

Characterization of Flow Drill Screwdriving Process Parameters on Joint Quality

Jamie Skovron, Laine Mears, and Durul Ulutan
Clemson University

Duane Detwiler and Daniel Paolini
Honda R & D Americas Inc.

Boris Baeumler
DEPRAG Inc.

Laurence Claus
EJOT GmbH

ABSTRACT

A state of the art proprietary method for aluminum-to-aluminum joining in the automotive industry is Resistance Spot Welding. However, with spot welding (1) structural performance of the joint may be degraded through heat-affected zones created by the high temperature thermal joining process, (2) achieving the double-sided access necessary for the spot welding electrodes may limit design flexibility, and (3) variability with welds leads to production inconsistencies. Self-piercing rivets have been used before; however they require different rivet/die combinations depending on the material being joined, which adds to process complexity. In recent years the introductions of screw products that combine the technologies of *friction drilling* and *thread forming* have entered the market. These types of screw products do not have these access limitations as through-part connections are formed by one-sided access using a thermo-mechanical flow screwdriving process with minimal heat. The friction drilling, thread forming process, hereto referred to as "FDS," is an automated continuous process that allows multi-material joining by utilizing a screw as both the tool and the fastener. The process uses the friction caused by the rotating screw to pierce and extrude the material. Threads are then created in this formed extrusion which allows the fastener to be screwdriven into the parts. A final torquing then securely clamps together the sheets of material. This study explores the quality design space as represented by resultant joint geometry as a function of the critical process parameters of fastener force and drilling speed. Feasible design space regions are explored to determine how process parameters affect joint geometry, and strength testing performed to validate the findings.

CITATION: Skovron, J., Mears, L., Ulutan, D., Detwiler, D. et al., "Characterization of Flow Drill Screwdriving Process Parameters on Joint Quality," *SAE Int. J. Mater. Manf.* 8(1):2015, doi:10.4271/2014-01-2241.

INTRODUCTION

In the automotive industry, joining aluminum is primarily conducted through conventional mechanical fasteners, self-pierce riveting (SPR), and resistance spot welding. Ultrasonic welding has been discussed as an alternative method, yet this technology requires a large amount of power (>5kW) and is limited to thin gauged sheets [1]. Depending on accessibility to one or both sides, either SPR or spot welding can be used. SPR is a robust and repeatable process yet is expensive due to different die-rivet combinations. Spot welding is economical and well-understood yet is not a viable option for joining dissimilar materials. It also requires double-sided access which poses as a serious design limitation. A modern

technology has been introduced that eliminates this dual-sided accessibility issue and creates a more open design space. Friction Drilling and Screwdriving (FDS) is a frictional process that utilizes a screw as both the fastener and the tool to (1) penetrate, (2) extrude, (3) create threads, and (4) torque to induce a clamping force between the sheets. FDS can be utilized to join both similar and dissimilar materials and thus creates a more open design space. The heat generation, caused by frictional force between the rotating tool and stationary workpiece, softens the material and allows the tool to penetrate at a reasonable fastener force [2]. FDS evolved from friction drilling which creates the same type of extrusion except using a completely smooth tool instead of a threaded fastener. As the tool is smooth, it does not create

threads, and thus requires additional processing steps. Friction drilling requires the use of a tap to create the threads, and manual installation of an additional threaded part. Friction drilling, therefore, has a much longer cycle time and more frequent material handling. FDS reduces cycle time and material handling as all these steps may be integrated into one single, automated process.

Miller has performed various studies on the friction drilling process, including microstructural analysis [3], force, torque, and temperature models [4], tool wear [5], petal formation in the bushings of cast metals [6], and thermo-mechanical finite element modeling [7]. His experimental and numerical analysis [4] can be related to the penetration and extrusion formation steps of FDS. His paper included models to predict the thrust force and torque based on the measured temperature, material properties, and contact area. These models will help create a better understanding of the FDS process as force and temperature profiles will assist in manipulating material flow and creating better joints. Miller's thrust force, F , and torque, T , models (equations 1 and 2) are as follows, where p is a uniform pressure estimated by the yield stress, μ is the tangential coefficient of friction, μ_a is the axial coefficient of friction, while h_1 , h_2 , and θ are tool geometric values shown in Figure 1.

