UNIVERSITY OF NIŠ
FACULTY OF MECHANICAL ENGINEERING IN NIŠ

THE 2nd INTERNATIONAL CONFERENCE

MECHANICAL ENGINEERING IN XXI CENTURY

PROCEEDINGS

313 - 2013.

June 20-21. 2013.

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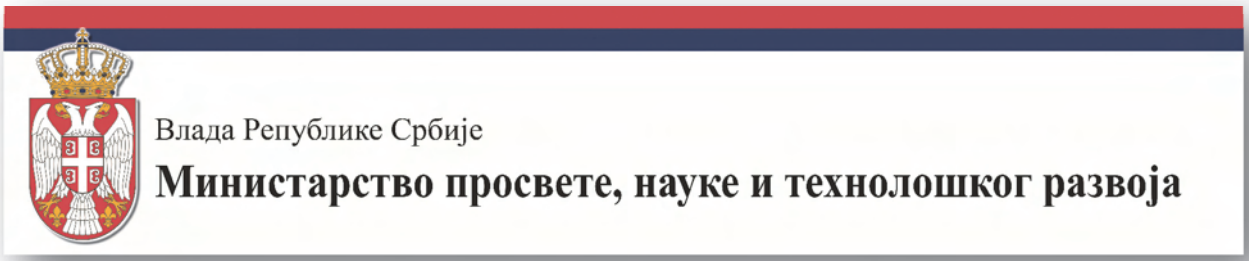
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PREFACE

Half a century of tradition, high standards in education of generations of students, modernly equipped classrooms, professional teaching and associate staff, their references and recognizability position the Faculty of Mechanical Engineering of the University of Niš as the leader in the field of engineering and technological sciences, not only on the territory of the Republic of Serbia, but also on the territory of the Western Balkans.

The proceedings of the Second International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** appear in the year when the Faculty of Mechanical Engineering of the University of Niš celebrates its fifty third anniversary. The Department of Mechanical Engineering of the Faculty of Engineering in Niš was founded on the 18th of May, 1960, and it developed into the Faculty of Mechanical Engineering of the University of Niš in 1971. The Faculty of Mechanical Engineering grew intensely, thus becoming one of the most renowned scientific and educational institutions in the country.

The mission of the Faculty is to organize and conduct academic study programmes and to develop and realise scientific and professional work in the field of engineering and technological sciences. Its vision to be recognisable in the european and world academic environment in the area of mechanical engineering.

More than 90 teachers and associates, about 60 non-teaching workers, as well as numerous teachers and associates from other faculties and from the industry, are working hard every day to accomplish the mission and vision of the Faculty.

The Faculty of Mechanical Engineering of the University of Niš is accredited in compliance with the Law on Higher Education within the scientific and educational field of engineering and technological sciences. It conducts the academic studies of the first degree – undergraduate studies, the second degree – master academic studies, and the third degree – doctoral studies, within the scientific area of mechanical engineering and engineering management.

The Faculty of Mechanical Engineering is also a scientific research institution apart from being an educational one. There are 14 international scientific research projects within the frame of FP7, TEMPUS, CEEPUS, DAAD, bilateral and cross-border programmes, as well as 24 national scientific research projects, being realised at the Faculty in this year. The participation of teachers and associates from the Faculty in these projects is of utmost importance for their educational and research work and their further career.

The Second International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** represents a forum for presentation of latest results, basic and development research and application within the topics of:

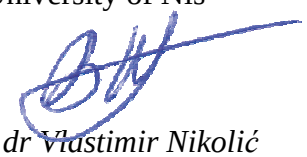
- Information Production Technologies and Industrial Management,
- Thermal and Process Engineering,
- Mechatronics and Control,
- Machine Constructions, Development and Engineering,
- Traffic Engineering, Transport and Logistic,
- Theoretical and Applied Mechanics,
- Applied Mathematics,
- Engineering Profession: State and Prospects,

as well as the Workshop in honor of Prof. dr Ljiljana Petković "Iterative methods in applied mechanics".

