Serbian Tribology Society

University of Belgrade,
Faculty of Mechanical Engineering

11th International Conference on Tribology

SERBIATRIB '09

PROCEEDINGS

EDITORS: Aleksandar Vencl, Aleksandar Marinković

May 13 – 15, 2009, Belgrade, Serbia

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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 and 2003). This year the 11th International Conference on Tribology – SERBIATRIB '09 takes place on May 13-15, 2009 in Belgrade.

This Conference is organized by the Serbian Tribology Society (STS) and the University of Belgrade, 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. In the frame of the Conference a worth while jubilee: 15 Years of Serbian Tribology Society, which was in 2007, will be laid out with an appropriate publication of the STS history and activities (in Serbian).

The scope of the 11th International Conference on Tribology – SERBIATRIB '09 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 69 papers of authors from 19 countries (USA, Taiwan, Russia, Belarus, Ukraine, Slovakia, Germany, Austria, France, Netherlands, Italy, Slovenia, Bosnia and Herzegovina, Romania, Bulgaria, Greece, Turkey, Iraq and Serbia) are published in the Proceedings. Approximately 38 papers were submitted by the foreign authors and app. 31 papers by the Serbian authors. All papers are classified into seven chapters:

- Plenary lectures (5)
- Tribological properties of solid materials (12)
- Surface engineering and coating tribology (9)
- Lubricants and lubrication (8)
- Tribology in machine elements (8)
- Tribology in manufacturing processes and other topics related to tribology (11)
- Trenje, habanje i podmazivanje (16) – 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. Branko Ivković and prof. Aleksandar Rac for the helpful suggestions and support.

The Conference is financially supported by the Ministry of Science and Technological Development of the Republic of Serbia, CSM Instruments, Serbian Chamber of Commerce, Messer Tehnogas AD, Oil Rafinery Modriča, Technology Transfer Center Hanover and RAR Batajnica.

We wish to all participants a pleasant stay in Belgrade and we are looking forward to seeing you all together at the 12th International Conference on Tribology – SERBIATRIB '11.

Belgrade, May 2009

Editors

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atures, when the matrix gets softening, a certain amount of coarse hard phases are necessary to withstand grooving and therefore keep the wear on a low level.

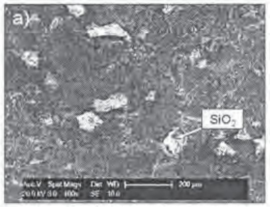

Figure 13. SEM micrographs of typical worn austenitic surfaces after CIAT at 600°C.
a) impacting zone, b) abrasive dominated region

4. CONCLUSIONS

Based on the investigations within this work, following conclusions can be drawn:

1. Coarse microstructure with carbides performs well under glancing impact angle, whereas brittle behaviour is observed at normal impact angle in erosion test.
2. Single phase austenitic materials show ductile behaviour and in-situ formation of mechanically mixed layers (MML) which is more pronounced at higher temperatures which enables a temperature independent behaviour under normal impact angle.
3. Breaking of coarse hard phases at high temperatures takes place due fatigue effects and insufficient mechanical support by the matrix.
4. In abrasion conditions, a certain content of hard phases is necessary to keep wear on a low level, therefore a pure austenitic structure is not favourable in case such conditions appear at least in certain areas of the loaded parts.
5. In impacting loading conditions, a coarse microstructure is a disadvantage.
6. As future development direction austenitic structures reinforced with hard phases could be of high interest.
7. Complex Nanoalloys® are state of the art for protection under combined wear with a dominant abrasive component where austenitic materials have much less wear resistance.

ACKNOWLEDGEMENTS

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SERBIATRIB '09

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HEAT GENERATION DURING FRICTION STIR WELDING PROCESS

Miroslav B. Đurđanović[1], **Miroslav M. Mijajlović**[1], **Dragan S. Milčić**[1], **Dušan S. Stamenković**[1]
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ract: *Friction stir welding – FSW was a promising welding technology from the same moment of its ce because of its easy use, low energy costs, being ecology friendly process and with no need for filler FSW works in the solid state of weld metals and basic goals of the process are to generate thermal by friction on contact of FSW tool and welding pieces, which will soften weld pieces and stir it with etal into weld. FSW process has five main phases: plunging into weld pieces, dwelling, moving along ine for the weld creation, final dwelling and pulling out of the welding tool from the weld. Generated is in proportion with large number of parameters, but most significant are contact pressure between weld pieces and speed. Significant thermal energy is generated during FSW and there is mathematical which describe these stages but still there are several inaccuracies of the model that give some nces between theoretical and experimentally determined amount of heat.*

