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## Overview of the mean of production used for FSW

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**Abstract:** The Friction Stir welding process is now introduced in production plants. More and more applications are developed and the most part of the work is now centered on the mean of production to be used. Institut de Soudure and Arts et Métiers ParisTech are working on this subject since mid of 2005. The results of this work is a recognize knowledge on the methodology for qualifying a Friction Stir Welding Equipment [1]. In the same time, and based on this work, Institut de Soudure has bought a new kind of Friction Stir Welding machine based on a KUKA Robot.

### 1. Introduction

The main advantages of friction stir welding (FSW) lie in the fact that it is a solid state welding process [2]. This particularity gives it the availability to weld almost all types of aluminum alloys, even the one classified as non-weldable by fusion welding due to hot cracking and poor solidification microstructure in the fusion zone [3].

To perform FSW, a non-consumable rotating tool, made up of a shoulder and a pin, is inserted into the interface of two workpieces rigidly clamped. Once the shoulder in contact with the surface's workpieces, a constant down force is applied on the tool and is moved along the joint line, bounding the workpieces together. The thermo-mechanical tool/material interactions generate high forces during the welding operation [4] [5]. The welding equipment must be rigid enough to satisfy them [6]. Furthermore, the machine should be able to weld complex joint geometry to offer a wide range of applications. So, to produce industrial weld, special dedicated machine were developed. These kinds of equipments, as not standard, are generally expensive. Therefore, the industrials are reluctant to adopt this new technology.

The objective of this research work is the industrialization of the friction stir welding process in order to provide tools to industrials to select and qualify a machine for their FSW applications. The industrialization can be split into three aspects the analysis of the product, the process and the resources, these three entities being in interactions.

This paper presents a methodology to determine the Friction Stir Welding equipment adequate to an application. The adequate equipment can be every machine that can perform friction stir welds. Therefore, this paper presents a short review, based on literature survey, of the existing friction stir welding equipments.

### 2. The existing friction stir equipment

Today, the machine commonly used to perform FSW, industrially and in laboratories, are dedicated FSW machine, modified milling machine, serial and parallel kinematics robots.

#### a. *Modified milling machine*

Milling and FSW machine have the same general characteristics [7], spindle rotation, travel speed and CNC control process necessary to perform FSW welds. They generally offer high stiffness and a good accuracy. The biggest disadvantage of most the milling machine is unavailability to propose a force controlled operation [5]. But, new milling machines technologies can offer a force controlled process.

b. *FSW dedicated machine*

FSW dedicated machine allows a force control operation and generally the possibility to weld with the three tool technologies, conventional, retracting and bobbin tool. Each machine is designed to weld, 2- or 3-dimensional and has a predefined workspace. The main advantages of these machines are their high payload capacity due to high framework stiffness. They generally offer large workspace. The disadvantages of this kind of equipment is its high investments cost and the poor accessibility of the tool.

c. *Parallel and serial kinematics robot*

FSW on Tricept 805 robot has been developed by GKSS research centre. This kind of machine is commonly used for high speed milling applications [8]. Tricept robots are characterized by high stiffness and to assure good position accuracy [6]. This kind of equipment possesses high investments costs and small workspace due to its design [9]. These two characteristics are major obstacles to widespread its industrial used for FSW.

Modern industrial serial robots (Figure 1) ensure flexibility, multidimensionality and lower investments cost than dedicated FSW machine [10]. They also possess a highly developed user interface for rapid programming [9]. Their disadvantage is their lack of force / load capacity due to their lack of stiffness [4] [10]. Therefore, to assure the robot welding capabilities and provide a wide range of applications, the robot must be a high payload robot [4]. Furthermore, the robot must be force controlled during the operation; its stiffness doesn't allow a position control [11]. Furthermore, their lack of stiffness involves the deviation of the tool according to the seam [10] [12]. Despite these two disadvantages, the industrial robot seems to be a good FSW mean of production. The different publications on the robotic FSW, [4] to [10] show a real development improvement and a real potential for industrial applications. They appear to be a good compromise between complex weld geometry, range of applications, workspace and investments costs.



