Serbian Tribology Society

Faculty of Mechanical Engineering
University of Kragujevac

SERBIATRIB '11

12th International Conference on Tribology

11 – 13 May 2011, Kragujevac, Serbia

PROCEEDINGS

SERBIATRIB '11

Serbian Tribology Society

Faculty of Mechanical Engineering
University of Kragujevac

SERBIATRIB '11

12th International Conference on Tribology

11 – 13 May 2011, Kragujevac, Serbia

PROCEEDINGS

EDITORS: Branko Ivković, Miroslav Babić, Slobodan Mitrović

SERBIATRIB '11

12th International Conference on Tribology – SERBIATRIB ‘11
PROCEEDINGS

ISBN: 978-86-86663-74-0

Editors: **Branko Ivković**, Ph.D.
Serbian Tribology Society
Miroslav Babić, Ph.D.
Faculty of Mechanical Engineering, University of Kragujevac
Slobodan Mitrović, Ph.D.
Faculty of Mechanical Engineering, University of Kragujevac

Publisher: **Serbian Tribology Society**
Sestre Janjić 6, 34000 Kragujevac, Serbia
Faculty of Mechanical Engineering, University of Kragujevac
Sestre Janjić 6, 34000 Kragujevac, Serbia

For the Publisher: **Branko Ivković**, Ph.D., Serbian Tribology Society
Miroslav Babić, Ph.D., Faculty of Mechanical Engineering

Technical editor: **Slobodan Mitrović**, Ph.D.
Faculty of Mechanical Engineering, University of Kragujevac

Printed by: **SKVER**,
34000 Kragujevac, Serbia

Circulation: 100 copies

The publication of these Proceedings was financially supported by the Ministry of Science and Technological Development of the Republic of Serbia.

Supported by

Ministry of Science and Technological Development of the Republic of Serbia

CETR, Center for Tribology Inc, USA

CSM Instruments, Switzerland

International Scientific Committee

Nikolai Myshkin	V.A. Belyi Metal-Polymer Research Institute of National Academy of Sciences of Belarus (Belarus)
Konstantinos-Dionysios Bouzakis	Aristotle University of Thessaloniki (Greece)
Friedrich Franek	Vienna University of Technology (Austria)
Nyagol Manolov	Technical University of Sofia (Bulgaria)
Emilia Assenova	Technical University of Sofia (Bulgaria)
Mara Kandeva	Technical University of Sofia (Bulgaria)
Andrei Tudor	University Politehnica of Bucharest (Romania)
Niculae Napoleon Antonescu	Petroleum-Gas University of Ploiesti (Romania)
Mehmet Baki Karamiş	Erciyes University (Turkey)
Hakan Kaleli	Yildiz Technical University (Turkey)
Branko Ivković	Serbian Tribology Society (Serbia)
Aleksandar Rac	Serbian Tribology Society (Serbia)
Miroslav Babić	University of Kragujevac (Serbia)
Slobodan Mitrović	University of Kragujevac (Serbia)
Slobodan Tanasijević	University of Kragujevac (Serbia)
Aleksandar Vencl	University of Belgrade (Serbia)
Aleksandar Marinković	University of Belgrade (Serbia)
Dušan Stamenković	University of Niš (Serbia)
Miodrag Manić	University of Nis (Serbia)
Damir Kakaš	University of Novi Sad (Serbia)
Bogdan Sovilj	University of Novi Sad (Serbia)

Organising Committee

Presidents:

Miroslav Babić	University of Kragujevac (Serbia)
Branko Ivković	Serbian Tribology Society (Serbia)

Members:

Slobodan Mitrović	University of Kragujevac (Serbia)
Blaža Stojanović	University of Kragujevac (Serbia)
Aleksandar Vencl	University of Belgrade (Serbia)
Fatima Zivić	University of Kragujevac (Serbia)
Dragan Dzunić	University of Kragujevac (Serbia)
Marko Pantic	University of Kragujevac (Serbia)

Preface

The International Conference on Tribology – SERBIATRIB, is traditionally organized by the Serbian Tribology Society every two years, since 1989. The previous conferences were held in Kragujevac (1989, 1991, 1993, 1999, 2005 and 2007), Herceg Novi (1995), Kopaonik (1997) and Belgrade (2001, 2003 and 2009). This year the 12th International Conference on Tribology – SERBIATRIB '11 takes place on 11-13 May 2011 in Kragujevac.

This Conference is organized by the Serbian Tribology Society (STS) and the University of Kragujevac, Faculty of Mechanical Engineering. Organizing Scientific Conferences, STS plays a significant role in helping engineers and researchers to introduce in the fundamentals of tribology and to present their experience, solutions and research results.

The scope of the 12th International Conference on Tribology – SERBIATRIB '11 embraces the state of art and future trends in tribology research and application. The following two aspects of tribology practice require special attention. Firstly, the requirement for higher productivity of machinery means that machines must operate under higher loads and at higher speeds and temperatures, and that is why finding the right solutions for tribological processes is extremely important. Secondly, the good tribology knowledge can greatly contribute to the saving of material and energy.

The Conference program generally includes the following topics: fundamentals of friction and wear; tribological properties of solid materials; surface engineering and coating tribology; lubricants and lubrication; tribotesting and tribosystem monitoring; tribology in machine elements; tribology in manufacturing processes; tribology in transportation engineering; design and calculation of tribocontacts; sealing tribology; biotribology; nano and microtribology and other topics related to tribology.

