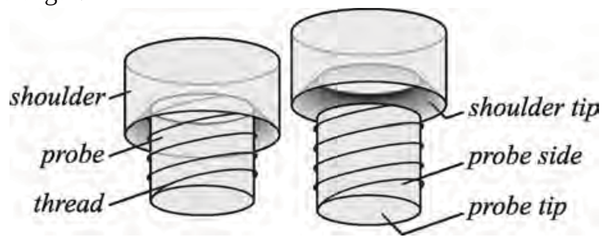


Fig. 1: Scheme of the welding tool

When welding tool reaches maximum of plunging depth, welding tool stops translational movement and rotates in place – dwells. After some time period it starts transversal movement along the joint line. Preheated material of welding plates is being pushed and confined by the welding tool and particles of welding plates travel around the welding tool they slide, stick, deform and mix with other particles. As a result of this behavior mixed material of both plates is left behind welding tool and creates weld. Welding last until tool reaches the "end point" on joint line and after that transversal velocity drops to zero, welding tool dwells and eventually pulls out from welding plates leaving "tool footprint" in plates (as a hole).

From the early beginning of FSW application (in 1991 and 1992 [1]), researches on FSW are done on "try – fail

– change – try again – change until succeed” principle. Changes after failures were made on technological parameters of the welding process, geometry, shapes, welding and surrounding conditions, machines etc. Basically, quality of weld depends from numerous parameters, however, quality of the weld, created by the FSW, directly depends from deformation of welding plates’ material deformation depends from technological parameters, temperature of welding plates and friction on contact welding tool – welding plates [2].

Finally, it can be concluded that quality of the FSW weld, beside weldability of welding plates, depends on welding tool and its ability to transform mechanical power, provided by the welding machine, into “FSW consumables” – heat and deformation(ability), for specific technological parameters of welding process and loads given to the welding tool.