words: *Friction Stir Welding, Technological Hole, Heat Generation.*

INTRODUCTION

iction stir welding is non melting process of ng invented in 1991. From the early beginning application, this process showed good cteristics in welding pieces that have to keep nged their structure and properties as much it sible. First application of the friction stir ing process was with aluminum and its alloys, s technique is widely used with various types tals nowadays. Welding is achieved with one that is in contact with weld pieces. This tool is drical, mostly with a profiled threaded probe t is rotated at a constant speed (n) and fed ted) at the constant traverse rate (v_x) into the line between two weld pieces which are ly clamped onto a backing plate and butted her. Backing plate prevents abutting of the faces from being forced apart [1-5].

PHASES OF THE FSW PROCESS; BASIC REVIEW

here are various shapes and design of welding backing plate etc, but that does not affect basic on stir welding process, without any concern technology varieties. friction stir welding process can be separated to five phases: a) plunging, b) dwelling, c) welding, d) dwelling, and e) pulling out [5].

Figure 1 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 1, a) and it is the classical welding process.

In the case analyzed in this paper, weld pieces are previously prepared so that they have a "technological hole" and welding tool is plunged directly into the hole instead of making one during the first phase. Technological hole can ease welding process since there is no need for significant vertical force (in z direction) that is necessary in the case with plunging into pieces without the technological hole. The plunge phase is followed by the dwell phase, where the toll stays steady relatively to the welding pieces but still constantly rotating (Figure 1, 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 1, c).

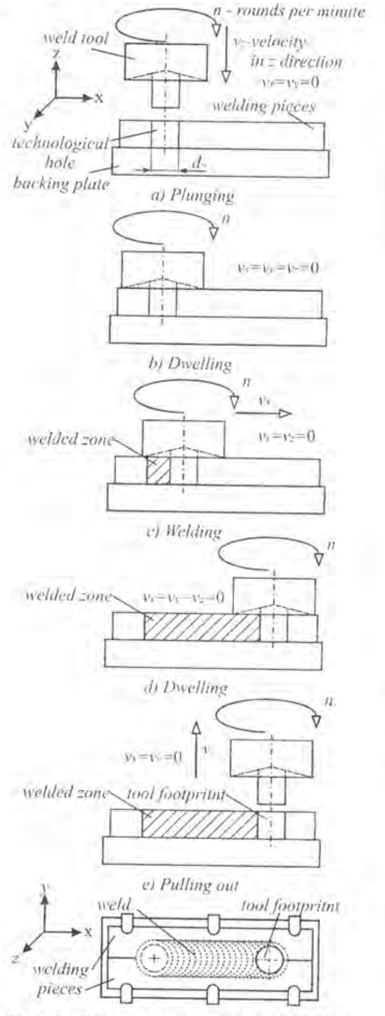

Figure 1. Phases of the friction stir welding process

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 1, 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 1, e)

Friction welding tool or simply *tool* has two basic parts: the shoulder and the probe. Shoulder is massive cylindrical part that carries smaller cylindrical part – probe. Figure 2 shows the basic shape of the tool. New tool designs have special features on probe like multi-facets, threads, gear teeth and flutes which are manufactured to produce advantageous conditions in heat generation, stirring and to assist the joining process.

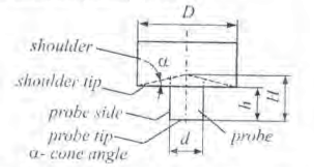

Figure 2. Basic shape of the friction stir welding tool

There are three surfaces of the tool that perform the heat generation by friction and enable joining of weld pieces. Probe has two surfaces that can generate heat – the tip and the side of the probe. The probe tip generates significant heat during plunging phase if there is no technological hole. But in any other case and in the following phases of welding its contribution to the heat generation is ignorant. The probe side surface is directly in the contact with the work pieces and this surface gives the greatest tribute to the heat generation. When welding pieces are previously prepared with technological hole with diameter d_0, it can be expected that diameter of the weld tool's probe d can be equal, smaller or greater than d_0. In theory contact [7] between cylindrical weld tool's probe and hole's cylindrical surface is:

- in one contact line, if $d<d_0$ and
- surface to surface, if $d \geq d_0$.