All together 73 papers of authors from 18 countries (USA, Taiwan, Russia, Belarus, Ukraine, UK, Germany, Switzerland, India, Slovenia, Croatia, Bosnia & Herzegovina, Montenegro, Romania, Bulgaria, Greece, Turkey and Serbia) are published in the Proceedings. Approximately 32 papers were submitted by the foreign authors and app. 41 papers by the Serbian authors. All papers are classified into five chapters:

- Plenary lectures (4)
- Tribological properties of materials and coatings (29)
- Tribology in machine elements (14)
- Tribometry (20)
- Trenje, habanje i podmazivanje (5) – papers written in Serbian language

It was a great pleasure for us to organize this Conference and we hope that the Conference, bringing together specialists, research scientists and industrial technologists, and Proceedings will stimulate new ideas and concepts, promoting further advances in the field of tribology. The

Editors would like to thank the Scientific and the Organizing Committee and all those who have helped in making the Conference better. We would like to thank especially prof. Miroslav Babić and prof. Branko Ivković for the helpful suggestions and support.

The Conference is financially supported by the Ministry of Science and Technological Development of the Republic of Serbia, Center for Tribology Inc (CETR), CSM Instruments and Technology Transfer Center Hanover.

We wish to all participants a pleasant stay in Kragujevac and we are looking forward to seeing you all together at the 13th International Conference on Tribology – SERBIATRIB '13.

Kragujevac, May 2011 Editors

Contents

Plenary Lectures

Tribological Properties of Materials and Coating

Tribology of Machine Elements

Tribometry

Trenje, habanje i podmazivanje

3. CONCLUSION

Refering to the above mentioned we conclude:

- combine graphics which connect all three roughness parameters if one of them is known that other two can be directly easy determined.
- graphics in exponential and linear form can be equaly used, but linear is more appropriate.

REFERENCES

[1] Dyachenko, P.E., and all., About elaboration International standard of machined surface roughness Surface Quality machine elements, Papers of Seminar of the surface quality Proceedings A, Edition AN SSSR Moscow, 1959. (in Russian)

[2] Sekulic, S., Kovac, P., Correlation between the maximal roughness height and aritmetic deviation of the profile from the mean line of machined surface in finish turning, Tribology in Industry, vol. VIII, No.1, 1986. (in Serbian)

[3] Sekulic, S., Kovac, P., Correlation between bearing ratio and mean aritmetic deviation of profile from mean line of machined surface. Proceedings International Conference on Advanced Manufacturing and Technology – AMST 187, October, 1987., Opatia (in Serbian)

[4] Sekulic, S. Correlation between the maximal roughness height and aritmetic deviation of the profile from the mean line of machined surface in finish turning, Abstracts of the papers of the World Tribology Congress, London, September, 1997., p.791.

[5] Sekulic, S., Correlation between some roughness parameters of the machined surface in finish turning, Proceedings of the conference: Situation and Perspective of Research and Development in Chemical and Mechanical Industry, Book 1: Mechanical Engineering, 22-24, 10, 2001, Krusevac, pp. 364-369.

[6] Sekulic, S., Correlation between roughness parameters of the machined surface in finish turning in Proceedings VIII International Symposium INTERTRIBO 2002, 14-17, 10, 2002, Stara Lesna – Tatarska Lomnica, 2002, pp. 85-88.

SERBIATRIB '11

Serbian Tribology Society

12^{th} International Conference on Tribology

Faculty of Mechanical Engineering in Kragujevac

Kragujevac, Serbia, 11 – 13 May 2011

ABOUT THE INFLUENCE OF FRICTION COEFFICIENT ON HEAT GENERATION DURING FRICTION STIR WELDING

Miroslav Mijajlović[1], Dušan Stamenković[1], Miroslav Đurđanović[1], Dragan Milčić[1]
[1] Faculty of Mechanical Engineering Niš, Serbia
mijajlom@masfak.ni.ac.rs; dusans@masfak.ni.ac.rs; djurdjan@junis.ni.ac.rs; milcic@masfak.ni.ac.rs

Abstract: *Friction Stir Welding uses mechanical energy and heat as welding process's activation energy. Mechanical energy is given to the welding tool by welding machine and great portion of that energy is consumed in heat generation on or near the contact between welding tool and base metal. Many studies on FSW processes imply duality of generated heat appearance: it is a direct product of sliding and sticking processes that happen during FSW. Moreover, it is shown that frictional processes dominate in all processes included in heat generation. Almost 20 years after first application of FSW, friction remains unclear and hard to explain tribological phenomenon. Serious studies on FSW point out the necessity of friction demystification as a need for heat generation explanation. Paper gives brief state of the art analysis on influence of friction to the FSW, especially on heat generation process. Numerous studies propose contact and boundary conditions of processes that appear during FSW but very few loudly propose explanations of frictional processes. Since heat and friction are depending and changing one from another, paper will give ideas and experimental researches that show the dependency of heat and friction and might help in further work on heat generation explanation.*

Keywords: *Friction Stir Welding, Friction Coefficient, Heat Generation*

1. INTRODUCTION

As a solid state welding procedure, Friction Stir Welding (FSW) [1] uses pure mechanical energy as welding process activation energy and distributes it from the welding machine to the base material (welding plates) over a specialized, profiled welding tool. However, only one part of the mechanical energy is used directly as a mechanical energy while the rest of it is transformed in other types of energy: into heat, light, electricity, radiation etc. Researches, experience and engineering practice have shown that, as a result of any kind of energy transformation, direct or indirect product of energy use is transformation of input energy into heat, partially or almost completely. This is a phenomenon that appears during the FSW process as well: mechanical energy given to the welding tool is dominantly transforming into the heat, some of it stays mechanical and the rest of it is transformed in other types of energy (Figure 1).

Transformation of power happens on the intimate contact between welding tool and welding plates or in a thin layer of the softer material (in this case it is the material of welding plates).