Eighty three papers, whose authors come from 11 countries, are published in these Proceedings. Papers present the research results of numerous projects financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia, as well as the research results within international projects. There is no doubt that the papers published in these Proceedings will contribute to the development of a highly significant area – Mechanical Engineering.

As a Dean of the Faculty of Mechanical Engineering in Niš, I am honoured to greet all participants of the Conference and wish them successful work.

Dean of the Faculty of Mechanical Engineering,
University of Niš



Prof. dr Vlastimir Nikolić

Niš, June 2013.

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Application of Triz for Development of the Welding Tool for Friction Stir Welding

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***Abstract*— One of the latest welding procedures – friction stir welding, has become a common welding procedure used in situations where no other welding procedures give adequate results. Advantages of this procedure are of greatest interest in welding of aluminum and its alloys, different materials etc. Friction stir welding is a typical example of usage of indirect frictional heat generation where welding is performed by the welding tool. Welding tool is a specialized tool consisting of shoulder and pin with the thread at the side. The profile of the thread is different from case to case and usually firmware. This paper is giving an example of development of the friction stir welding tool using the contradictions overcoming procedure – TRIZ. Welding tool is mentioned to be used for welding of thick parts made of high strength materials.**

***Keywords*— friction stir welding, the theory of inventive problem solving, welding tool**

I. INTRODUCTION

Friction stir welding (FSW) is invented and experimentally verified by Wayne Thomas and his colleagues from the Institute of Welding, London, UK (The Welding Institute UK - TWI) during December 1991. The participant in the research process and the first user of FSW was the company Hitachi (Hitachi Ltd.). At the end of 1991 and the middle in 1992, Hitachi developed machine which was possible to process FSW weld on 25 meter long aluminum chassis for light, exo- rail vehicles used for the required underground railways of Japan, called. "Hitachi A-Train."

This method is routinely used, especially in many cases where no other method gives satisfactory results, but the main advantages of FSW are mostly reflected in the welding of materials such as aluminum and its alloys, austenitic stainless steels difficult to be weld by conventional methods, titanium, non-metal materials, etc. [1]. In real applications is irrefutably demonstrated that this process provides a homogeneous welds with good mechanical properties, often for parts difficult to be welded by conventional methods and techniques. The process is most applicable to components which are flat and long (plates, strips, etc.), but some adaptations can be welding of pipes of different elements as well hollow spot welding.

II. FRICTION STIR WELDING

FSW welding process is a typical example of the use of indirect method of generating heat by friction. FSW procedure (Figure 1) is implemented as follows: sheets (workpieces, the parts to be joined, base metals) are pressed together and fixed to the under panel. Welding is performed using a special tool having cylindrical shape, which consists of a large body diameter shoulder and smaller diameter pin usually sliced and left-hand thread.

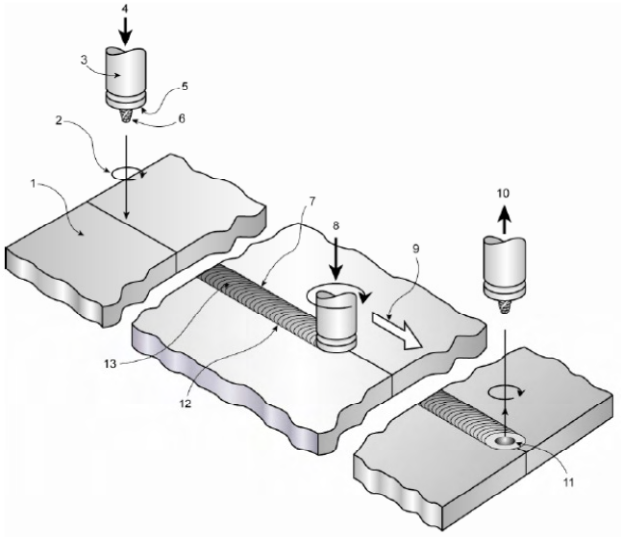


Figure 1 Nomenclature of the friction stir welding, 1-base metal, 2-tool rotation direction (clockwise), 3-welding tool, 4-plunging of the tool, 5-shoulder, 6-pin, 7 - advancing side of the weld 8-axial force, 9-direction of the welding 10-pulling out, 11-exit hole, 12-retreating side of the weld 13-weld face [2, 4]

