Friction drilling, form tapping and rotary broaching for fast joining technologies

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1. Introduction

Joining of two dissimilar materials is an important technology requirement in various industrial sectors.

In order to elaborate technological solutions for such joining purposes in the industry, the project by the title "A rapid joint by alternative processes", acronym J-FAST was proposed in the frame of the Manunet Program, by several partners of the Basque Country of Spain and Romania. This project is currently on the run in both countries.

The J-FAST project aims to develop new technologies mainly based on friction and forming processes [1-11], to enhance the unions between dissimilar materials. These unions are common in industrial sectors such as manufacturing of appliances, automotive industry or power generation. Form processes have become increasingly important because they reduce the need for further processing, because these processes can make joints without nuts.

For instance, joining steel and aluminium is needed for applications in automotive industry for car chassis and bodies. In such combinations, steel plays the role of structure frame that supports the loads, to avoid large strains. On the other hand, aluminium plays the role of the skin element, for corrosion protection.

Joined parts of copper and aluminium are needed in the electric power generation for distribution bars and various connections, in order to reduce the consumption of copper.

Within this project, the partners intend to expand these form processes to a number of materials and applications, with the aim that the produced parts will be able to match and exceed the performance of conventional elements. Thus, the project should lead to new added products on different industrial areas (joining of sheets in cars and appliances, respectively plates in electric power generation, etc.). Besides, these are clean processes that do not need lubricants and do not generate chip.

Another alternative process is Friction Stir Welding (FSW) [12-18], as a relatively new and attractive technique to the scientific world, which in recent years has generated high interest among industrial producers, especially those in the fields of naval, aircraft, space and land transportation. This process is investigated by the Romanian partners, for comparison with the mentioned ones.

This article presents some concerns and data used by the authors in the programs of experiments, as well as analysis of the technical characteristics of the joints obtained with the mentioned alternative processes.

2. Friction drilling

Friction or form drilling (FD) process [1-5] is a non-conventional process to make holes on metal sheets. It is an alternative process, compared to conventional drilling. It is based on the material flow, by using the heat caused by the friction of a conical shape rotary tool without cutting edges. The FD tool has two different sections: a conical surface that penetrates the hole and softens the sheet material and a cylindrical segment that produces the final hole diameter. As a result, a significant burr appears at the hole exit, the so-called cup. Burrs are undesirable in common machining operations, because they reduce machined part quality. But FD takes advantage of burrs, as they produce the cup that eliminates the need of using a nut in the joint, since threading is applied on the cup inner surface.

Experiments have been performed on two dissimilar joint types in the frame of the project J-FAST [1]:

***Case A*:** square-section tubes (30 mm x 30 mm) of AISI 1045 and sheets of Al 5754 (thickness = 1.5 mm).

Case B: square-section tubes (30 mm x 30 mm) of stainless steel AISI 304 and sheets of Al 5754 (thickness = 1.5 mm).

The mentioned tubes, sheets, the fixture and the specific tool used in the experiments are shown separately in the Figure 1.

Regarding friction drilling tools, in all the cases, carbide tools (90% WC and grain size 1 micron), Ø7.3 mm were employed for achieving M8x1.25. The main geometrical sizes are presented in the Figure 2, where: h_s = 15 mm, $Ø_s$ = 8 mm, h_l = 5.4 mm, $Ø_c$ = 7.3 mm, h_n = 7.6 mm, h_c = 0.9 mm, β = 40°, α = 90°.

The clamping fixture for the experiments is shown in the Figure 3.

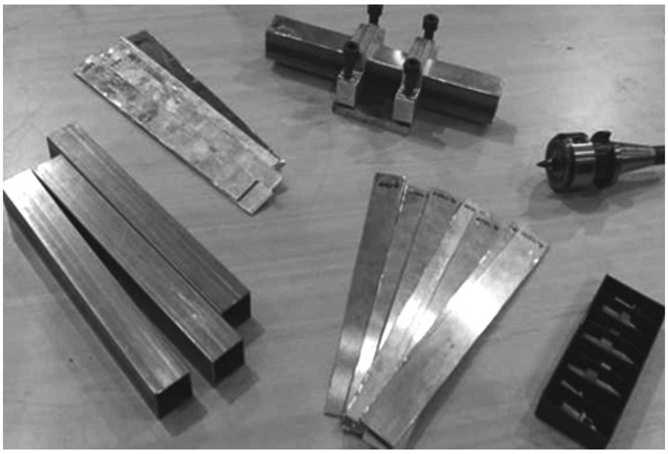

Figure 1. Workpieces: sheets, tubes and clamping adaptor.

