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A review of process parameters in friction drilling on joining of steels

R.M. Selvaraj [a,*], **N.R.J. Hynes** [b]
[a] Department of Mechanical Engineering, AAA College of Engineering and Technology, Sivakasi, Tamil Nadu, 626005, India
[b] Department of Mechanical Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu, 626005, India
* Corresponding e-mail address: mebyselvaraj@gmail.com
ORCID identifier: https://orcid.org/0000-0002-2679-473X (N.R.J.H.)

ABSTRACT

Purpose: Friction drilling is a unique way of creating holes in steel. In a solitary advance, a rotating conical tool is utilized to enter by penetrating as an opening on the surface of the sheet and making a bushing without making a chip. During this process, the heat produced by the frictional power linking the device and the sheet metal workpiece is used to pierce and make a bushing out of work. The goal of this novel hole-making process is to improve the bushing length in the thin-walled sheet metals by forming a bush and then combining thin sheet metals. The inconceivable utilizations of warm grating penetrating in a few modern areas will introduce another period of interfacing processes for different work materials in automobiles.

Design/methodology/approach: Researchers have undergone numerous experiments based on the machining parameters, including spindle speed, feed rates, Friction Contact Ratio (FACR), tool angle, tool diameter, sheet thickness, and the output of the friction drilling, includes the bushing length, surface roughness, tool wear, hardness, thrust force, torque and microstructural evaluation.

Findings: The crucial concerns that should be addressed and researched by researchers in the near future, such as determining the optimal machining parameters of such process and analysing, bushing length, microstructural impacts on the many aspects and their performance, are highlighted.

Research limitations/implications: This research paper tends to examine the advancements in research on the friction drilling method and its applications, taking into account the benefits and limits of friction drilling.

Practical implications: The present paper identifies the machining parameters and their contribution towards the output level of various materials like Stainless steel, Brass, aluminium, titanium, tempered steel and nickel-based compounds of different thickness.

Originality/value: The machining parameters like spindle speeds, feed rate, tool angles, thrust force, Torque, surface roundness, bushing height, frictional heat and tool diameter are optimized in the friction drilling. The incorrect bushing is formed due to the high thrust force, and Low temperatures cause ductility and softening issues.

Keywords: Friction drilling, Conical tool, Bushing length, Microstructure, Machining parameters

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

In 1923, a Frenchman, Jean tried to build a technique capable of drilling holes in a workpiece using friction heat rather than processing. It has been realised for quite some time that if there is enough hotness when applied, the material will dissolve, and an opening will create. He developed a customized drill to enhance friction heat having the fact in mind. Since the fitting materials were not yet open, it was just a mediocre achievement. Moreover, until the 1980s, it was not formalised that the correct form for this sort of equipment was set up. Expanding yield in the vehicle and piping areas, just as headways in machined parts, materials, and joint plans in common and mechanical designing, propel makers to build yield and utilize creating innovation [1]. Friction drilling, form drilling, flow drilling, and thermal drilling are alternative metal drilling processes that employ a bit without a leading edge. The most common application of the friction drilling method is in all automotive areas, such as propeller shafts and drive shafts, the brake system, the seat frame, the exhaust components, the seat handle, the foot pedal, and the oxygen sensor are all included [2].

The primary flaws and damages in traditional drilling occur in metal inlets and outlets within the hole's wall. These mistakes occur mostly due to the material's asymmetry [3]. Friction drilling is a recent technical advancement above traditional drilling. Friction drilling is the latest trend in hole creation that does not use chips and has a depth of 12 mm. Friction drilling requires much force to make a hole [4]. When a conical tool is rotated at great speed, the work material softens, and the tool penetrates the workpiece owing to the heat created by friction, creating a hole in the workpiece. While heat upgrades the hardness of a material expels on both the front and back sides of the opening [5]. On the workpiece, the expelled work material structures a chief and a hedge, with the bushing being multiple times the size of the work material. The benefits of contact boring incorporate expanded stringing profundity and a perfect, sans-chip opening making strategy [6]. A substantial influence is played by high-speed cutting or decreasing point angle and a low feed rate in reducing damages at the entry and exit. Several researchers have utilized various materials to conduct studies on hole formation using traditional friction drilling. Multiple workpiece materials and tools play a significant role in decreasing damage. The performance of drilled holes may be improved by appropriate parameters, utilizing optimization techniques, and tool material can be determined [7].

2. Friction drilling

2.1. Principle

Flow drilling, in other words, is a friction drilling methodology used to form a bushing on sheet metal, tubing, or thin-walled profiles for connecting devices simply and effectively. A bushing made via frictional drilling is typically three times higher as thick as the original workpiece. This additional thickness may be threaded, giving a more robust connection than attempting to thread the initial sheet. Friction Drilling is an unconventional hole-making technique. The friction linking a revolving conical tool and the workpiece creates heat, which softens the work material and causes a hole to form in it. Friction drilling employs a conical bit constructed of a high-temperature-resistant substance. This device applies a fast rotating speed and high pressure to a target material. As a result, a significant local generation of heat softens and plasticizes the item. The tool then sinks into the item, creating a hole in it. Lubricants can aid in the prevention of work-material adhesion to the bit. In contrast to drilling, material that flows out creates a sleeve around the hole rather than being lost.