At the beginning of the welding, tool is located above the plates and the work pieces so that its axis is usually perpendicular to the line of contact sheets. In this position, the tool rotates and starts downward translational movement, the pin penetrates through both plates simultaneously at a point on the joint line, the friction generated heat heats plates and continuously, stirs, deforms and mixes the material of workpieces. When shoulder touches the surface of the plate, the frontal area of the welding tool is very close to the anvil, tools downward movement is interrupted while continuing rotation of the tool. For some time tool remains in that position, and then starts moving horizontally along the line of plates. In the further course of the process, the pin heats both new layers of sheet material and mixes them, and deposes it behind, creating a zone of deformed material that hardens thus forming a monolithic structure. Tool shoulder seam forms a flat surface on the top sheet and the bottom does the same base-base plate. The process ends with termination of translational motion and

drawing tools from the base material. An important kinematic characteristic of FSW tool is that it always has a continuous rotational movement of the main and most often performed simultaneously on both translational extra movement, although it is possible to perform translational motion base plate with work pieces.

III. THE BASIC SHAPE OF THE WELDING TOOL

Because of the specific function and the purpose, the welding tool must have a geometric, metallurgical and chemical properties adapted to the shape, mechanical properties, metallurgy and chemical composition of the base metal, and the technological parameters of the welding process. The basic form of the tool is cylindrical in shape and consists of two main components:

- probe,
- shoulder.

Both parts are necessary for the successful formation of the welded joint, each in their own way. Wedge tool is usually cylindrical or conical in shape with the wedge height *h* which is equal to or slightly less than the thickness of the base material, while the diameter of the pin *d* should be approximately equal to that of the base material [5, 6]. If welding tool has a cone-shaped pin, cone angle tool is taken as the value of $\beta \leq 20°$. The pin has to initiate contact with metal, but also directly affects the formation of weld.

Shoulder is cylindrical part of the welding tool that "carries" a pin, and is used to connect all tools with clamping jaws of the machine. Diameter of the tool holder *D* is larger than the diameter *d* of the pin, in order to push out the pin material to the shoulder during the welding process to be shaped and aligned with the front surfaces of tool.

More advanced versions of the tools have a thread on the pin (Figure 2). They are used as metric threads, spherical, and of a special form. The purpose of the thread is to:

- increase the contact surface between welding tool and workpieces,
- influence the type of contact and contact pressure distribution between the tool and the base material (over point, line or area),
- increases the deformation of materials necessary for creating of a weld (stirring material),
- improving the movement of materials from workpieces (improved mixing),
- helps weld shaping,
- minimizes welding resistances.

There are welding tools with a constant pitch of thread *P*, while often changeable tread pitch is used. It is often used thread with left direction, especially if the rotation tool is done "to the right" - in the clockwise direction.