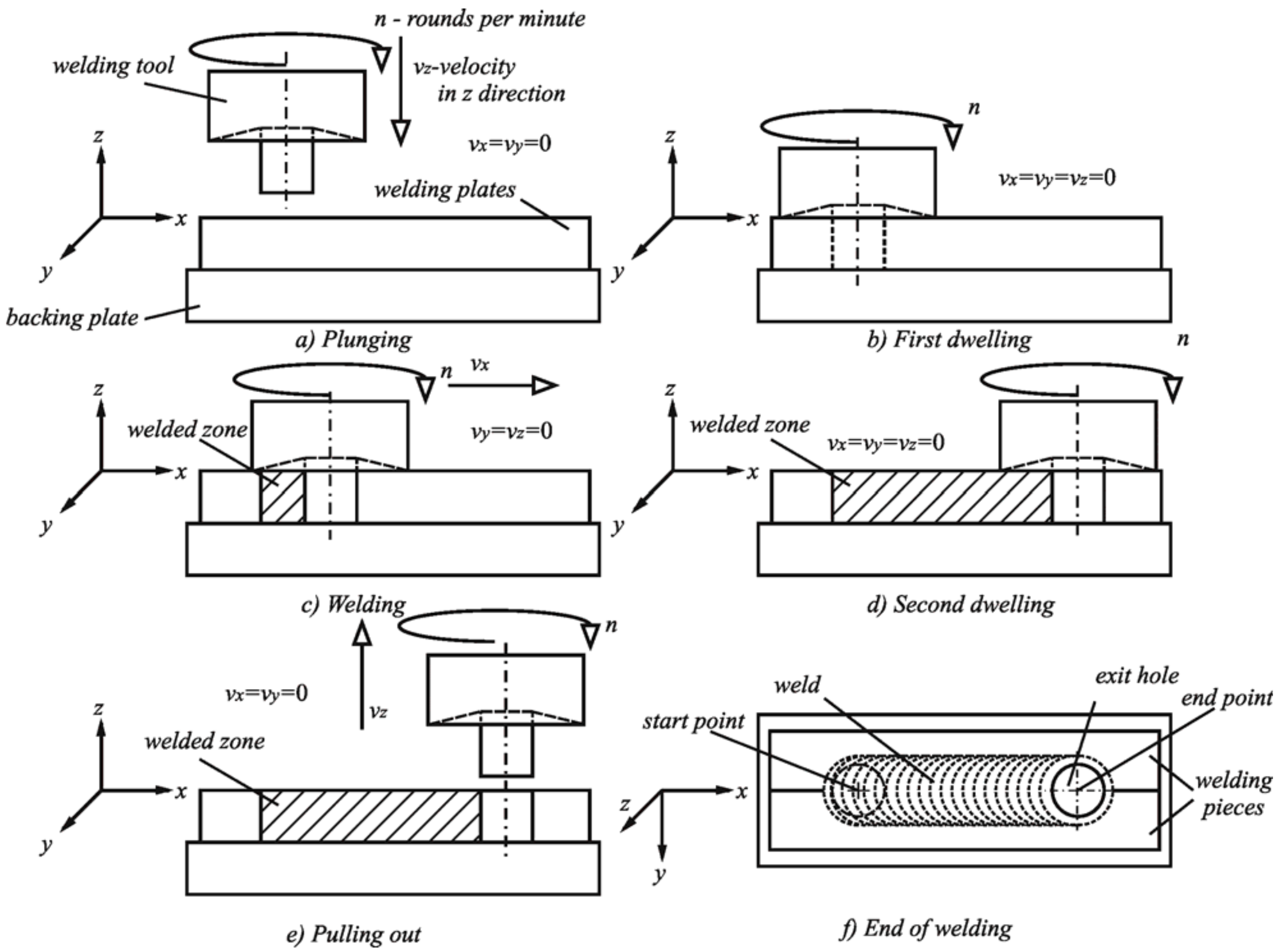


Fig.2: Phases of the FSW 2

1.1. Previo s researches abo t FSW

Previous researches on FSW are numerous, but it is possible to classify them in four different groups:

- researches about welding tool,
- researches about welding parameters,
- researches about micro and macro changes in welding plates,
- researches about physical processes that appear as a product of friction stir welding.

All researches aim to the same targets: to find optimal solution(s) for friction stir welding issues for different materials or to find patterns for controlling the welding process and ability to repeat achieved results (understanding the physics of the process).

One of the issues is loading delivered to the welding tool during welding. Welding tool receives complex and intensive dynamic loadings throughout complete welding cycle. At the beginning of the process –plunging phase, plunging force ($F_z(t)$) has significant values what results in possible overloading of the machine used for welding or destruction of the welding tool’s pin.

This issue can be overcome using the technological hole in welding plates. This aspect of decrease of plunging force (overloading) and influence of this technological change in FSW design haven’t been investigated so far (or investigated, but authors not familiar with that investigation).

2. GEOMETRICAL ANALYSIS OF CONTACT ETWEEN WELDING TOOL WELDING PLATES WITH TECHNOLOGICAL HOLE

To understand the FSW process with applied technological hole, it is important to provide in depth geometrical analysis of intimate contact between welding tool and welding plates. It is important to recognize that technological hole will eventually get filled with the pressed material some active surfaces of welding tool will delay with activation in the welding process etc. Applied on FSW technological hole must have at least two tasks:

1) to improve quality of the weld, or in the worst case – not to reduce it and
2) reduce intensity of the plunging force $F_z(t)$.

Technological hole affects only plunging and first dwelling phases of the FSW if diameter of welding plates is not larger than diameter of the probe (d_0 d). Otherwise, it might critically affect on quality of the weld – all phases of the FSW are affected.