If we consider situation where $d<d_0$, real situation is slightly different than theoretical traversal force of the tool, which is parallel to the joint line, forces tool's probe to contact surface of the technological hole in one contact line. Elastic deformations of the probe and the hole make this contact to spread from the linear to the contact in the surface, defined with contact angle θ (Figure 3). Elastic properties of the realistic materials do not allow linear contact between two cylindrical surfaces except in some special situations [7].

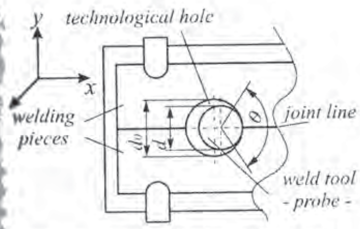

Figure 3. Contact angle θ between the probe and technological hole

The shoulder surface is the area where certain amount of heat is generated only if cone angle has a value of $\alpha=0°$. In the case of $\alpha>0°$ this surface has relatively small contact surface with solid metal and generated amount of heat is slightly smaller. Coned part of the shoulder confines the underlying material of the weld so prevent formatting of porosity in the weld behind the probe. The conical tool shoulder helps establishment of the constant pressure under the shoulder necessary for the welding, but also acts as an escape volume for the material displaced by the probe during the plunge phase. The probe height is limited by the work piece thickness h. The probe tip must not contact, damage or penetrate the backing plate.

ANALYSIS OF THE TOOL-WELD PIECES CONTACT DURING WELDING PHASES

It is more than clear that heat, necessary for the welding, is generated by friction during active contact of at least two surfaces – one surface from the tool and front surface of the weld pieces. Number of contact surfaces, surface area and ability to generate heat vary from phase to phase of the welding and parameters of the welding process – rotation speed n, traversal speed v_x *etc.* Active contact is consequence of weld tool rotation and transverse movement of weld tool, weld pieces or both.

The simplest possible shape of the welding tool has cylindrical shoulder, with the cone on the shoulder tip, cone angle α and cylindrical tool probe (Figure 2). According to the assumed geometry of the tool (Figure 2) and weld pieces (Figure 1) heat can be generated during all phases of the welding on the following surfaces:

1) Plunging phase: dependable to the diameter of the tool d and diameter of the technological hole d_0, there are three possible situations:

1.a) $d<d_0$ – tool probe's pin surface has no contact with the weld pieces surface so there is no heat generation on these surfaces; tool probe's side surface has no contact with side surface of the technological hole and there is no heat generation on these surfaces.

1.b) $d=d_0$ – tool probe's pin surface has no contact with the weld pieces surfaces so there is no heat generation on these surfaces; tool probe's side surface has limited or no contact with side surface of the technological hole and there is expected small amount of heat generation on these surfaces, contact length between tool probe's side surface and weld rises from 0 to h.

1.c) $d>d_0$ – tool probe's pin surface has contact with the weld pieces surfaces so there is some heat generation on these surfaces; tool probe's side surface has contact with side surface of the technological hole and there is significant amount of heat generation on these surfaces, contact length between tool probe's side surface and weld rises from 0 to h.

2) Dwelling phase: tool probe's side surface is in contact along height h (H) with weld pieces and shoulder's tip surface is in contact with plate surface of the weld pieces.

3) Welding phase: tool probe's side surface is in contact along height h (H) with weld pieces and pushes forward along the joint line for weld creation; shoulder's tip surface is in contact with plate surface of the weld pieces.

4) Dwelling phase: tool probe's side surface is in contact along height h (H) with weld pieces and shoulder's tip surface is in contact with plate surface of the weld pieces.

5) Pulling out phase: toll probe's side surface generates heat from the contact with weld pieces; contact length between tool probe's side surface and weld decreases from h to 0.

From the aspect of welded joint heat treatment during welding, friction stir welding can be described in four 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.