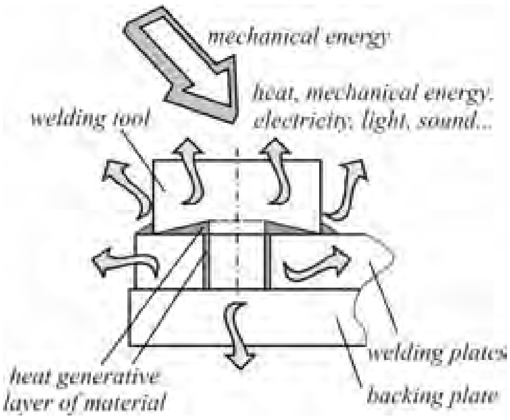


Figure 1. Power transformation during FSW

Recognizing the fact that almost all mechanical power given to the welding process (input power) transforms into the heat[1], also assuming:

---

[1] The common phrase that explains transformation of the mechanical power into heat is "heat generation".

- heat generated by rotation of the welding tool (Q_{rot}) is far greater than the heat generated by translation of the welding tool (Q_{tran}) and translation heat is equal to the $Q_{tran} \approx 0$ W,
- contact condition between welding tool and welding plates can be defined as pure adhesion, pure deformation and partial adhesion – deformation[2],

Colegrove [2] and Schmidt [3] have proposed equations for estimation of generated heat on a contact surface of the welding tool, influenced by rotation, $Q_{surf,\,rot}$:

$$Q_{surf\,,rot} = \omega \cdot S_{surf} \cdot \tau_{contact}, \tag{1}$$

where:

ω [rad/s] – angular speed of the welding tool,

S_{surf} [m^3] – voluminous constituent of the generated heat, dependable from the shape of the contact surface (probe tip, probe side, shoulder tip, basic active surfaces on the FSW welding tool [4]), For example, voluminous constituent of the generated heat for the probe tip – *pt* (Figure 4) surface of the welding tool [4] can be defined as:

$$S_{pt} = \frac{2}{3} \cdot \pi \cdot \left(\frac{d}{2}\right)^3, \tag{2}$$

d [m] – diameter of the probe on the welding tool [4], and

$\tau_{contact}$ [N/m^2] – shear stress on contact between welding tool's surface and welding plates.

Angular speed of the welding tool ω and voluminous constituent of the generated heat S_{surf} are pure technological and geometrical parameters of the FSW process and their influence on amount of the generated heat is not so complicated to explain: the greater values of ω and S_{surf} are, the greater value of the generated heat $Q_{surf,\ rot}$ is. However, there is indirect influence of these parameters on other parameters that involve heat generation. Tribological parameter of the generated heat, defined as shear stress on contact between welding tool and welding plate $\tau_{contact}$ is, in fact, describing the true nature of the generated heat by describing the contact condition.

2. CONTACT CONDITION

While rotating and moving along the joint line in the welding phase of FSW [4] welding tool induces contact pressure and contact shear stress in the layer of welding plates [2, 4]. Based on assumed dual nature of the contact condition (adhesion – deformation what is terminologically equal to sliding – sticking), contact shear stress can be estimated as:

$$\tau_{contact} = \begin{cases} \mu\left(t, p, T, \omega ...\right) \cdot p_m\left(t\right) & \text{- sliding} \\ \tau_{yield}\left(T, \varepsilon\right) = \dfrac{\sigma_{yield}\left(T, \varepsilon\right)}{\sqrt{3}} & \text{- sticking} \end{cases} \tag{3}$$

where:

μ (t, p, T, ω …) = μ – friction coefficient on the contact of the welding tool's surface and welding plates,

t [s] – time,

p [N/m^2] – contact pressure,

T [°C] – temperature,

p_m (t) [N/m^2] – time dependent median contact pressure,

τ_{yield} (T, ε) [N/m^2] – temperature and strain dependent yield shear strength of welding plates,

ε [-] – strain rate,

σ_{yield} (T, ε) [N/m^2] – temperature and strain dependent yield shear strength of welding plates.

This means that heat is generated while welding tool presses and slides over the material of welding plates and while deforms the particles of welding plates; these heat generation processes happen mutually, simultaneously, and dependable one from another.

3. INFLUENCE OF THE FRICTION COEFFICIENT ON HEAT GENERATION

Equation 3 shows that the friction coefficient on contact μ (t, p, T, ω …) influences the contact shear stress $\tau_{contact}$ when pure or partial sliding condition appears. Sliding is a dominant contact mechanism and it is always present in contact problems, when relative movement appears [2, 4]. Basically, friction coefficient is always influencing the contact condition between welding tool and welding plates.

However, relationship between contact condition – friction coefficient – heat generation is not purely one sided nor single parametrically influenced. For example, if some analyze only previously mentioned tribo – parameters (e.g. p, T, ω, $\tau_{contact}$) and neglect all other tribo – parameters (surface hardness, surface roughness, surface corrosion, lubrication, cleanness etc.) that might influence heat generation or friction coefficient, graph of mutual relationships between parameters will get a bit difficult to follow (Figure 2).

For example, following the graph given in Figure 2, and symbolic representation of influences and relationships between parameters[3], S_{surf} is

---

[2] Also can be found as pure sliding, pure sticking and partial sliding – sticking.

[3] Relationship between parameters ① and ② can be:

directly influencing μ but μ is not influencing S_{surf}; μ is directly influencing p and p is directly influencing μ; μ is directly influencing $\tau_{contact}$ and $\tau_{contact}$ is directly influencing Q_{surf}, *rot, so* μ is indirectly influencing Q_{surf}.