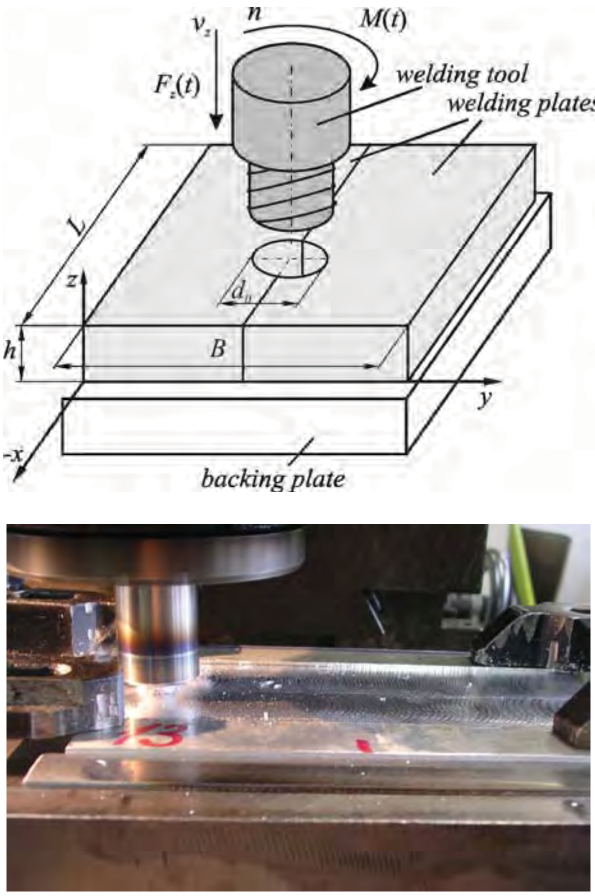


Fig. 3: Welding tool and welding plates with previously prepared technological hole of diameter d_0 before plunging phase – a) scheme, b) experiment 3

While the probe plunges into the weld plates it pushes some of the stirred material upwards and presses some material downwards into the technological hole (Figure 4).

The sum of the volumes V_1 and V_2 is total volume of material dV moved during plunging of the probe and it is equal (Figure 4):

$$\Delta V = \frac{d^2 - {d_0}^2}{4} \cdot \pi \cdot z = V_1 + V_2. \tag{1}$$

When probe reaches critical plunging depth z_k technological hole will be completely filled with material pressed downwards (volume V_2, Figure 5).

Critical volume pressed downwards can be estimated as:

$$V_2 = \frac{{d_0}^2}{4} \cdot \pi \cdot \left(h - z_k\right), \tag{2}$$

and critical plunge depth z_k when technological hole becomes filled with pressed material is:

$$z_k = \frac{4 \cdot V_1}{d^2 \cdot \pi} + \left(\frac{d_0}{d}\right)^2 \cdot h. \tag{3}$$

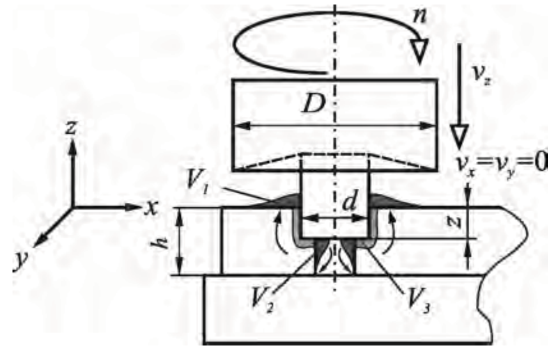


Figure 4 Material flow during plunging of the welding tool V_1 – volume of material pressed upwards, V_2 – volume of the material pressed downwards into the technological hole, V_3 – volume of the material affected with action of the welding tool, z – plunge depth

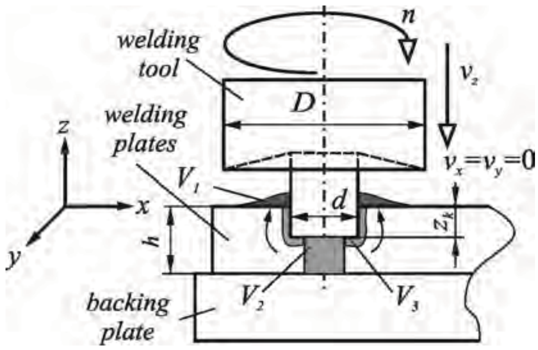


Fig. 5: The moment when technological hole gets completely filled with pressed material of welding plates