Table 1. Friction stir welding phases and the contact areas between surfaces

Welding phase	Surfaces	Area
Plunging	Probe tip	$d<d_0\ \ A_{pt}=0$ $d=d_0\ \ A_{pt}\approx 0$ $d>d_0\ \ A_{pt}=\frac{\pi}{4}\cdot\left(d^2-d_0^2\right)$
	Probe side	$d<d_0\ \ A_{ps}=0$ $d=d_0\ \ A_{ps}\approx d\cdot\pi\cdot dz$ $d>d_0\ \ A_{ps}=d\cdot\pi\cdot dz$ $dz=0\div h$
	Shoulder tip	$A_{st}=0$
Dwelling	Probe tip	$A_{pt}=0$
	Probe side	$d<d_0\ \ A_{ps}=\theta\cdot\frac{d}{2}\cdot h,$ $\theta=0\div\pi\ \ rad$ $d\geq d_0\ \ A_{ps}\approx d\cdot\pi\cdot h$
	Shoulder tip	$A_{st}\approx 0$
Welding	Probe tip	$A_{pt}=0$
	Probe side	$A_{ps}\approx\theta\cdot\frac{d}{2}\cdot H$ $\theta=0\div 2\pi\ \ rad$
	Shoulder tip	$A_{st}\approx\frac{D^2-d^2}{4}\cdot\pi$
Dwelling	Probe tip	$A_{pt}=0$
	Probe side	$A_{ps}\approx d\cdot\pi\cdot H$
	Shoulder tip	$A_{st}\approx\frac{D^2-d^2}{4}\cdot\pi$
Pulling out	Probe tip	$A_{pt}=0$
	Probe side	$A_{ps}\approx d\cdot\pi\cdot dz$ $dz=H\div 0$
	Shoulder tip	$A_{st}=0$

If we analyze surfaces involved in the heat generation, shown in Table 1, but it is completely clear that physical phases of welding process are not identical with phases that describe heat generation and heat flow within work pieces, weld tool and surrounding.

4. ANALITICAL METHOD FOR HEAT GENERATION ESTIMATION

All amount of generated heat can be assumed as a direct product of weld tool's rotation and it is coming as a product of the adhesion and the deformation of the material around the tool. Heat generated from the traverse movement is significantly smaller amount then from the rotation so it can be excluded from calculations.

$$Q=Q_{adhesion}+Q_{deformation}$$

$$Q_{adhesion}=Q_{sliding}\ ;\ Q_{deformation}=Q_{sticking} \quad (1)$$

On the other hand, total amount of the heat generated by the cylindrical friction stir welding tool can be calculated as a sum of the energy generated on the tool probe's tip surface Q_{pt}, tool probe's side surface Q_{ps} and tool shoulder's tip surface Q_{st}.

$$Q=Q_{pt}+Q_{ps}+Q_{st} \quad (2)$$

Some assumptions about heat generation [1] suggest that heat is generated predominately under shoulder tip's surface because of the great contact surface between tool and weld pieces. Newer experiments and analysis of the welding process have partially declined these assumptions and gave some explanation about influence of all contact surfaces in the heat generating [1, 2].

Heat is generated during two basic tribological processes that appear in the contact of the tool and weld pieces: *pure sliding* - adhesion and *pure sticking* - deformation. Pure sliding condition assumes shear in the contact interface and can be described as fully Coulomb friction condition. Assumption is that the contact pressure between tool and weld piece p and friction coefficient μ are constant or linearly dependable values from various variables. If contact shear stress has smaller value than the internal yield shear stress of the weld pieces, segment volume of the weld piece shears slightly to the elastic deformation where shear stress becomes equals to dynamic contact shear stress. Pure sticking assumes shearing in the layer of the material of weld pieces very close to the contact surface and uniformity of the shear stress τ. In this situation surface of the weld piece will stick to the moving tool's surface only if friction shear stress exceeds the yield shear stress of the weld piece. Segment of the weld piece material is being chopped and accelerate along the tool, until the equilibrium state is established between the contact stress and shear stress of the weld pieces. Unfortunately, real situation during welding process gives combination of the pure sliding and the pure sticking and it is absolutely correct to say that heat generating during friction stir welding is product of pure sliding, pure sticking and combination of sliding and sticking.

Basic equation for heat generation with infinitesimal surface in contact with the weld pieces is equal to

$$dQ=\omega\cdot dM[\mathrm{J}] \quad (3)$$

where

ω tool angular rotation speed, rad^{-1}

dM torque of the welding tool.

If torque is replaced as a product of the ter force dF and radial distance r, and ter force is replaced as a product of a shear τ and infinitesimal area of observed surface equation for generated heat is

$$dQ=\omega\cdot r\cdot\tau\cdot dA\,. \quad (4)$$

Application of the equation (3) and deration of sticking and sliding condition equations for the heat generating at the fic surfaces.