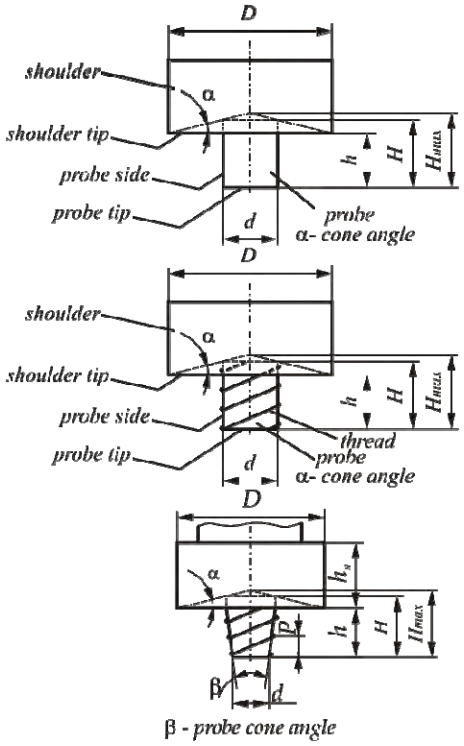


Figure 2 Shape of tools with threaded and tapered pin

There are many different designs of tool, but all agree with the basic shapes. There are structures with additional grooves on the wedge (Fig. 3), with a molded wedge forehead, with a cylindrical recess in the head carrier etc. There are structures that preclude the use of anvils because the controlling of resistance force is much simpler in such a design The use of appropriate design of tools affects the quality of welded joints to the same extent as the technological parameters of the welding process (rpm, travel rate, etc.).

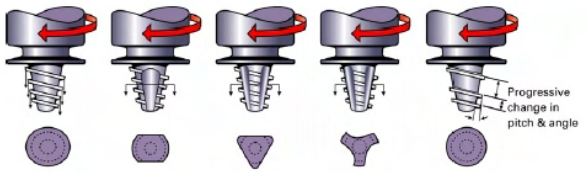


Figure 3. Shapes of the welding tool

IV. THE THEORY OF INVENTIVE PROBLEM SOLVING – TRIZ METHOD

During 1946 in the city of Baku (now Azerbaijan), a young Soviet officer, engineer and inventor Genrih Altschuller with his second coworker Rafael Schapiro began work on the methodology of solving inventive problems - TRIZ (Theory of inventive problem solving). Then and today, the ruling method of "trial and error" has become inefficient for the growing needs of technical and technological innovations.

Based on a thorough review of more than 200,000 patents from prestigious technical fields, they have developed a criterion for ranking the findings at 5 inventive levels of technical improvements up to scientific discovery. They pointed out the 40,000 patents and another higher level after the comprehensive analyzes - they have identified about 1,200 types of contradictions that are generated, couples than 39 technical parameters (e.g. if the product should increase the speed of vehicles -

engine mass increases, i.e. improving one parameter leads to a deterioration in the second) and 40 inventive principles which these contradictions overcome (e.g. segmentation, use of composite materials, etc.).

This is how the famous Altschuller matrix of contradictions has appeared, as a kind of knowledge base extracted from 40,000 high quality patents. Unlike methods which are improved by the classical method of trial and error principle (e.g. brain storming, morphologically blocks, etc.) that allowed inventors to generate more ideas, TRIZ methodology was based on the objective laws of the development of technical systems and has generated the objective ideas which are directed towards the ideal/optimal final solution and that may be valorized by the newly discovered objective criteria.

Due to Altshculler's arrest and referral to the gulag in Vorkuta (Western Siberia), the first paper [3] on the TRIZ of innovative creativity was published in the late 1956. year. In the following thirty years Altschuller has contributed more than 70 seminars throughout the former USSR. He opened the school's of science and technical creativity and their number in the 1980s grew to over 500. The development of TRIZ included hundreds of students, engineers, researchers and scientists.

Due to ignoring the economic laws and the absence of competition in the socialist economy of USSR, TRIZ is predominantly applied in research and development of military technology and space research programs. TRIZ methodology is experiencing flourishing after the collapse of the USSR when a large number of "TRIZ-ers" emigrated in the United States, the most developed countries of Western Europe, and the Far East Asia region.

Economic growth of many companies in South Korea (especially Samsung Corporation [4]), is credited to applying the methodology of TRIZ. There is no company, not listed in "Fortune 500" that uses no TRIZ principles. . Particularly in the USA, TRIZ has been embedded in many technological areas, including the election campaign, explicitly non technological area of life.

Basic concepts of modern TRIZ are:

- TRIZ – toward the invention,
- TRIZ – how to shape the future,
- TRIZ – goal tending way of thinking.