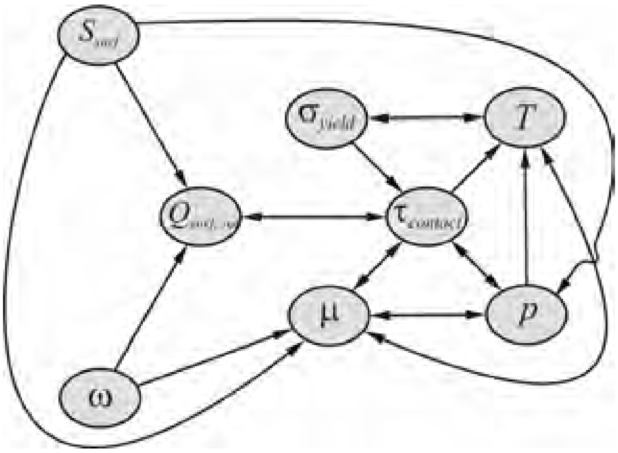


Figure 2. Graph of mutual relationships between some of the tribo – parameters

Analyzing the graph in Figure 2, one can say that friction coefficient μ is directly depending from the most of FSW parameters (technological, geometrical or/and tribological) and indirectly depending from all other (tribological) parameters. This conclusion returns the analysis to the beginning: friction coefficient is a tribological parameter whose value is relatively easy to measure but whose nature is difficult to explain.” [5].

When researchers from TWI [1] patented the Friction Stir Welding as a novel welding procedure they were fully aware of the importance of the “friction” processes / phenomena in application of their patent so they used it for name of the procedure. With such a great number of influencing parameters, with complex relationships between parameters and still present ambiguity of the FSW process itself, friction coefficient in FSW is not at all a value easy to measure and even more hard to explain. Without any doubt, TWI researchers had no idea what a challenge will they make to the FSW researches around the globe with the word “friction” in FSW.

Early researches on the FSW were based on the “try and error” principle and aimed to the optimal geometry of the welding tool retrieval, technological parameters (speed and rotation of the machine) selection and proper materials usage (as well for the welding tool, as well for the welding plates). When usable results were found, researches have extended to the increase of weld’s quality, stress and strain analysis, and material flow, thermal influences on welding plates and welding tools, heat generation during FSW etc. At the beginning, friction coefficient was not of interest in researches. However, when researches aimed into FSW modelling (heat, temperature fields, stress and strain, material flow, residual stresses etc.), friction coefficient became interesting and necessary to be estimated. As one of the pioners in this area, Schmidt et al [3, 6, 7] has researched analytical thermomechanical model in FSW with a goal to understand material disposal during rotation of the welding tool in a qualitative manner. Friction coefficient was a necessity for the analysis made in ABAQUS / Explicit software used in this work, and authors have used the value of 0.3 for the complete process. In the following works, friction coefficient was mentioned as an important parameter that takes values from 0.3 to 0.4 for the welding phase of the FSW [6]. Results were not confirmed analytically or experimentally – they were predicted due to the experimental setup of conducted experiments [3].

Chen et al. [7] used a theoretical approach on friction coefficient estimation and calculated that the coefficient of friction cannot be greater than 0.577 in FSW. Duffin et al. [9] experimentally determined the friction coefficient exceeds 0.57 during friction welding processes (not FSW), and reported the coefficient of friction to be 1.5, 1.9, 2.1 and 2.7 for the welding of mild steel. Similar results were reported by Reid [10] for the welding of pure copper. Heurtier et al. [11] has modelled material flow around the welding tool and showed thermal history of the flown material with application of the friction coefficient of 0.2 to 0.9. Values of the friction coefficient were assumed.

Numerous authors [6 – 25] have experimentally and analytically worked on problems of heat generation during FSW, thermal modelling, stress distribution, deformation and material flow and they have suggested that friction coefficient in FSW varies from 0.1 to 1.6 dependably on contact pressure, temperature, materials etc. However, none of them has experimentally measured friction coefficient or analytically estimated the value of friction coefficient. Furthermore, no one has suggested that friction coefficient changes its value. All of the mentioned results were assumptions due to the results from similar researches, guesses or analogies with the machining processes – milling, drilling etc.

Summarization of the friction coefficient: it varies from 0.1 to 2.7 in friction welding processes (FSW and other frictional welding processes, for welding of aluminium, steel, copper etc.).

There are only few works that have reported experimental estimation of the friction coefficient.

“①→②” what means: ① is influencing ②, no vice versa effect; “①↔ ②” what means: ① is influencing ② and vice versa, “① ②” what means: no relationship between ① and ②.

Main reasons for such a lack of researches on friction coefficient lays in complexity of the process, difficult measuring task and ambiguity of the process itself.

However, Kumar et al. [26] reported experimentally estimated values of the friction coefficient during plunging and the first dwelling phases of the FSW welding process. Experiment is based on the well known equation for the friction coefficient:

$$\mu = F_t(t) / F_n(t). \tag{4}$$

To determine friction coefficient μ, it is necessary to measure tangential force F_t (t) and normal force F_n $(t) = F_z$ (t) that appear during experiment.

Experimental setup that measures normal and tangential forces applied on the welding tool is given in Figure 3.