Shoulder tip surface:

king

$$Q_{st}=\frac{2}{3}\pi\cdot\tau\cdot\omega\cdot\left[\left(\frac{D}{2}\right)^3-\left(\frac{d}{2}\right)^3\right]\cdot(1+\tan\alpha) \quad (5)$$

ing

$$Q_{st}=\frac{2}{3}\pi\cdot\mu\cdot p\cdot\omega\cdot\left[\left(\frac{D}{2}\right)^3-\left(\frac{d}{2}\right)^3\right]\cdot(1+\tan\alpha) \quad (6)$$

Tool probe tip surface:

king

$$\begin{aligned}&d<d_0\ \ Q_{pt}=0\\&d=d_0\ \ Q_{pt}\approx 0\\&d>d_0\ \ Q_{pt}=\frac{2}{3}\cdot\pi\cdot\tau\cdot\omega\cdot\left[\left(\frac{d}{2}\right)^3-\left(\frac{d_0}{2}\right)^3\right]\end{aligned} \quad (7)$$

ding

$$\begin{aligned}&d<d_0\ \ Q_{pt}=0\\&d=d_0\ \ Q_{pt}\approx 0\\&d>d_0\ \ Q_{pt}=\frac{2}{3}\cdot\mu\cdot p\cdot\omega\cdot\left[\left(\frac{d}{2}\right)^3-\left(\frac{d_0}{2}\right)^3\right]\end{aligned} \quad (8)$$

Tool probe side surface:

Sticking

$$Q_{ps}=\theta\cdot\tau\cdot\omega\cdot\left(\frac{d}{2}\right)^2\cdot H,\ \ \theta=0\div 2\pi \quad (9)$$

Sliding

$$Q_{ps}=\theta\cdot\mu\cdot p\cdot\omega\cdot\left(\frac{d}{2}\right)^2\cdot H,\ \ \theta=0\div 2\pi \quad (10)$$

In situation of the mixed state – what is the most usual situation, welding is done with combination of the sliding and sticking and it is necessary to define a contact state variable δ. This constant is ratio of velocity of contact points at the weld piece segment v_{cp} that are in contact with tool and velocity of the tool v_ω that comes from rotation of the tool.

$$\delta=\frac{v_{cp}}{v_\omega} \quad (11)$$

Pure sticking is defined for δ=1, pure sliding for δ=0 and combination of the sticking and sliding is assumed for values 0<δ<1.

Amount of the generated heat for combination of the sticking and sliding state is equal to:

$$Q=\delta\cdot Q_{sticking}+(1-\delta)\cdot Q_{sliding}\,. \quad (12)$$

Shoulder tip's surface generates approximately 85% of the total amount of heat while probe generates about 15% when welding is applied without technological hole [1]. Technological hole changes ratio of the generated heat on surfaces and it is expected to get different values with than in [1].

5. DISCUSSION ABOUT UNCERTAINTIES WITHIN HEAT GENERATION IN THE FRICTION STIR WELDING PROCESS

Mathematical model describes geometrical conditions for heat generating and if statement that "heat generated from traverse movement of the welding tool has a minor value" [5, 8] is correct, value of analytically calculated heat has to be close to the experimentally measured value of the generated heat.

Experiments with heat generating during friction stir welding, conducted by various scientists in various laboratories with different expectations give completely different results. Some results have an excellent matching with theoretical (analytical) results, but huge number of experiments gives results incomparable with analytical results [9].

If we agree that mathematical model used to describe geometrical inputs to the friction stir welding process is adequate and precise enough, this suggests that there are some parameters, involved in mathematical model, which lead to uncertain or imprecise results.

If we exclude geometrical and machining parameters from total generated heat Q equation (13) we get parameters that might influence precision of the results: contact state variable δ, friction coefficient μ between tool and wield pieces, contact pressure between tool and weld pieces p and the shear stress τ of the wield pieces.

Contact state variable δ precisely define border conditions of welding: pure sticking or pure sliding. Condition involving both sticking and sliding remain uncertain and imprecise since there is huge variation of the variable δ. Contact state variable δ is directly influenced with tool's number of rotations per minute n and traversal speed vx and selection of those parameters will directly influence on value of δ. Still, there is uncertainty about intensity of weld piece segment velocity vcp since measuring requires complex tribological measuring system. Some authors [8, 9] give numerical values of the δ depending on materials and machining parameters, but still there are no mathematical models or experimental values that will cover complete palette of materials and machining parameters. Nowadays δ values are determined buy expert assessment or buy usage of artificial intelligence and neural networks. Fuzzy set theory has adequate mathematical tools that might solve this uncertainty in some specific cases.