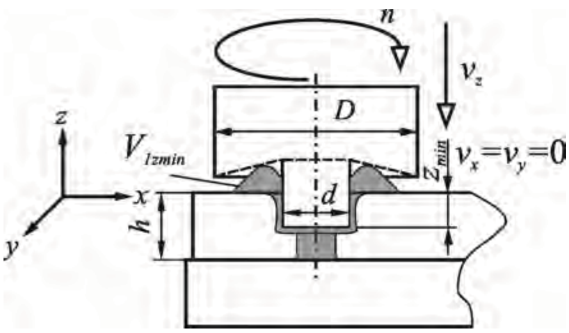


Fig. 6: The moment when shoulder tip initiates contact with the material of welding plates

Beside movement downwards, softened material of welding plates is pushed upwards as well, under the pressure of the welding tool's probe. This will initiate contact between shoulder tip and pressed material before the tool reaches maximal plunging depth of h. This will happen when plunging depth reaches the value of z_{min} (Figure 6). The volume of material pushed upwards V_1 and distributions of this material over welding plates both

have stochastic nature and they directly affect value of z_{min}.
At some moment of time free volume V_{free} under the shoulder tip will be completely filled with the upward pressed material, volume V_{1max} (Figures 7 and 8) if $V_{1\max} > V_{free}$. If $V_{1\max} \leq V_{free}$ shoulder tip will, simply, lay on top surface of welding plates and cone volume below shoulder tip will remain partially filled with material.
In both cases it will happen when the plunging depth of the probe is z_{max} (Figure 7) and for second case: z_{max} h.

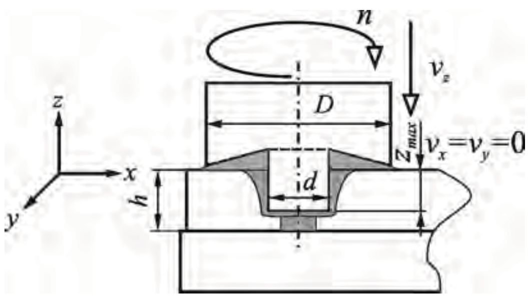


Fig. 7: The moment when shoulder tip fully presses material of welding plates

Volume of upward pressed material V_{1max} during plunging phase can be estimated as:

$$V_{1\max} = \frac{\left(d^2 - d_0{}^2\right)\cdot\pi}{4}\cdot z_{\max} \tag{4}$$

Free volume V_{free} is consisted of free volume of cone shoulder tip V_{cone}, free volume of cylinder between tool and welding plates V_{cyl} and free volume of the technological hole that is not filled with pressed material $V_{z_{\max}}$ (Figure 7):

$$V_{free} = V_{cone} + V_{cyl} + V_{z\max}. \tag{5}$$

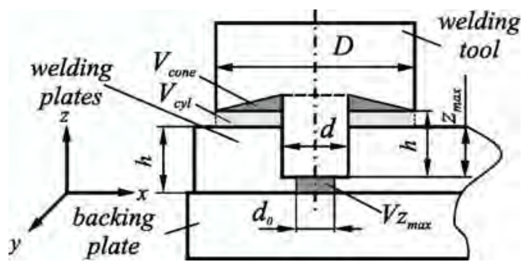


Fig. 8: Volume summarization

Free volume of the cone shoulder tip is:

$$V_{cone} = \frac{\pi}{24}\cdot \mathrm{tg}\alpha\cdot\left(D^3 - 3\cdot d^2\cdot D + 2\cdot d^3\right), \tag{6}$$

free volume of cylinder between tool and welding plates is:

$$V_{cyl} = \frac{\pi}{4}\cdot\left(D^2 - d^2\right)\cdot\left(h - z_{\max}\right), \tag{7}$$

and free volume of the technological hole that is not filled with pressed material is:

$$V_{z_{\max}} = \frac{d_0{}^2\cdot\pi}{4}\cdot\left(h - z_{\max}\right). \tag{8}$$

Based on Equations 2 to 8 and inequality $V_{1\max} > V_{free}$, plunging depth z_{max} is:

$$z_{\max} \geq \frac{\frac{1}{6}\cdot\mathrm{tg}\alpha\cdot\left(D^3 - 3\cdot d^2\cdot D + 2\cdot d^3\right) + \left(D^2 - d^2 + d_0{}^2\right)\cdot h}{D^2}. \tag{9}$$