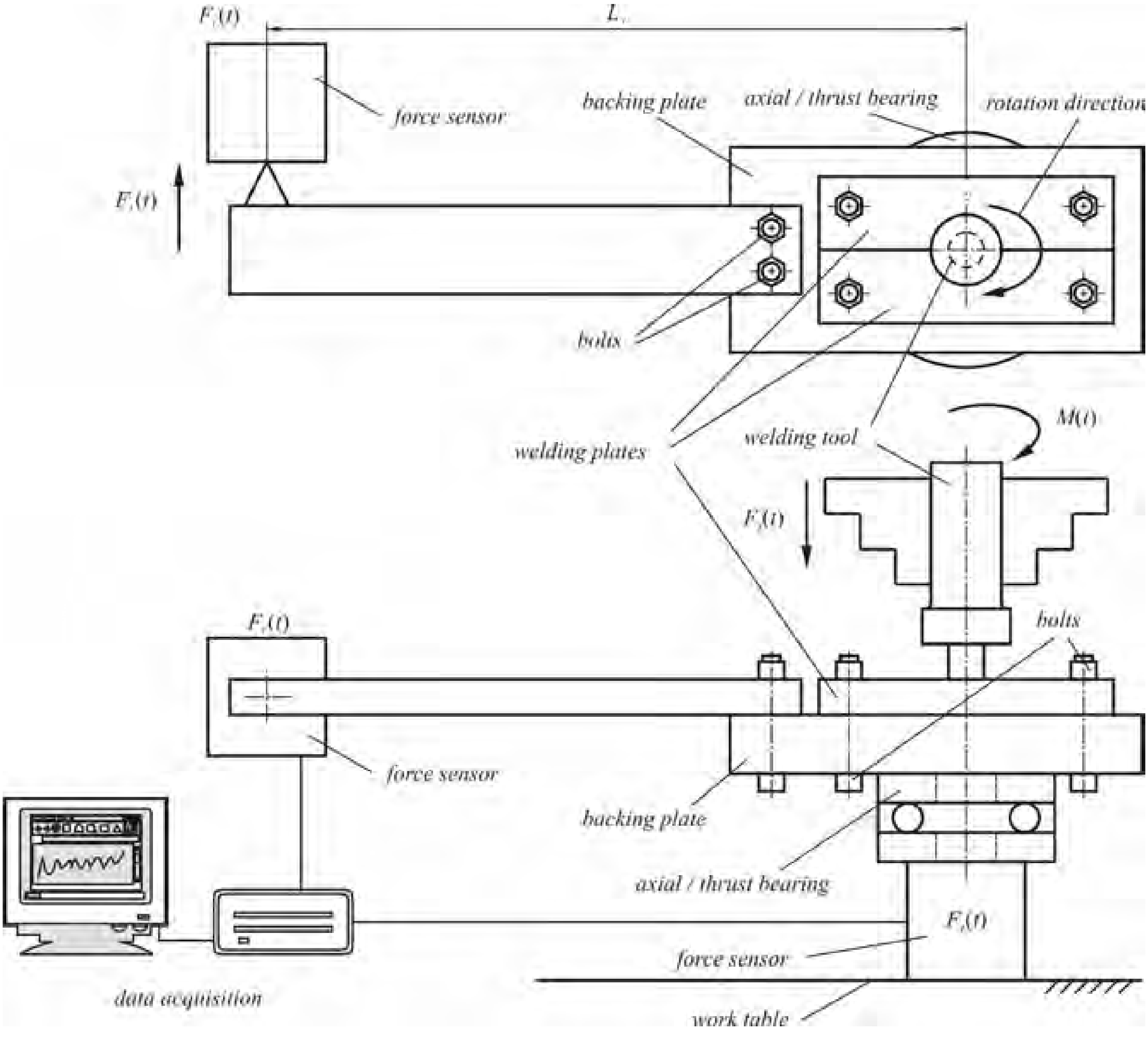


Figure 3. Scheme of the experimental setup for friction coefficient estimation during plunging and first dwelling phases of the FSW process

Following the Equation 4 and analyzing contact mechanics, Galin [27] proposed a dependency between torque M (t), friction coefficient μ and normal force F_z (t) between two solid bodies (semi-rigid punch and elastic half space) in contact:

$$M\left(t\right) = \frac{1}{3} \cdot \mu \cdot F_z\left(t\right) \cdot d\left(t\right) \tag{5}$$

where: d (t) [m] – is diameter of the punch, value dependable on time t and the phase of the FSW process [28]. Transformation of the Equation 5 gives the friction coefficient:

$$\mu = \frac{3 \cdot M\left(t\right)}{F_z\left(t\right) \cdot d\left(t\right)} = \frac{3 \cdot F_t\left(t\right) \cdot L_t}{F_z\left(t\right) \cdot d\left(t\right)}. \tag{6}$$

Kumar has proposed results for a set of conducted experiments where he changed value of contact pressure (normal force), angular rotation of the welding tool and plunging time. Friction coefficient varied from 0.2 to 1.6 (during phases of the FSW and for different technological parameters of the FSW process) [25]. His results are comparable with the results of other presented works.

However, despite the relatively simple construction of monitoring system and excellent results that can be used for further researches Kumar's model has some flaws:

1) it can be used only for the first two phases of the FSW process – plunging and first dwelling phases, due to the rigidity and immovability of the monitoring system;
2) friction coefficient calculated according to the Kumar's model has to be treated as approximate since Galin's equations [27] are usable only for the punch (in this case: probe tip of the welding tool) not for the side of the punch. During these experiments probe side (punch side) is actively involved FSW process and this influences the accuracy of Equations 5 and 6.
3) Kumar's model does not recognize active surfaces of the welding tool [4] nor active surface engagement (ASE, Figure 4) in FSW. Active surfaces of the welding tool are in contact with the welding plates and they generate heat, convey weld, stir and depose material etc. and how much they involve in FSW depends on the ASE. Without concern on the ASE, friction coefficient in FSW by Kumar can be considered only as median value, what is, in most of the cases satisfactory.