$$F = \pi p (h_2^2 - h_1^2) \left(\tan \frac{\theta}{2} \right)^2 + \mu_a p \pi (h_2^2 - h_1^2) \tan \frac{\theta}{2} \quad (1)$$

$$T = \frac{2\pi\mu p (h_2^3 - h_1^3) \left(\tan \frac{\theta}{2} \right)^2}{3 \cos \frac{\theta}{2}} \quad (2)$$

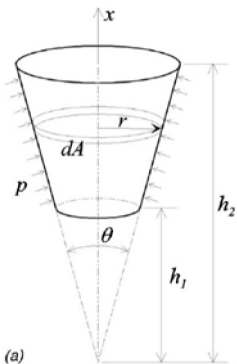


Figure 1. Miller's tool nomenclature [4]

The focus of this study is to understand how varying process parameters affect the joint geometry, and if they in turn affect the mechanical performance of the joints. Joint characteristics, such as under-head gap and material deflection, are observed and related to overall joint strength in an effort to better understand how process parameters affect joint strength.

FDS PROCESS

The FDS process is classified by 6 steps (Figure 2): *heating*, *penetration*, *extrusion forming*, *thread forming*, *screwdriving*, and *tightening/final torquing*. In the *heating* step, the fastener is rotated at high speeds (2000-6000rpm) on the surface of the material. The high frictional forces endured by the material surface cause an increase in the surface temperature, which is usually measured to be 150-250°C depending on material choice and stackup thicknesses. Elevated temperatures reduce mechanical resistance of the material and allow the initiation of the *penetration* step. The machine is capable of applying a fastener force of up to 2450N. The *penetration* step is characterized by the formation of a hole in the top material. The material extrudes up and down along the points of the screw and forms a boss, which is defined as the material that flows upwards underneath the fastener head. The fastener continues to penetrate the material stackup until the tip of the fastener penetrates the bottom side of the bottom material (step 3: *extrusion forming*). The conical geometry of the fastener allows the creation of an extrusion by gradually increasing the width of the formed extrusion. In step 4, *thread forming*, female threads are created in the formed extrusion by utilizing the thread-forming zone of the fastener. This step is performed at a lower speed of approximately 2000rpm. After the threads are created, the screw is threaded into the newly created nut member until its head seats against the top sheet (*screwdriving step*); this is performed at a low speed of 200rpm as to not risk damage of newly created threads. The speeds of 2000 and 200rpm were utilized during this study but vary depending on material selection. The last step, *tightening/final torquing*, is to ensure the joint is torqued to the appropriate pre-set value.

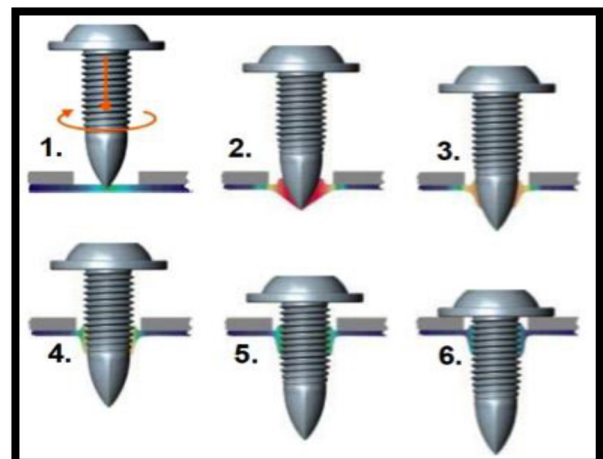


Figure 2. 6 steps of FDS

FDS carries many advantages over resistance spot welding and conventional mechanical joining (nut and bolt). FDS, unlike the other two, allows one-sided accessibility which enables more design freedom. The fastener is simple to remove which can be advantageous towards serviceability. Clearance holes have been used with FDS in the case of 3+ ply applications to allow material flow, although future applications are aimed towards removing this material preparation step. There are no issues regarding thread tolerances since threads formed with standard pitches are created and engaged by the same fastener. In the case of reparability, International Organization for Standardization (ISO) metric threads can be utilized. Lastly, there is no material waste as no chips are formed during this forming process as opposed to a drilling and tapping process.