Modern TRIZ also includes:

- All systems are being developed to meet the specific function.
- There is no rule to come up with ideas and solutions. The basic rule is a particular way of thinking.
- All systems should provide some efficacy but in harmony with the environment.
- All systems are developed to be different from the existing ones. It is a fundamental requirement for improving the level and scope of application and solutions.
- Contradictions between incompatible characteristics and the need to overcome the orientation of the primary functions and technical problems.
- The solution of contradictions is an invention.
- The number of different types of contradictions is limited.
- The method for solving the contradiction can be obtained by analyzing inventions and patents.
- The method for solving the contradiction consists in thinking, imagination, intellect...
- The method for resolving contradictions can be applied to other methods for the development of complex technical systems.

V. ESTIMATION OF TECHNICAL CONTRADITCTIONS

To achieve a higher temperature (what is a prerequisite for successful welding by FSW) in hard materials, it is required to have a greater axial force, or higher power equipment. The first contradiction is the increased power. This contradiction leads to the necessity of major powers the new contradictions - higher volume of moving objects. The third contradiction in welding material of greater mechanical characteristics is the shorter tool lifespan. Thus, the next contradiction is reliability of the welding tool.

Table 1 is coming from the analysis of contradictions in the development of new FSW welding tool.

TABLE 1 AN OVERVIEW OF CONTRADICTIONS AND PRINCIPLES THAT ARE RECOMMENDED FOR THEIR ELIMINATION

Technical contradiction (with coordinates of the matrix)	**Recommended principles**	**Name of principle**
Improving 17: Temperature without damaging 10: Force (Intensity)	35	Parameter changes
	10	Preliminary action
	3	Local quality
	21	Skipping
Improving 17: Temperature without damaging 27: Reliability	19	Periodic action
	35	Parameter changes
	3	Local quality
	10	Preliminary action
Improving 10: Force (Intensity) without damaging 7: Volume of moving object	15	Dynamics
	12	Equipotentiality
	9	Preliminary anti-action
	37	Thermal expansion

A. Contradiction overcoming

1) Analysis of the principle:

35. Parameter changes

It is not a simple, for example, from a solid to a liquid state, but the transition to a "pseudo" or "quasi-state" ("quasi-liquid") and intermediate, for example, the use of elastic solids.

10. Preliminary action

- Perform, before it is needed, the required change of an object (either fully or partially).
- Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.

To apply the principle 10 means that new tools must be installed prior to welding work in its original position and set - pinched by necessary force. The new tool will have no standing as a conventional FSW welding above material, it will have a technological hole drilled in the plates, the tool is set to the operating position and pinched the necessary work force with bolted connections.

3. Local quality

- Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform.
- Make each part of an object function in conditions most suitable for its operation.
- Make each part of an object fulfill a different and useful function.

The welding tool in a conventional FSW process in the form of a monoblock - homogeneous structure. The new tool will be a non-homogeneous structure composed of multiple components that perform different functions. The new tool will have its own pin and a pin holder, except that, due to the necessity of setting up a working tool and its clamping position, the tool will have two shoulder, which will be on opposite sides of material to be welded.

21. Skipping

- Conduct a process , or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.

19. Periodic action

- Instead of continuous action, use periodic or pulsating actions.
- If an action is already periodic, change the periodic magnitude or frequency.
- Use pauses between impulses to perform a different action.

15. Dynamics

- Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
- **Divide an object into parts capable of movement relative to each other.**
- If an object (or process) is rigid or inflexible, make it movable or adaptive.

New detachable tool for the FSW welding must allow welding of parts of different thicknesses, and it will provide new tools designed of several parts that are installed in the operating position before welding.

12. The other way round

- In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field).

9. Preliminary anti-action

- If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.
- Create beforehand stresses in an object that will oppose known undesirable working stresses later on.

Placing the tool in the initial working position will be provided with the necessary clamping force which is necessary for the realization of friction at the contact of two f tools and materials to be welded and the contact pins and materials. Necessary force tightening will be achieved by bolted connection.