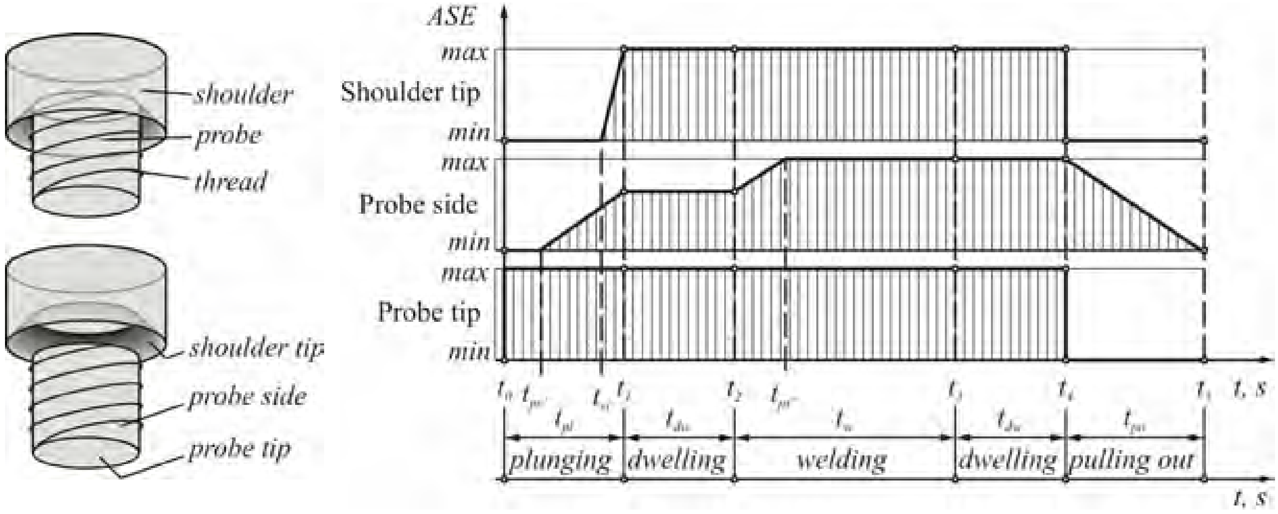


Figure 4. Active surfaces of the welding tool and active surface engagement (ASE) during FSW welding process

4. CONCLUSIONS

Two decades away from the first application of the FSW in industry, friction process stays the least investigated parameter / phenomenon of the FSW process. All published researches about the FSW imply the importance of the friction in every aspect of this welding process's application but do not provide adequate experimental background or mathematical models that will take the influence of the friction (coefficient) in the process of frictional welding. Friction phenomenon or simply – the friction coefficient is considered to be a single value (in most of the researches), mostly from 0.3 to 0.7.

Furthermore, the influence of the friction coefficient to the heat generation process(es) is very poorly investigated or not investigated at all.

Generally speaking, increase of the friction coefficient increases the amount of the generated heat, what implies that mechanical power delivered to the welding tool by machine has to increase. Decrease of the friction coefficient delivers decrease in heat generation and decrease in power consumption during welding process. Problem is simple: friction coefficient is not some technological parameter (such angular rotation is) which can be altered manually / automatically for the purpose of process improvement. So, influence of the friction coefficient on heat generation is in relationship with all other parameters of the FSW and they have to be investigated in depth and mutually.

Understanding the nature of friction coefficient and its relationships with other parameters / phenomena in FSW process is a difficult task and requires in – depth analysis of all parameters that influence friction.

ACKNOWLEDGMENT

The paper presents pre – results of the research project TR35034 – "The research of modern non – conventional technologies: applications in manufacturing companies with the aim to increase efficiency of use, product quality, reduce of costs and save energy and materials". Project is *supported by the Ministry of Science and Technological Development of the Republic of Serbia.*

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] Colegrove P 2000 2nd Int. Symp. on Friction Stir Welding (Gothenburg, Sweden).

[3] 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.

[4] Đurđanović. M., Mijajlović, M., Milčić, D., Stamenković, D.: Heat generation during friction stir welding process. SERBIATRIB ’09, 11th International Conference on Tribology, Beograd, 13-15 May 2009, pp. 135-140.

[5] Bowden, F.P. and Tabor, D. Friction – An Introduction to Tribology, Anchor Press / Doubleday, Reprinted 1982, Krieger Publishing Co., Malabar 1973.

[6] H. Schmidt, J. Hattel: A local model for the thermomechanical conditions in friction stir welding, Modelling Simul. Mater. Sci. Eng. 13 (2005) 77–93.

[7] H. Schmidt, J. Hattel: Thermal modeling of friction stir welding, Scripta Materialia, Volume 58, Issue 5, Pages 332-337, 2008.

[8] Chen, Z.; Thomson, P.F. Wear 1996, 201, 221–232.

[9] Duffin, F.D.; Bahrani, A.S. Wear 1973, 26, 53–74.

[10] Reid, J.V.; Schey, J.A. Adhesion of copper alloys. Wear 1985, 104, 1–20.

[11] Heurtier P., Jones M.J., Desrayaud C., Driver, J.H. Montheillet F., Allehaux D.: Mechanical and thermal modelling of Friction Stir Welding, Journal of Materials Processing Technology 171 (2006) 348–357.

[12] Chen, C. M.; Kovacevic, R. Finite element modeling of friction stir welding - thermal and thermomechanical analysis, Int. J. Mach. Tool. Manu., v.43, p.1319-1326, 2003.

[13] Ulysse, P. Three-dimensional modeling of the friction stir-welding process, Int. J. Mach. Tool. Manu., v.42, p.1549-1557, 2002.

[14] Colegrove, P.A.; Sherclif, H. R. 3-Dimensional CDF modelling of flow round a threated friction stir welding tool profile, J. Mater. Process. Tech., v.169, p.320-327, 2005.

[15] Nandan, R. et al., Numerical modelling of 3D plastic flow and heat transfer during friction stir welding of stainless steel, Science and Technology of Welding and Joining, v.11, p.526-537, 2006.

[16] Nandan, R. et al., Three-dimensional heat and material flow during friction stir welding of mild steel, Acta Materialia, v.55, p.883-895, 2007.

[17] Song, M.; Kovacevic, R. Thermal modeling of friction stir welding in a moving coordinate system and its validation, Int. J. Mach. Tool. Manu., v.43, p.605-615, 2003.