The screw that acts as both the tool and the fastener has three distinct zones. These zones include a section for forming of the extrusion, a section of thread-forming threads, and a section of standard ISO threads for generating load and clamping the plies together. The equipment performing the process also has several control requirements. The machinery must have the capacity to produce the required force, be able to operate in the high revolutions per minute (rpm) range, and have torque control and extensometers to measure displacement of the machine head. The process monitoring is an excellent tool for understanding how the process is performing and may be obtained through feedback of angle monitoring along with torque vs. cycletime data.

EXPERIMENTAL DESIGN

Two process parameters have been chosen as the variables for this process: fastener force and drilling speed, with the outlined test matrix shown in [Table 1](#). The screwdriving and final torquing programs were left constant to minimize any variation in the process and only look at the effects of fastener force and drilling speed. The joint geometry will be categorized by minimizing the length of the under-head gap between the two materials, A, and observing the deflection of the material sheets. The joint nomenclature is shown in [Figure 3](#). The fastener manufacturer, EJOT®, established a set of criteria for classifying the joint success: (1) the FDS® head must sit on the top sheet, (2) the gap between the materials does not extend beyond the boundaries of an imaginary cylinder projected through the plies and defined by the periphery of the head, [Figure 4](#). The purpose of this study is to understand how these process inputs affect joint geometry. Parameters across the design region are varied and joint quality measures are observed. The candidate material for this study is Al5052-O, material properties displayed in [Table 2](#), with coupon sizes of 100mm × 50mm × 1.5mm, [Figure 5](#). The stackup consists of two of these coupons that add up to 3mm in thickness.

Table 1. FDS test matrix

Fastener Force (N)	Drilling Speed (rpm)	Replications
1087	3000	3
1344	3000	3
1601	3000	3
1858	3000	3
1087	4500	3
1344	4500	3
1601	4500	3
1858	4500	3
1087	6000	3
1344	6000	3
1601	6000	3
1858	6000	3

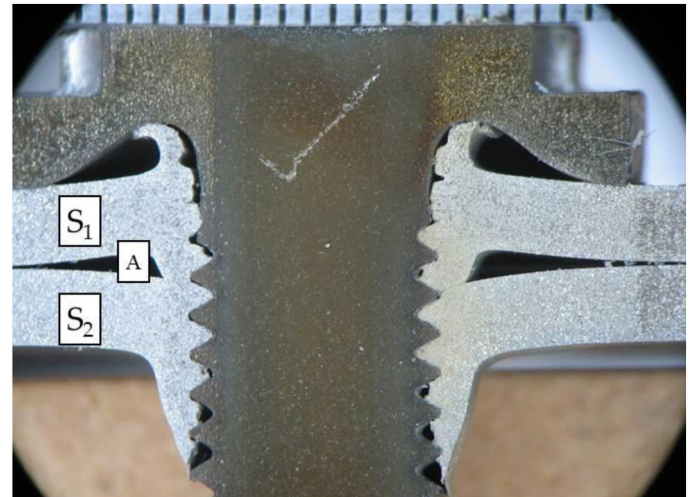


Figure 3. Joint geometry nomenclature

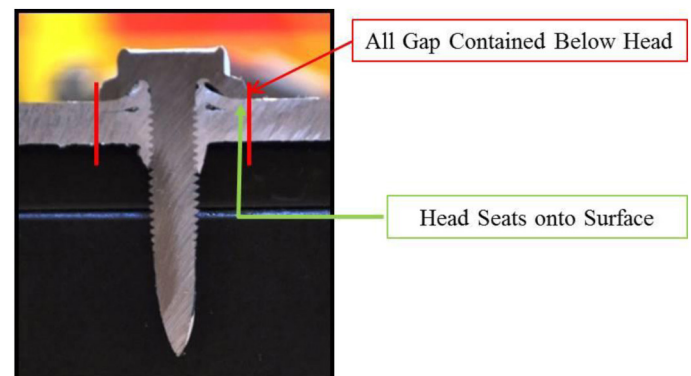


Figure 4. FDS® joint criteria