37. Thermal expansion

- Use thermal expansion (or contraction) of materials.
- If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.

Application of this principle gives a welding tool that will be more efficient for welding of material of higher strength and more universal - possibility of welding different thicknesses.

TRIZ methodology used towards a new tool whose structure is differently from the construction of tools for the "classic" way of FSW, and thus the new way FSW is different from the "classic" FSW. The application of new tools requires pre-drill holes in the parts to be welded, then setting the tightening of the tool, which enables the necessary force of friction due to the physical nature of FSW process. Also, the tightening of the tool holder in the machine used for the FSW welding is needed. Unlike traditional FSW welding method, when using this tool is not required base plate. The new tool, heat is generated and the bottom and the top of the plates that are welded. The initial position of the new FSW tool is shown in Figure 4

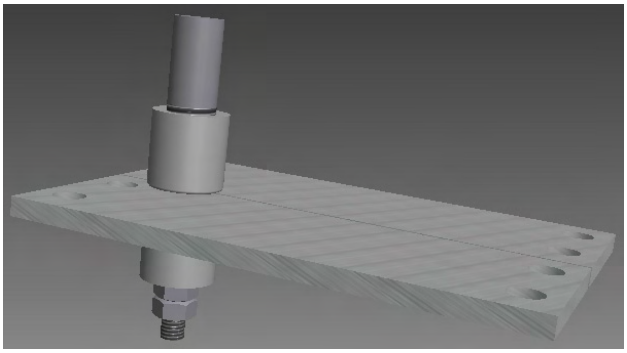


Figure 4 Position of the novel welding tool at the beginning of the FSW

TRIZ methodology provided the tools in four variants shown in Table 2 All design tools are prefabricated with 2 tool holders in which or through which the mandrel is mounted and fixed by bolts. For each offered variant pin on the bottom secures the nut and provides the self-loosening by a nut and a spring washer. It is essential that during the entire process of welding fastening force is constant with intensity defined welding technology (WPS), which influences the friction between tools and materials to be welded. Therefore the heat that is generated in this area in a controlled manner. Offered variants of tools differ in the decision fixing or clamping tool holder and the second part of the pin.

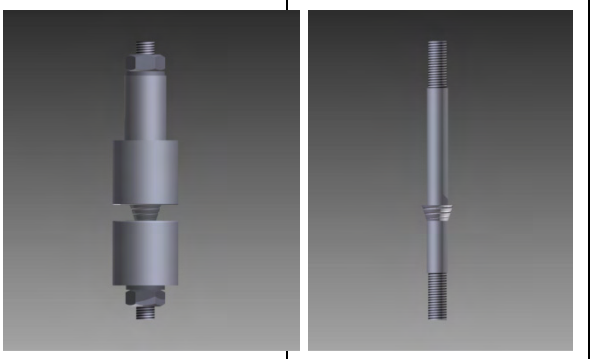
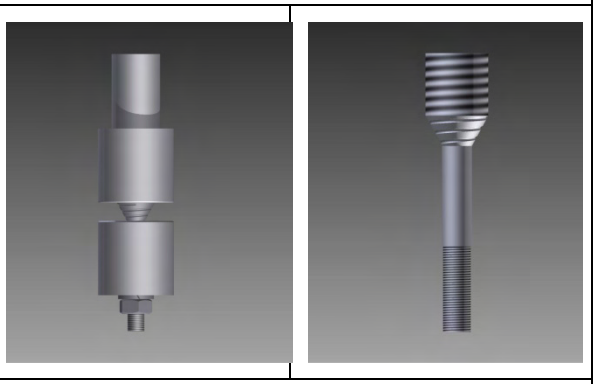
In variant 1: the pin is on the top tool carrier attaches via nuts and spring washers, taking into account the dimensions of the nuts are smaller than the diameter of tool holders, clamped by the jaws of the machine.

In variant 2 the role of a nut is given to the shoulder. It is very important for these variants to know the direction of rotation of the used machine (milling machine, lathe machine, or special welding FSW) and the direction of the thread (left or right).