Figure 1: Serial kinematic robot for FSW application

### 3. Presentation of the developed methodology

The proposed methodology is based on a global and a local approach (see figure 2). The last one consists of an analysis of the FSW process. It corresponds to the determining of the value of the driving parameters of the FSW process in order to obtain a weld satisfying its functional specifications.

These parameters are:

- The position and the orientation of the tool relative to the seam. Precisely, they correspond to the distance between tool axes and the seam and two angles determining the orientation of the tool relative to the vector normal of the work pieces and the vector tangent of the seam.
- The rotation speed and the travel speed of the tool.
- The down force applied by the tool on the material.

In order to qualify a mean of production it is necessary to determine the tolerances associated to each parameter. Concerning the three main driving parameters, the admissible variations are defined by the process windows.

The tolerances concerning the position and the orientation of the tool relative to the weld seam are important characteristics for serial kinematics robots. These tolerances are also linked to the tolerances for the design of the workpiece work-holding device and the manufacturing of the workpieces to be welded.

The tool/material mechanical interactions depend on the processing parameters. So, for parameters of process windows, it is necessary to associate the welding forces and torque generated during the whole welding operation. The description of the tool/workpiece mechanical interactions is discussed in the next part.

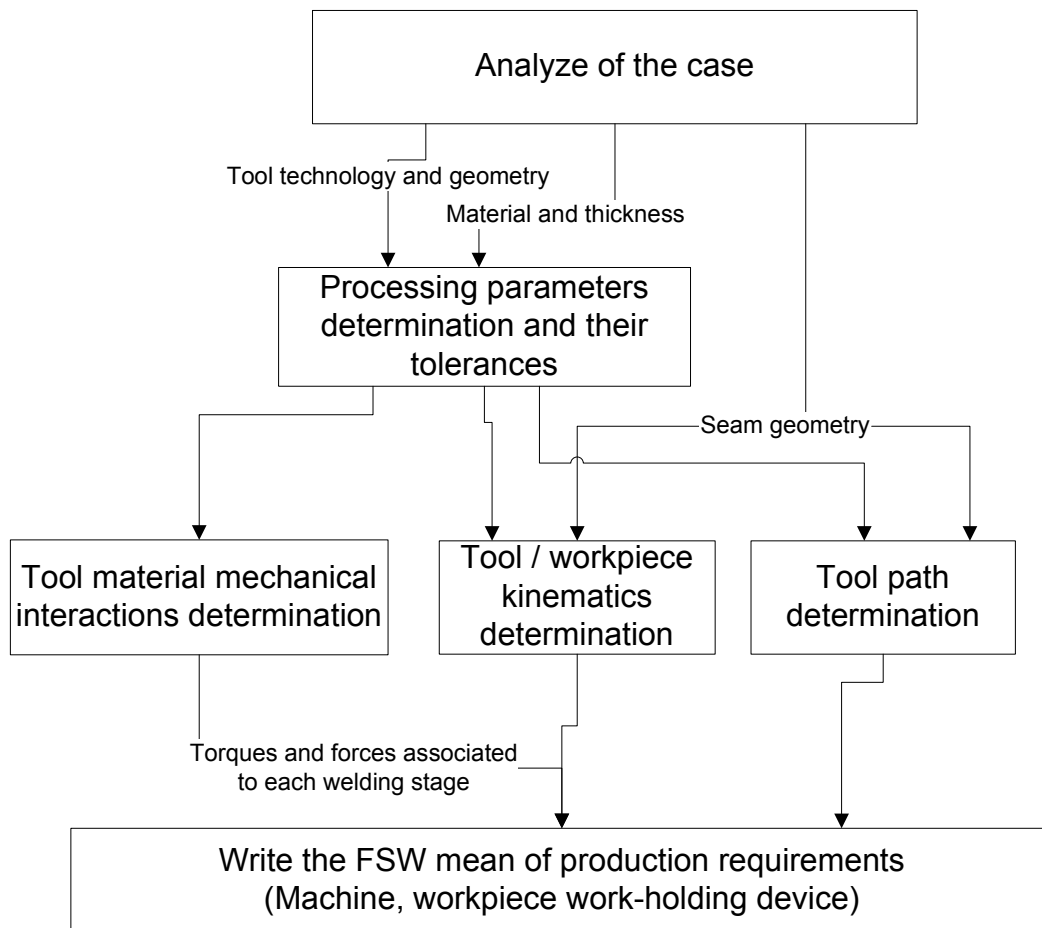


Figure 2: Scheme of the methodology used to define the FSW means of production requirements

The global analyze of the welding operation consists in determining the geometry of the weld path. At each point of the seam a local reference frame  $R_{Mi} (M_i, t_i, v_i, n_i)$  is defined (Figure 3). The vector  $t_i$  is tangent to the seam line,  $\mathcal{L}$ , and oriented according to the welding direction. The vector  $n_i$  is normal to

the plane tangent to the workpiece welded surfaces. The third vector  $v_i$  is chosen in order to form an orthonormal reference frame.

The determination of the processing parameters and the weld seam allows the definition of the complete tool path (see figure 3).

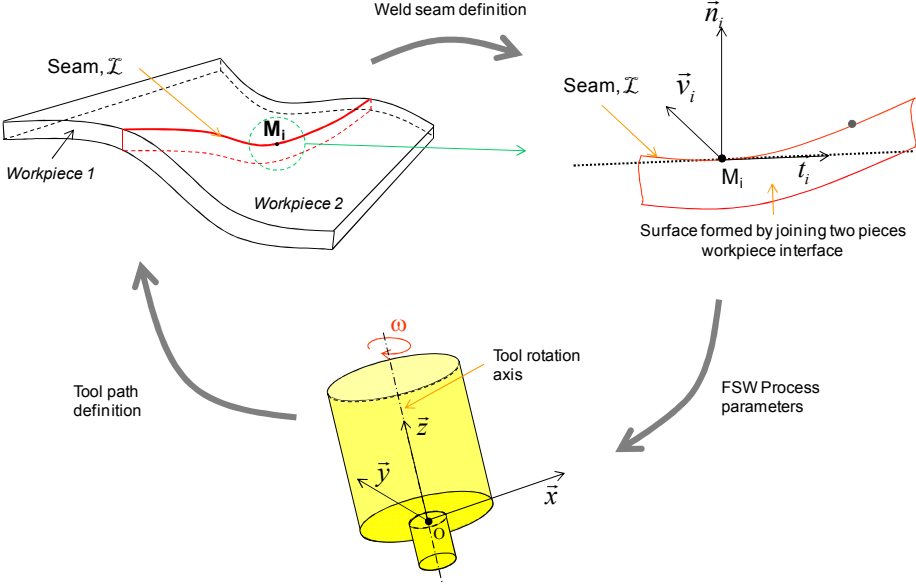


Figure 3: Definition to the tool position and orientation at each location of the welding path

4. Description of the tool/workpieces mechanical interactions

Generally the FSW operation is described by two main stages, the plunge and the welding stages [13] and [14]. As the tool - workpiece interactions differ according to the welding stage, it is necessary to decompose the whole welding stages. So, the tool kinematics was analyzed leading to the decomposition of the welding stages into six independent sub-stages: plunging, dwell time, acceleration, welding at constant speed, deceleration and pin retracting. The figure 4 presents the tool kinematics and the corresponding stages during FSW.