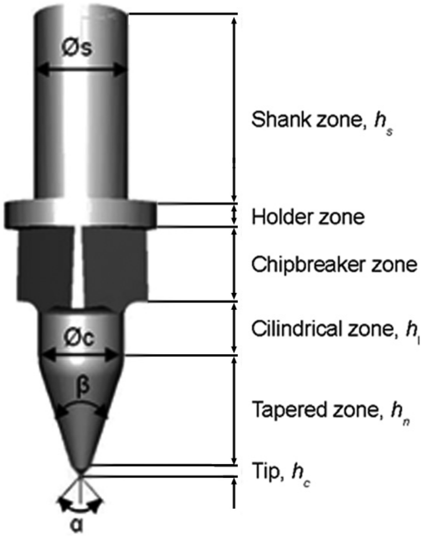

Figure 2. Friction drilling tool.

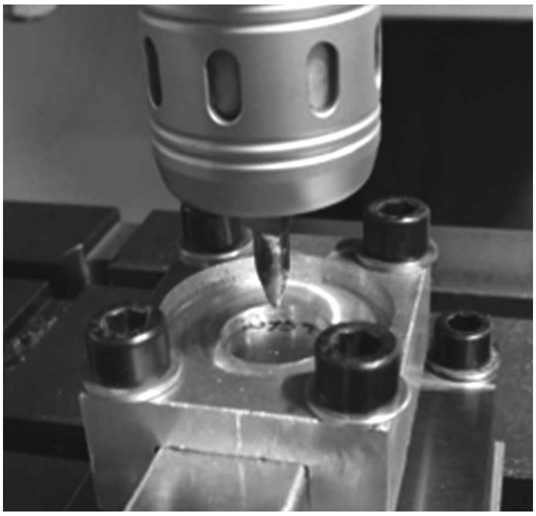

Figure 3. Detail of the clamping fixture [1].

3. Form tapping

Subsequently, the hole needs to be threaded by form tapping [1, 6-11]. Regarding the tool, taps have often polygonal geometries with at least five lobes. Taps are often made of HSS coated with titanium nitride (TiN) to provide a core with enough toughness, but harder surface. In some cases, anti-friction coatings or internal lubrication are advisable. Also, they may include tapered cutting edges with smaller diameter to initiate the material removal. According to the hole machined with the Ø7.3 mm form tool, a form tap (Emuge©) for M8 was selected.

In form tapping, the maximum depth of the thread and the maximum thread pitch are the most important parameters (Figure 4). A form tapping is characterized by:

1) the entrance zone, at the tool tip, which is a tapered geometry where the lobes progressively rise the nominal diameter (ISO 8830);

2) the cylindrical part, which acts as a supporting system, guiding the tap during threading operation.

The maximum depth of thread is significantly higher than in the case of conventional threading (cutting) tools, being limited by the quality of the coolant and the tool length. The maximum pitch of the thread depends on the material properties of the workpiece. The upper limit is often below 3.5 mm. Indeed, not all the materials are suitable for form tapping; due to the intrinsic deformation involved, the material should have a minimum ductility (minimum failure resistance at 5%) and should not exceed a maximum mechanical resistance of 1,400 N/mm^2.