In variant 3 the body of the tool is as a monoblock, which is partly due to the realization of thread-bolted connections (achieving the necessary clamping force). It is very important with these variants to take into account the direction of rotation of the head machine screw and direction (left or right).

In variant 4 pin is made equal to the tool body and the upper shoulder. Necessary force/torque is achieved through bolted connection pin and the frame on the bottom.

TABLE 2 VARIANTS OF THE WELDING TOOLS GENERATION WITH TRIZ METHODOLOGY

VARIANT 1

VARIANT 2

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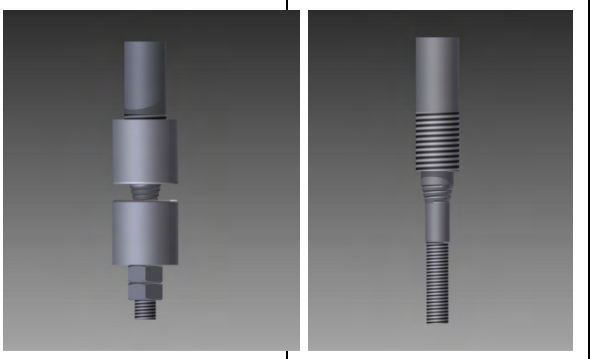
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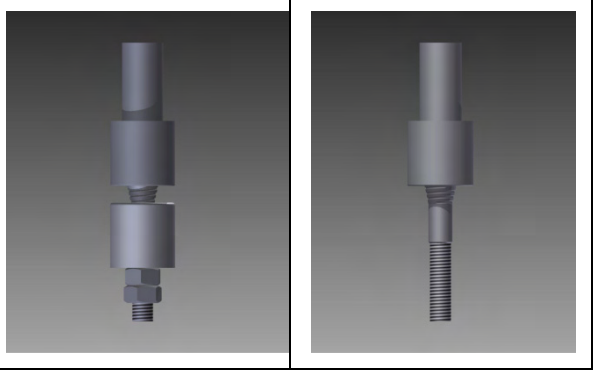

The conceptual design phase in which the TRIZ methodology is used to generate variants of FSW tool has given four possible variants tools Conceptual design phase ends with the choice of variants.

After selection of variants, tools are accessed for implementation - the final formatting of the tools. At this stage, the material of welding tool s is selected. Reviewing past researches, as a starting material tool was adopted X155CrMoV12-1, which was used for welding of copper and brass [6-8].

After the adoption of the tool material, it is necessary to define the diameter of the shoulder and pin. Bolted connection which fixes shoulder and the probe has to be calculated taking into account the temperature cross flow conditions are achieved during welding. Prototypes of all varieties of tools and experimental testing will be carried out tools and based on that we will opt for the best solution tools.

VI. CONCLUSIONS

The process of FSW is one of the newest welding processes. This procedure is routinely used, especially in situations where no conventional welding method gives satisfactory results. It is mostly applied in the welding of the materials such as aluminum and its alloys, austenitic stainless steels, titanium, non-metal materials, etc. FSW welding process is a typical example of the use of indirect methods of generating heat by friction, where the friction to generate heat using a tool consisting of the - shoulder and tool pin on which is usually sliced left-hand thread.

The problem of application of conventional FSW tools occurred in welding dissimilar materials with different mechanical properties. It has caused the need to develop new tools. For the development of a new concept of FSW tool was used TRIZ methodology. Based on the results obtained by applying TRIZ methods are 4 versions of the new tools for FSW welding. All design tools are prefabricated with 2 tool holders in which or through which the pin is mounted and fixed by bolts. New concept tools require different; FSW welding process:

- Plates must be welded to the thigh, but not necessary because the base plate with a new tool generating heat by friction between a bearer of tools and materials, and the bottom.
- The materials to be welded must have a technological hole.
- The tool must be tightened by bolts - tightening force which is defined by the welding technology.

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