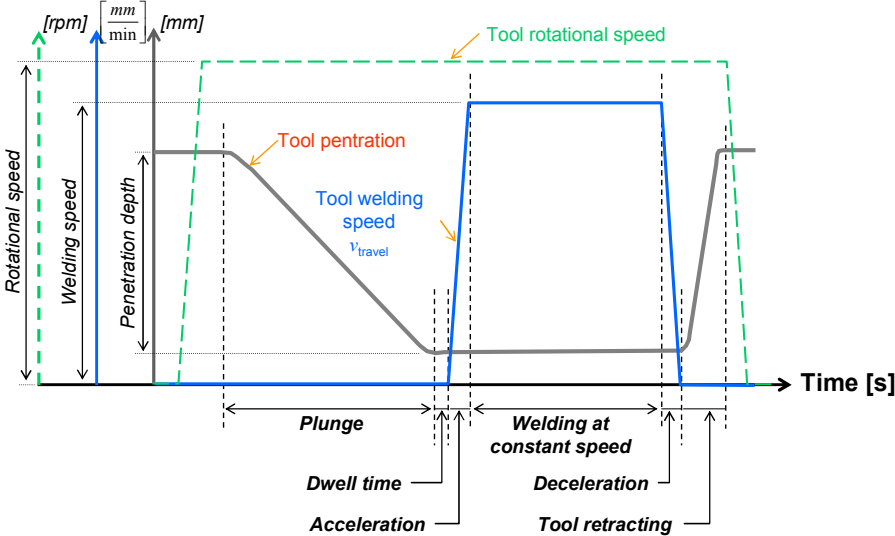


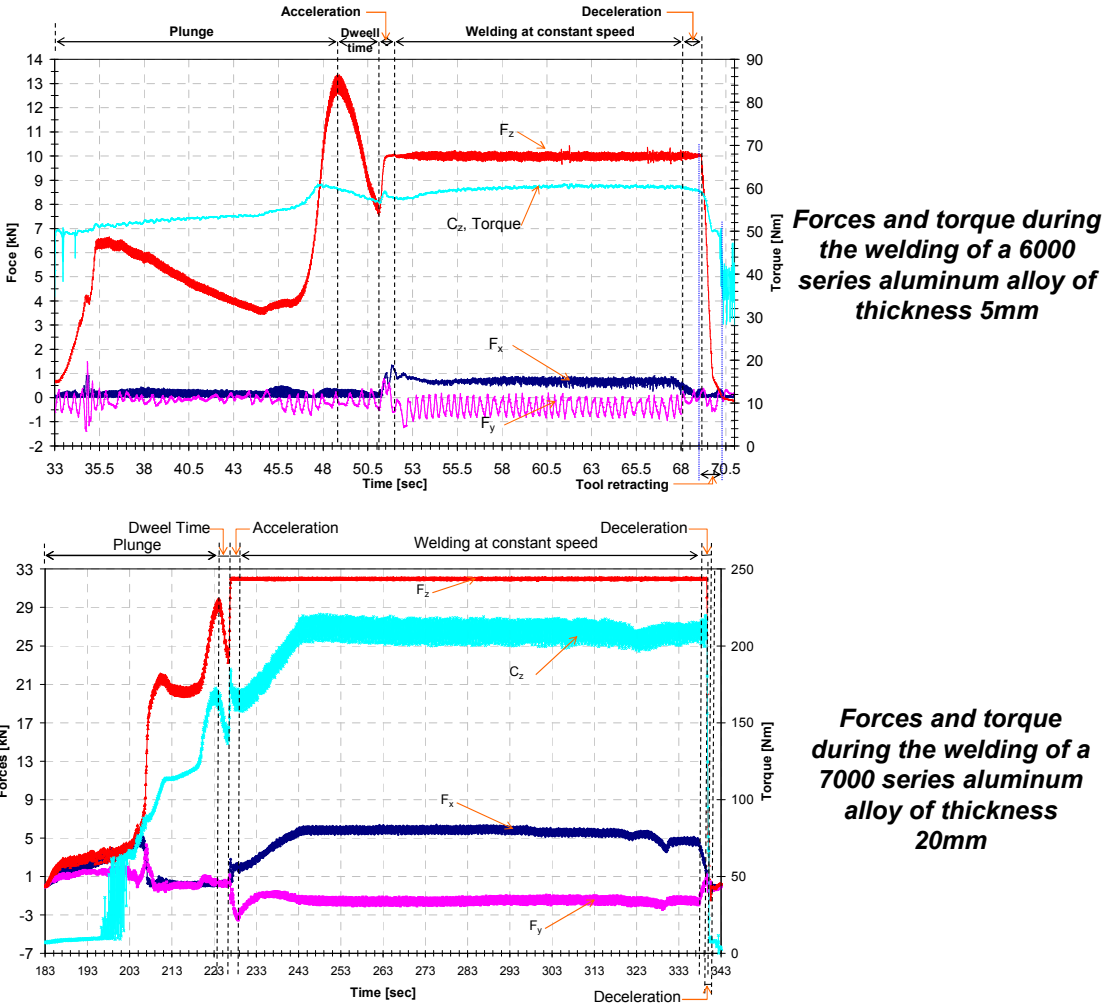
Figure 4: Presentation of the tool kinematics during the welding stage