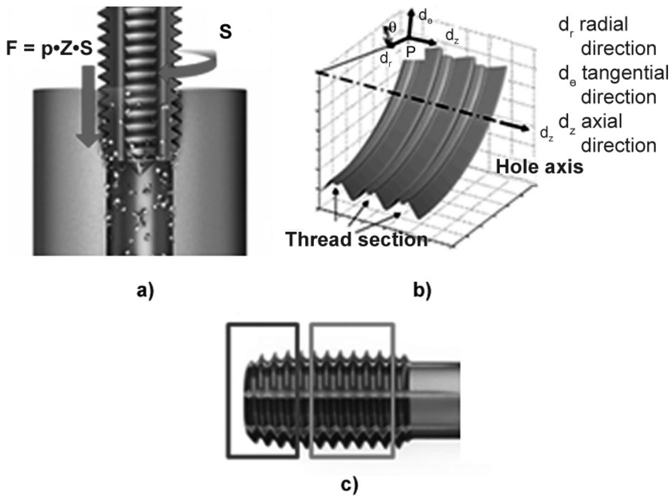

Figure 4. Cutting and geometrical parameters in form tapping [1]; a. Thread operation; b. Thread section; c. Geometry of a tap.

Another important aspect is the influence of the pre-machining diameter. Too small diameters will lead to excessive rolling phenomena and forces during the process. Inversely, if this diameter is too large, the core section is not enough rolled and the core diameter will be too small.

Regarding to possible changes in the material, due to deformation mechanisms, work hardening may arise too in the affected zone. This phenomenon is accentuated the greater the wear. Additionally, since there is crushing and deformation, internal compressive stresses appear which are advantageous to enhance the mechanical resistance of the thread.

As in the previous section, a test series was designed to select the most suitable process parameters for consistent thread through holes generated by drilling, followed by trials of rolling friction. To do this, the same clamping system used for form drilling was employed (Figure 5).

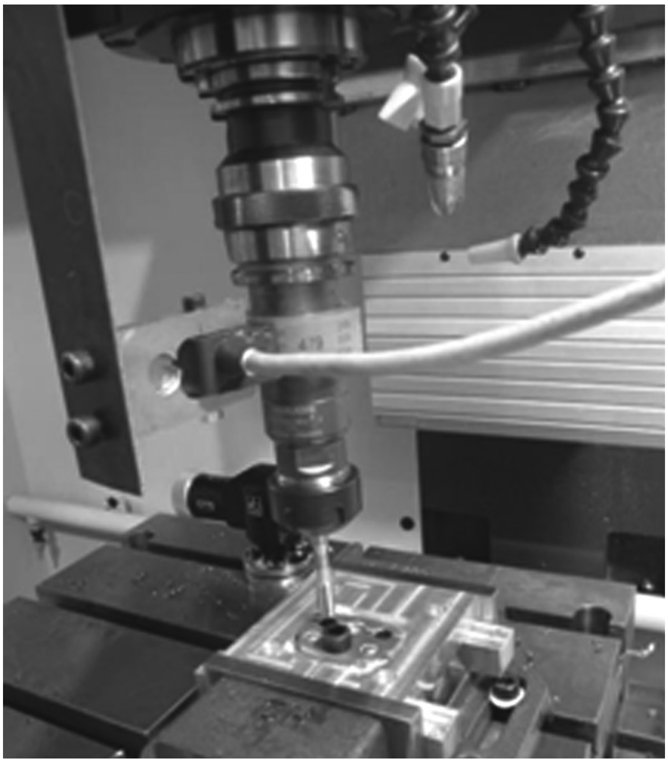

Figure 5. Form tapping in Kondia© A6 machining centre [1].

4. Rotary broaching

Three different grades of high speed steel (AISI designations: ASP 2052, M2 and T15), as well as a tungsten carbide have been chosen for the comparison in cutting tests by rotary broaching [1]. They are all supplied by the same manufacturer, Somma Tools, what reduces uncertainty.

In the table 1, the materials of the investigated broaches are presented with their most relevant physical properties.

In the Figure 6, the typical shape of the experimented broaches is shown.

a. Steel ASP 2052

The quality ASP 2052 refers to high speed steel (HSS) with high content of W, designed specifically for high demands. European designation: HS 10-2-5-8.

Figure 6. Typical shape of the used broach.

The main advantage from using ASP 2052 quality is that it is capable of performing various processes, such as broaching, milling, plastic forming, welding, electrical discharge machining etc. One important property is that it has a good aptitude to be coated by PVD (Physical Vapor Deposition) or CVD (Chemical Vapor Deposition), as well as for nitriding.