With sufficient precision it can be assumed that initial contact between shoulder tip and welding plates appears when:

$$z_{\min} \approx \frac{2}{3}\cdot z_{\max}. \tag{10}$$

3. CONTACT PRESSURE

Median value of the contact pressure $p_m(t)$ on contact between welding tool and welding plates without technological hole (d_0 0) during plunging phase can be estimated as:

$$p_m(t) = \frac{4\cdot F_z(t)}{d^2\cdot\pi},\ 0 \leq t < t_{pl}. \tag{11}$$

where t_{pl} is moment of time when plunging phase ends.
If there is technological hole ($d_0 \neq 0$, d_0 d) in welding plates, median contact pressure is:

$$p_m(t) \approx \begin{cases} \dfrac{4\cdot F_z(t)}{\left(d^2 - d_0{}^2\right)\cdot\pi},\ 0 \leq t < t_{zk} \\ \dfrac{4\cdot F_z(t)}{d^2\cdot\pi},\ t_{zk} \leq t < t_{pl} \end{cases}. \tag{12}$$

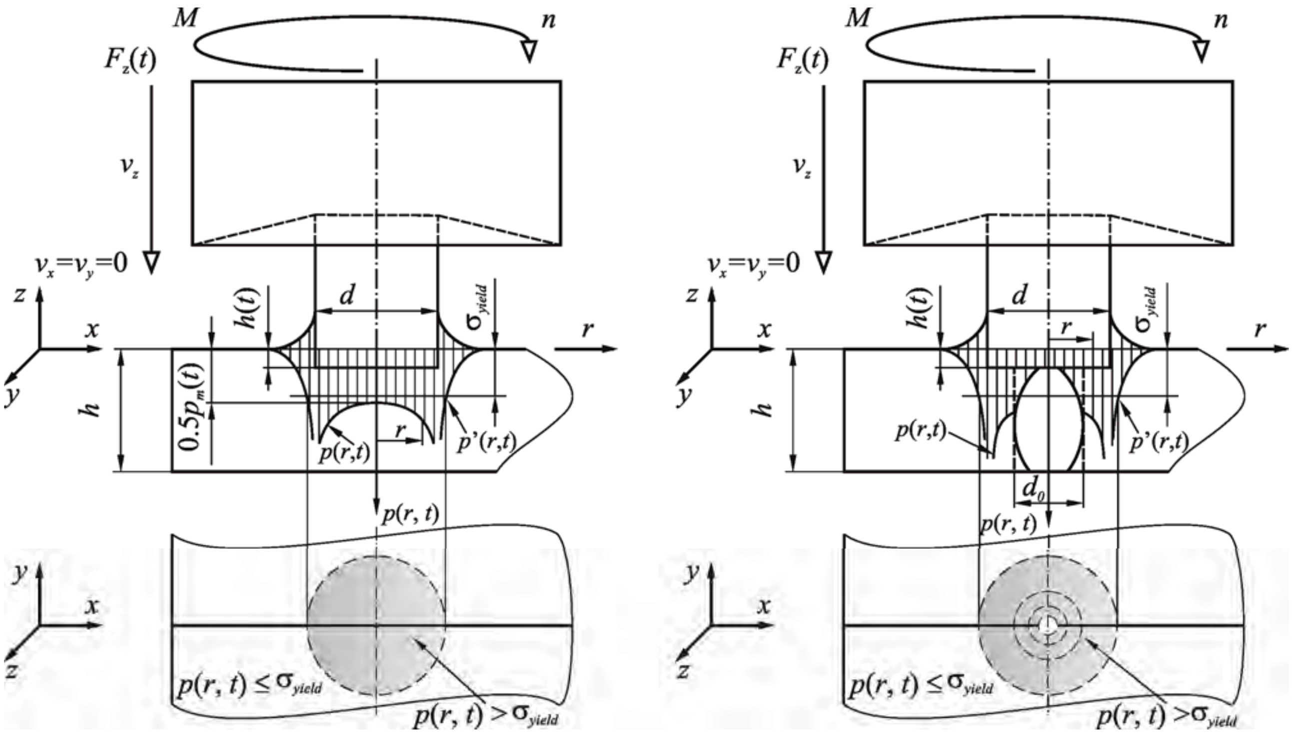
where t_{zk} is a moment of time when plunging depth is equal to z_k (technological hole is completely filled with material of welding plates).
Plunging of welding tool into the matrix of welding plates is possible only when median contact pressure $p_m(t)$ exceeds critical value of yield strength $k\cdot\sigma_{yield}(T, \varepsilon)$ [4, 5]:

$$p_m(t) > k\cdot\sigma_{yield}(T,\varepsilon),\ \ k = 1.5 \div 3 \tag{13}$$

where $\sigma_{yield}(T, \varepsilon)$ is yield strength of material of welding plates, dependable from temperature T and strain rate of material ε. Temperature of welding plates T is in direct dependency of generated heat (t) while strain rate ε depends from technological parameters of the welding process and geometry of welding tool.
Figure 9 shows schematic interpretation of the median contact stress in both cases (without and with technological hole in welding plates) and its distribution along contact surface.

4. HEAT GENERATION DURING PLUNGING PHASE

Problem of analytical estimation of heat generation during FSW is complex and very difficult to explain, however, recognition that maximal (plunging) force appears during plunging phase slightly eases the explanation of problem.



a) no technological hole *b) with technological hole*

Fig. 9: Median contact pressure distribution during plunging phase

During plunging phase, almost 100 of heat is generated on contact between probe tip and welding plates [2]. Total generated heat during plunging (t) can be estimated as [2, 6]:

$$(t) \approx \frac{2}{3} \cdot \pi \cdot \omega \cdot \mu(t) \cdot p_m(t) \cdot \left(\left(\frac{d}{2} \right)^3 - \left(\frac{d_0}{2} \right)^3 \right) \tag{14}$$

where μ (t) is friction coefficient on contact between probe tip and welding plates and ω angular speed of welding tool.

Several authors [6-9] suggest that dominant active surface in heat generation is shoulder with more than 80 in total heat amount. Shoulder tip has small influence on generation during plunging phase, and in the case of welding plates with technological hole this influence is extremely smaller. Moreover, newer researches on heat generation [2] on influence of shoulder tip prove that shoulder tip does not involve in heat generation so drastically and for this analysis shoulder tip is of no interest.

5. DISCUSSION AND CONCLUSIONS

Friction Stir Welding process bases on softening of welding plates' material and mechanical mixing of them into the weld. Analyzing Equation 12, it is easy to conclude that the larger technological hole is, median contact pressure is rising, with an assumption that plunging force is changing. Comparing this analysis with Equation 13 it is clear that inequality will be true faster than in the case when technological hole does not exist – plunging of the welding tool will be much easier and applied plunging force can be much less intensive. How ever, analyzing Equation 14, it is clear that generated heat changes as well.

If technological hole is of diameter d_0 $a \cdot d$, $0 \leq a \leq 1$, and plunging force, friction coefficient and other parameters preserves its values, ratio of median contact pressure ψ_p (without technological hole and with technological hole) is:

$$\psi_p = \frac{p_m(t)_{d_0=0}}{p_m(t)_{d_0=a \cdot d}} \approx \begin{cases} 1-a^2, & 0 \leq t < t_{zk} \\ 1, & t_{zk} \leq t < t_{pl} \end{cases}, \tag{15}$$

and ratio of generated heat ψ is:

$$\psi = \frac{(t)_{d_0=0}}{(t)_{d_0=a \cdot d}} \approx \begin{cases} \frac{1-a^2}{1-a^3}, & 0 \leq t < t_{zk} \\ 1, & t_{zk} \leq t < t_{pl} \end{cases}. \tag{16}$$

Considering Equations 15 and 16 for various values for a, $0 \leq a \leq 1$, it can be concluded that contact pressure and generated heat rise with the increase of the technological hole if the value of plunging force keeps steady in both cases. On the other hand, provided ratios ψ_p and ψ give a glance that plunging force might be less up to the 33 (for example, a 0,99 $\rightarrow$ $\psi_p \approx 0.02$, $\psi \approx 0.67$) when technological hole is applied on welding plates.