[18] Santiago, Diego; Urquiza, Santiago; Lombera, Guillermo and Vedia, Luis de. 3D modelling of material flow and temperature in Friction Stir Welding. Soldag. insp. (Impr.) 2009, vol.14, n.3, pp. 248-256.

[19] Gould, J.E.; Feng, Z. Heat flow model for friction stir welding of aluminum alloys, J. Mater. Process. Manu., v.7, 1998.

[20] Chao Y J and Qi X 1999 1st Int. Symp. on Friction Stir Welding (Thousand Oaks, CA, USA).

[21] Frigaard Ø, Grong Ø and Midling O T 2001 Metall. Mater. Trans. A 32 1189–200.

[22] Frigaard Ø, Grong Ø, Bjørneklett B and Midling O T 1999 1st Int. Symp. on Friction Stir Welding (Thousand, Oaks, CA).

[23] Russell M J and Shercliff H R 1999 1st Int. Symp. on Friction Stir Welding (Thousand Oaks, California, USA).

[24] Shercliff H R and Colgerove P A 2002 Math. Modelling Weld. Phenom. 6 927–74, Reynolds A P, Deng X, Seidel T and Xu S 2000 Proc. Joining of Advanced and Specialty Materials (St Louis,, MO, ASM International) pp 172–7.

[25] Xu S, Deng X and Reynolds A P 2001 Sci. Technol. Weld. Joining 6 191–93.

[26] Kumar, K., Kalyan, C., Kaias, Satish V., Srivatsan, T. S., An Investigation of Friction During Friction Stir Welding of Metallic Materials, Materials and Manufacturing Processes, 24:4,438 — 445, 2009.

[27] Galin, L.A.: Contact Problems; The legacy of L.A. Galin, Series: Solid Mechanics and Its Applications, Vol. 155, Galin, L. A., Gladwell, G.M. (Ed.), Original Russian edition published by Nauka, Moscow, Russia, 1953, 1980, 2008, XIV, 318 p., Hardcover, ISBN: 978-1-4020-9042-4.

[28] Mijajlović, M., Milčić D., Stamenković D., Živković, A. :Mathematical Model for Generated Heat Estimation During Plunging Phase of the FSW Process, Journal: Transactions of Famena, Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia, XXXV-1/2011, April 2011.

SERBIATRIB '11

Serbian Tribology Society

12th International Conference on Tribology

Faculty of Mechanical Engineering in Kragujevac

Kragujevac, Serbia, 11 – 13 May 2011

SELECTION OF THE MOST APPROPRIATE TECHNOLOGY OF REPARATORY HARDFACING OF WORKING PARTS ON UNIVERSAL CONSTRUCTION MACHINERY

V. Lazić[1], M. Mutavdžić[2], D. Milosavljević[1], S. Aleksandrović[1],
B. Nedeljković[3], P. Marinković[3], R. Čukić[1]
[1] Faculty of Mechanical Engineering, Kragujevac, Serbia
[2] Road Company Kragujevac, Kragujevac, Serbia
[3] Zastava automobiles, Kragujevac, Serbia

Abstract: *The aim of this work is to analyse the possibility to increase the service life of working parts on construction machinery exposed to intensive wear, such as steel blades of the rotary device for roadside vegetation maintenance and grass cutting. A special attention is paid to characteristic working conditions and complex wear mechanisms. In order to select the most appropriate reparation technology, both model and real investigations were conducted. The aim of the model investigations was to select the most appropriate procedure, filler materials and hardfacing technology. Worn cutting edges of the blades were hardfaced and sharpened by grinding to the shape and dimensions of new blades. Then, both new and repaired blades were alternately mounted on the rotor of the machine. Their wear was monitored under the same working and weather conditions. The repaired blades have proven more resistant to wear than the new ones, which is due to better properties of the hardfaced layers.*

Key words: *hardfacing, construction machinery, wear, hardness, microstructure.*

1. INTRODUCTION

Almost all working parts of construction machinery are exposed to complex tribological processes during operation. Sometimes, one type of wear is dominant, but in practice, combined wear is much more common. A typical example of combined wear is seen in blades of the device for roadside vegetation maintenance and grass cutting. These parts are exposed to abrasive, impact and fatigue wear as well as corrosion.

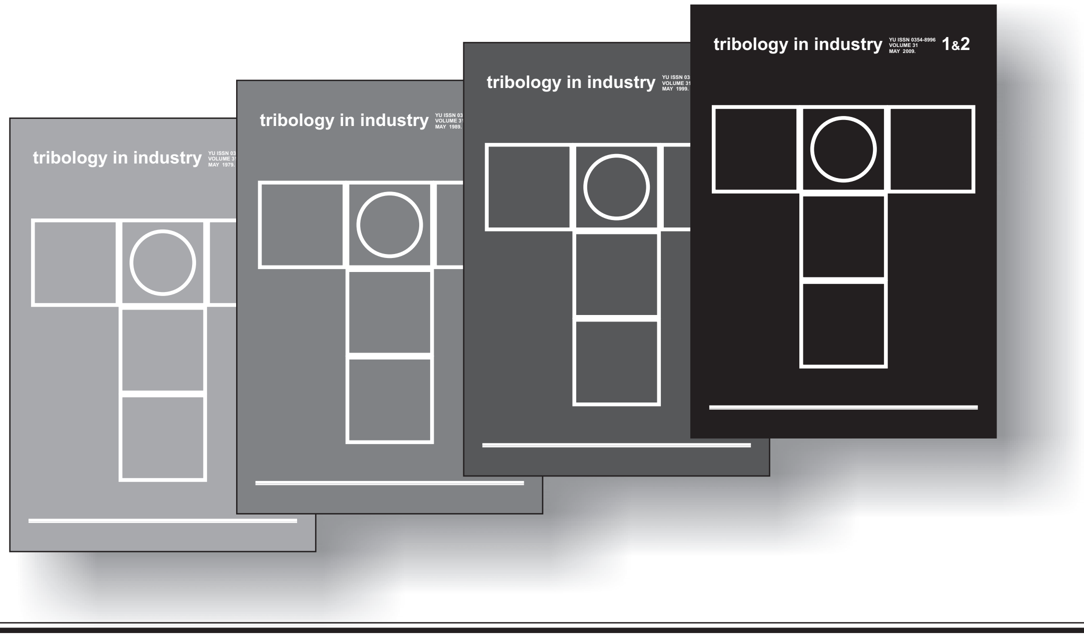
Working parts have relatively short service life, they increase machine downtime, it takes a long time to replace them, they decrease machine utilization rates, etc. However, reparatory hard facing can reduce or eliminate these problems. Hardfacing also offers an opportunity to determine wear resistance of different filler materials.