In a macro hardness test performed on the ASP 2052 broach (Rockwell C scale), the following values have been obtained:

- Hardness of brush (broach) ASP/1: 66.5 HRC
- Hardness of brush (broach) ASP/2 coat: 65.7 HRC.

b. Steel M2

The quality M2 refers to a fairly high speed steel alloy. European designation:

HS 6-5-2.

The tests were conducted with two broaches of this quality: uncoated (M2/1), respectively coated with CVD (M2/2).

From the hardness measurements the following results have been obtained:

- Broach Hardness M2/1: 64.4 HRC
- Broach Hardness M2/2 Coat: 64.5 HRC

c. Steel T15

The quality T15 refers to a fast (HSS) steel highly alloyed with tungsten (W). European designation: HS 12-0-5-5.

Table 1. Materials of the broach.

Category	Broach material	Characteristics	Temperature		
			20ºC	400ºC	600ºC
a	High Speed Steel ASP 2052, European designation: HS 10-2-5-8	Density [g/cm^3]	8.2	8.1	8.1
		Elasticity modulus E [kN/mm^2]	245	218	196
		Thermal expansion [/ ºC]	-	11.2 e^{-6}	11.7 e^{-6}
b	High Speed Steel alloy M2, European designation: HS 6-5-2	Density [g/cm^3]	8.1	8.1	8.0
		Elasticity modulus E [kN/mm^2]	225	200	180
		Thermal expansion [/ ºC]	-	12.1 e^{-6}	12.6 e^{-6}
c	High Speed Steel alloyed with tungsten (W), T15, European designation: HS 12-0-5-5	Density [g/cm^3]	8.3	8.03	8.03
		Elasticity modulus E [kN/mm^2]	248	248	193
		Thermal expansion [/ ºC]	-	6.2 e^{-6}	6.5 e^{-6}
d	Pure tungsten carbide, referenced as 88 WC 12Co	88% Tungsten Carbide; 12% Cobalt	-	-	-
		Hardness: outside Rockwell C scale	-	-	-
		Working temperature: max. 500ºC	-	-	-

Three types of broaches were used: simple, other CVD coated and another simple, where difference was the geometry of the edges. They will be referred as T15/1, T15/2 and WSWB-25A, respectively. The tool designated WSWB-25A comes from Wylcut manufacturer.

In the Figure 7, a comparison between cutting edges of ASP/1 and WSWB-25A broaches is illustrated.

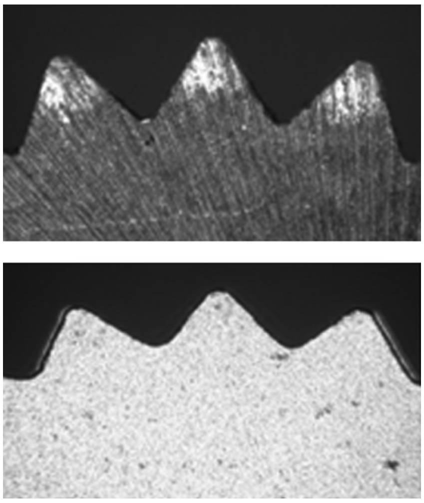

Figure 7. Comparison between cutting edges from ASP/1 and WSWB-25A.

The hardness measurements have given the following results:
- Hardness for T15/1: 66.2 HRC
- Hardness for T15/2 Coated: 66.1 HRC
- Hardness for WSWB-25th: 63.8 HRC

d. Tungsten carbide

Finally, pure Tungsten carbide with 12% Cobalt is used. This material is referenced as 88 WC 12Co, made of sintered powder. The purpose of this material is to have a material suitable for cutting to hold good wear, due to its high hardness (outside Rockwell C scale). The working temperature must be less than or equal to 500ºC.

Geometry

The geometry of the tool is presented in the Figure 8.