Former research works [1] showed that the analyses of the tool/workpiece mechanical interactions can be reduced to the analysis of the plunging and welding at constant speed stages for the qualification of a FSW means of production and the workpiece work-holding device.

According [14] and [15], the plunging stage is characterized by a brief peak of the vertical effort, when the shoulder comes into contact with the surface. The “peak” intensity mainly depends on the penetration velocity [15]. The maximal torque and force are obtained almost simultaneously, at the end of the penetration. In the last 25% remaining penetration, probably when the shoulder touches material displaced upwards by the pin penetration, the curves of the torque and force grow more rapidly until they reach a “peak”. That maximum occurs at the end of the plunge, when the tool shoulder is completely in contact with the plate’s surfaces.

The welding stage is force controlled; the down force  $F_z$  remains constant. After increasing during the acceleration stage, the travel force and transverse force seems to stabilize. The torque also stabilizes after a few seconds.

Figure 5 shows evolutions of the tool/workpiece mechanical interactions components for to applications.



**Figure 5: Forces and torque during the welding operation according to the time for different aluminium alloys and thicknesses**

The mechanical interactions between the tool and the welded material can be represented by two set of force and torque corresponding to:

- The maximum torque and force reached at the end of the plunge.
- The “stabilized” torque and forces (down force, travel and transverse forces) reached during the welding stage.

This knowledge will permit to focus on these two stages processing parameters in order to reduce the forces and torque applied on the tool. Thus, it will enable the FSW on machine with load / rigidity weaknesses. On the other hand, another way to reduce the process forces is to work on the tool geometry [14].

## 5. Conclusion and perspectives

The presented work focuses on the definition of the functional specification for the choice and/or the design of a FSW machine and the work-holding device. In the case of the use of a low-stiffness machine like serial kinematics robot, the evaluation of the tolerances concerning the position and the orientation of the tool can be a very determinant factor.

Contrary to conventional welding fusion process (GMAW or Laser Welding) mechanical interactions between the tool and the material have to be taken into account. They have to be taken into account for the determination of the forces and torques the FSW machine must apply during the welding operation.

Moreover, thanks a machine stiffness model, it is possible to estimate the tool deviation from the seam in order to compare it to the one admissible by the welding process. It validates the feasibility of the welding operation. The presented methodology must also include the workpieces work-holding device. The applied methodology must be completed by the study of the tool accessibility on the seam and the workpieces assembly and disassembly from the work-holding device. This kind of methodology is commonly used in machining process.

The process windows can be restricted by:

- The machines characteristics in terms of down force, rotational speed and travel speed.
- The tool deviation due to a lack of stiffness of the machine.
- The machine workspace or its lack of accessibility.

For certain types of machine, like serial kinematics robot, the force capacities and the stiffness depend on the tool position inside the workspace. Then the process windows is not directly restricted by the seam accessibility but by the fact that it is not possible to keep the required stiffness throughout the welding path.

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