Friction coefficient μ is tribological parameter that describes the ratio of the force of friction between two bodies and the force pressing them together. At the beginning of the welding process, weld tool – metal is in contact with weld pieces – metal so friction coefficient has regular and familiar value. During phases of welding, tool softens the surface of the weld pieces and it is clear that value of friction coefficient changes its value. It would be unwise to tell that value of friction coefficient increases/decreases. The most precise statement is that friction coefficient changes its value or that friction coefficient is function of at least two parameters – pressure p and traversal rate vx:

$$\mu = f(p, v_x, \ldots) \qquad (13)$$

Some authors [2, 4] give boundaries for friction coefficient for metal – metal contact as μ=0.08÷1.4. Still no one gives functional dependency of friction coefficient for parameters in friction stir welding phases.

Contact pressure p between tool and weld pieces is considered as a value changing between 0 and maximal value of p so there is no issue with this parameter.

Finally, assumptions about constant values of the parameters like linearization of the values or uniformity are, have to be analyzed and adapted to the problem of friction stir welding. Certain amount of imperfections and assumptions must be changed with goal to get better precision of the results.

6. CONCLUSION

Friction stir welding process is relying on heat generating for weld joint creation. Parameters involving proper welded joint creation are just the same parameters involved in heat generation and this amount is directly dependable from the geometrical parameters of the tool, speed – rotational and traversal, pressure, shear stress and friction coefficient.

Determination of precise amount of heat generated during friction stir welding process is complicated since there are various uncertainties, assumptions and simplifications of mathematical model that describes welding process. Various experiments conducted around the planet, from the very beginning of the FSW method's appli gave dispersive results about the generated The analytical heat generation estimate corre with the experimental heat generation, by assum either a sliding or a sticking condition. For sliding condition, a friction coefficient that lie the reasonable range of known metal to contact values is used in order to estimate experimental heat generation. Assuming sticking condition yield shear stress, which descriptive for the weld piece material at ele temperatures, is used to correlate the values.

Main uncertainties about process are wh welding condition is mixture of sliding sticking. In this situation ambiguity of the value the friction coefficient in every moment of welding process, contact pressure between tool and weld pieces and shear stress are m reasons for difference between analytical experimental results.

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CHARACTERIZATION OF NANO CRYSTALLINE LUBRICANT COATING TO STUDY THE EFFECT OF GRAIN SIZE AND PHASE STRUCTURE ON THE COATING BEHAVIOR

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act: *This paper presents the techniques used to comprehensively characterize the effect of current on the grain size, phase structure and the corresponding effect on the tribological, corrosion, wear adhesion behavior of nanocrystalline lubricant coating.*

ords: *Nanotribology, lubricant, Nano Crystalline coating*

INTRODUCTION

Figure 1. Schematic showing effect of pulsed deposition on final coating structure

Nanocrystalline materials, with smaller grain (order of some 100nm) used for lubrication and resistance, have been the subject of intensive arch. Among many processing techniques eloped for producing nanocrystalline materials electrode deposition has received siderable attention in recent years, owing to the sibility of changing the final coating properties regulation of pulse parameters. [1] This paper estigates the techniques used to prehensively characterize the effect of positing conditions on the tribological, corrosion, ar and adhesion behavior of nanocrystalline ating.

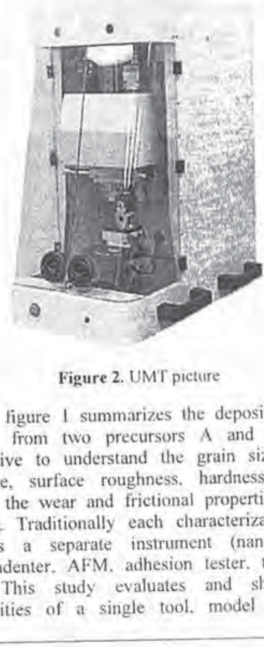

Figure 2. UMT picture

The figure 1 summarizes the deposition of a coating from two precursors A and B. It is imperative to understand the grain size, phase structure, surface roughness, hardness, etc to predict the wear and frictional properties of the coating. Traditionally each characterization step requires a separate instrument (nanoindenter, microindenter, AFM, adhesion tester, tribometer etc.). This study evaluates and shows the capabilities of a single tool, model UMT to

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