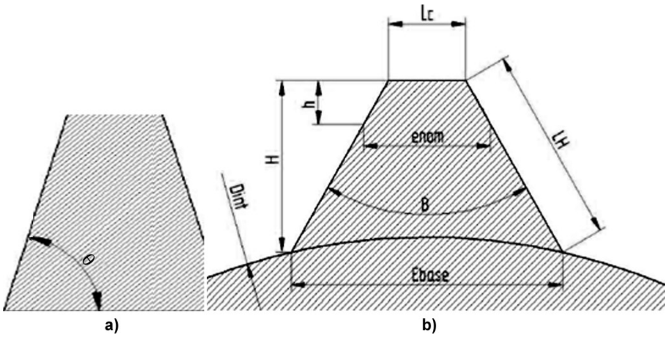

Figure 8. Geometry of the tool: a. Angle between rake and flank face; b. General dimensions for a cutting tooth.

For comparison purposes, the aspects to be analyzed are divided into angle measurements and longitudinal measurements. The most significant lengths considered are: Length of the flank face (designated as Lc); edge height (designated H); base thickness of blade (designated Ebase).

The experimental setup, including the special toolholder between tool and machine spindle is illustrated in the Figure 9.

Some examples of holes after the broaching process are presented in the Figure 10.

Figure 9. Experimental setup with special toolholder between tool and machine spindle [1].

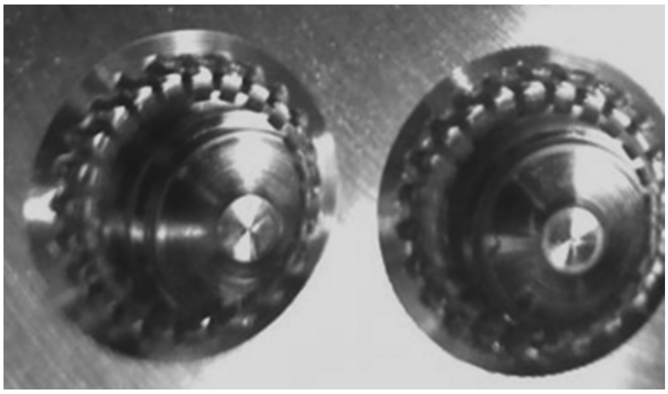

Figure 10. Holes after the broaching process [1].

The quality of the holes machining must be emphasized, as rotary broching is a specific process for calibration of holes.

5. Conclusions

The alternative processes approached in the project J-FAST are proposed for increasing the productivity in industrial large scale technologies.

Experiments on friction or form drilling have been performed on two dissimilar joint types: square-section tubes (30 mm x 30 mm) of AISI 1045 and sheets of Al 5754 (thickness = 1.5 mm); square-section tubes (30 mm x 30 mm) of stainless steel AISI 304 and sheets of Al 5754 (thickness = 1.5 mm). For the friction drilling tools, carbide tools (90% WC and grain size 1 micron), Ø7.3 mm were employed to achieve M8x1.25 thread.

According to the hole machined with the Ø7.3mm form drilling tool, a form tap for M8 was selected, to machine the thread. In form tapping, the maximum depth of the thread and the maximum thread pitch are the most important parameters. A form tapping is characterized, according to ISO 8830, by the entrance zone and the cylindrical part. The maximum pitch of the thread is often below 3.5 mm. The material should have a minimum ductility (minimum failure resistance at 5%) and should not exceed a maximum mechanical resistance of 1,400 N/mm^2.

For rotary broaching, three different grades of high speed steel (AISI designations: ASP 2052, M2 and T15, respectively European designations: HS 10-2-5-8, HS 6-5-2 and HS 12-0-5-5), as well as a tungsten carbide have been used, for the comparison of tests. The broaches made of these steels have the elasticity modulus in the range 225 – 248 kN/mm^2 at 20ºC, respectively 200 – 248 kN/mm^2 at 400ºC and 180 – 196 kN mm^2 at 600ºC. The hardness measured is in the range 63.8 – 66.5 HRC. The broaches made of sintered powder of tungsten carbide (88%WC, 12%Co) hold good wear due to their high hardness (outside Rockwell C scale). The working temperature is up to 500ºC. The geometry of the tool is presented with the most significant sizes: length of the flank face; edge height; base thickness of blade. An experimental setup for rotary broaching is shown, with an example of holes calibrated by broaching.

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