However, this analysis is very rough and these results are only descriptive. If some analyze aspect of weldability and quality of the weld, it is clear that application of technological hole has some limitations:

1) Heat generative layer (Figure 10) of material is not of very large width (30 μm – 50 μm) but this still

decreases the value of technological hole to the value less than the diameter of the probe d_0 d.

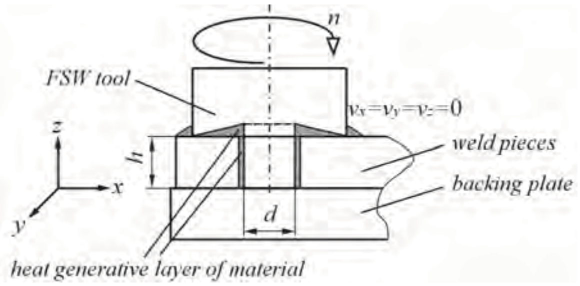


Fig. 10: eat generative layer of material

2) Since almost all welding tools have threads, gauges, facets etc. at the probe side, potential value of technological hole (d_0) decreases even more: in order to provide active contact between tool and material, d_0 must be smaller than core of the thread on the probe side d_3:

$$d_0 < d_3 = d - 2 \cdot t_d \tag{17}$$

where t_d is the maximal value of the thread depth.

3) Material flow around the probe has not been considered to be affected with the application of the technological hole in welding plates. Since material flow hasn't been mathematically explained, further work must aim to the investigation of material flow and application of "try and fail" principle during research of application of technological hole and its tribute to the ease of welding process, quality improvement (or quality preservation) and heat generation.

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REFERENCES

[1] THOMAS W. M. et al 1991 Friction stir butt welding International Patent Application No PCT/GB92/02203 THOMAS W. M. et al 1995 Friction stir butt welding GB Patent Application No 9125978.8 THOMAS W. M. et al 1995 Friction stir butt welding UP Patent No 5 460 317.

[2] ĐURĐANOVIĆ M, MIJAJLOVIĆ M, MILČIĆ D, STAMENKOVIĆ D: *eat eneration During Friction Stir Welding Process*, Tribology in Industry, no. 1-2, 2009, Serbia, Kragujevac, Faculty of Mechanical Engineering Kragujevac, May, 2009, Journal, vol. 31, pp. 8-14, no. 1-2, ISSN 0354-8996.

[3] ŽIVKOVIĆ, A (2011) *Influence of friction stir welding tool geometry on properties of welded joint of alloys Al 2024*, PhD thesis, University of Belgrade, Faculty of Mechanical Engineering.

[4] BOWDEN, F.P., TABOR, D. Friction – *An Introduction to Tribology*, Anchor Press / Doubleday, Reprinted 1982, Krieger Publishing Co., Malabar 1973.

[5] TABOR, D.: *A Simple Theory of Static and Dynamic ardness*, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 192, No. 1029 (Feb. 4, 1948), pp. 247-274, (article consists of 28 pages), Published by: The Royal Society, Stable URL: http://www.jstor.org/stable/98140

[6] SCHMIDT H, HATTEL J, WERT J: *An analytical model for the heat generation in Friction Stir Welding*, Modeling Simul. Mater. Sci. Eng. 12 No 1 (January 2004) p. 143-157, PII: S0965-0393(04)69225-4, http://iopscience.iop.org/0965-0393/12/1/013/.

[7] SHERCLIFF, H. R, COLGROVE, P. A, 2002 Math. Modelling Weld. Phenom. 6 927–74

[8] XU S, DENG X, REYNOLDS A P, 2001 Sci. Technol. Weld. Joining 6 191–93.

[9] KHANDKAR M Z H, KHAN J A, REYNOLDS A P 2003 Sci. Technol. Weld. Joining 8 165–74.

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