Our investigations [1-12] and investigations of other authors [13-15] have shown that worn and new parts can be successfully hard-faced. However, both reparatory and production hardfacing can be performed only in specialized facilities with expert staff and adequate equipment.

2. MACHINE AND DEVICE DESCRIPTION

The device for cutting grass and other vegetation is mounted on a universal machine Unimag (Fig. 1). This is a multipurpose vehicle on which thirty-two different devices can be mounted and operated. In addition to grass and vegetation cutting, it can be applied for snow clearing, aggregates spreading, land clearing and levelling, preparing soil or aggregate substrate for concrete or asphalt laying, digging holes in the ground, cutting and removal of trees, load lifting, trench digging for utility installation, etc.

Authors Index


tribology in industry
tribology in industry
tribology in industry
tribology in industry
1&2

Serbian Tribology Society

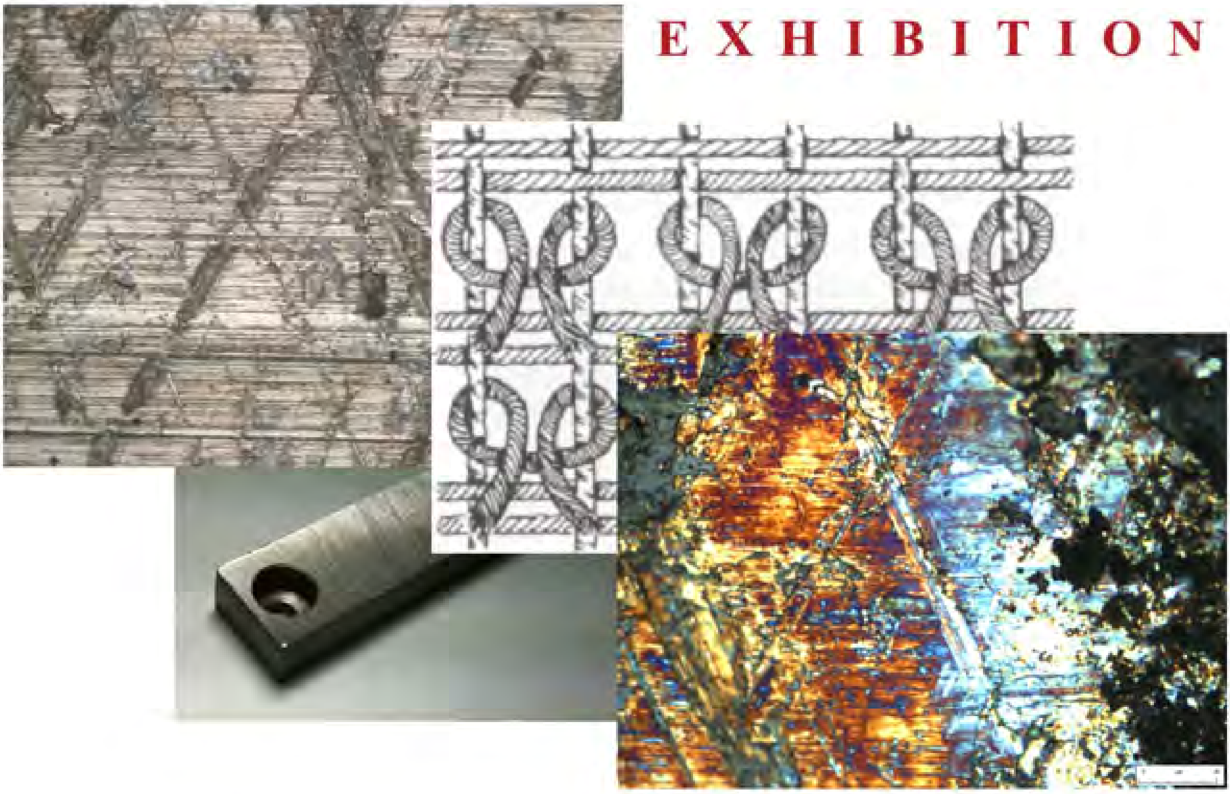
Faculty of Mechanical Engineering
University of Kragujevac

SERBIATRIB '11

12th International Conference on Tribology

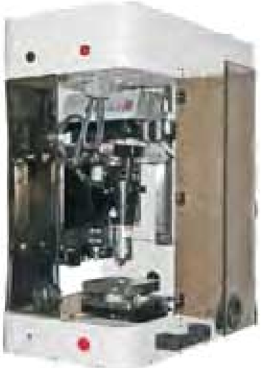
11 – 13 May, 2011, Kragujevac, Serbia

PROTECTIVE LAYER IN CARPET EXHIBITION



Lecturer Zeynep ÇAVDAR KALELİ*

*SAKARYA UNIVERSITY
FINE ARTS FACULTY
TRADITIONAL TURKISH HAND ART DEPARTMENT
SAKARYA / TURKEY




SERBIATRIB ‘11