This technology provides many choices. Bits may have a cutting mechanism that eliminates the normal collar of plasticized upward-flowing particles, resulting in an even top surface. Drilled starter holes minimize the necessary axial force while leaving a smooth finish on the bottom edge of the bushing. Taps and dies can be used to cut or roll internal screw threads. This process is described in Figure 1. Table 1 gives a friction drilling vs conventional fastening comparison. The first approach, which is frequently employed in sheet metal construction, is bolt fastening. It is the simplest and least expensive method since just one hole has to be drilled and threaded in the sheet metals. Second, riveting may be inserted by expanding the bushing length, and nuts can be welded to increase joint strength. These methods have certain limitations regarding stability, jamming, thermal aberration, and twisting during assembling.

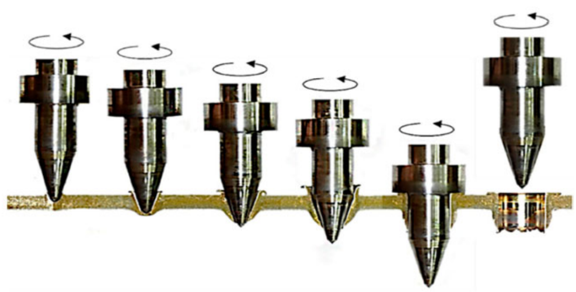

Fig. 1. Step by step process in friction drilling

Table 1
Friction Drilling vs Conventional Fastening Comparison.

S. No	Requirements	Traditional Fastening Techniques		Friction Drilling
		Weld Nut	Rivet Nut	
1.	The requirement for previously drilled holes and burring	☑	☑	☒
2.	Complex Situations	It takes a lot of time	It takes a lot of time	It takes minimum time
3.	A unique connection is needed.	☑	☑	☒
4.	Error	Extraordinarily high	Extraordinarily high	Extraordinarily low
5.	Automation	Possible, but will take a lot of work	Possible, but will take a lot of work	Easy and very flexible
6.	Machining using a closed-frame	Possible	Feasible for cylindrical tubes	Entirely feasible
7.	Reliability	High	Low	High
8.	Level of Torque	High	Low	High
9.	Type of joining	The microstructure is only partially connected by spot welding	Join by Keys	Uniformly sealed
10.	Distortion Issue	Increasing heat during welding	Fall over	There is no distortion

2.2. Process parameters and their significances

The shape of the friction drilling instruments is critical. The tool geometry comprises five areas: the centre, cylindrical, shank region, conical, and shoulder. The centre area, comparable to a twist drill's web, offers support in both the radial and axial directions. The angle in the conical portion is steeper than in the centre region. This area pushes on the workpiece item in the contact region, pushing the material sideways to form the bushing. To round the entrance of the hole's ring, contact the shoulder area to the workpiece. The tool is gripped to the machine holder via the shank area.[8] The heat in the workpiece causes material damage and incorrect bushing development. A substantial percentage of the heat is transmitted into the workpiece during friction drilling of materials with high thermal conductivities. Low temperatures induce inadequate ductility and softening, leading to a high thrust force and incorrect bushing development. These impacts are eliminated using low spindle speeds for materials with low thermal conductivity coefficients and high spindle speeds for materials with high thermal conductivity coefficients [9]. The poor material elongation implies a high rate of fracture and petal development. The thermal heat created at the workpiece- tool contact gives thermal property information. The material's strong thermal conductivity causes high heat to remove yourself from the workpiece-tool interface fast, ductility for bushing forms and lowering workpiece temperature. The melting temperature of the workpiece material is critical in friction drilling. The highest temperature produced is approximately 1/2-2/3 of the workpiece melting point. At pre-heating conditions and high rotational speed, the material plasticity increases as the temperature rises. The majority of the energy is converted to heat and transferred to the tool and workpiece [10]. The higher the spindle speed, the higher the tool surface temperature and the high friction heat is created. The friction coefficient, increases the area of contact between the workpiece and the tool, holes drilled increases, rising the surface temperature Helpless warm conductivity of the instrument and workpiece material raises both the device surface temperature and the temperature in the contact locale between the apparatus and the workpiece. In light of the decreased apparatus warm conductivity, there was less variance in pivotal push power produced and instrument surface temperature [11].

With rising spindle rotational speed, the metal crystallisation power increases, resulting in an uneven melting temperature and a lower surface roughness value. Large input rates result in low melting temperatures as well as the material's partial melting. The incompletely melted material adheres to the drill, increasing the surface roughness of the hole. Fewer feed rates are caused by metal melting temperatures, which cool at various rates. The top material layer cools down faster than the bottom material layer. As a result, the drill bit adheres to the metal chip, resulting in poor hole surface integrity [12]. This is due to the increased surface roughness caused by the tool's adherence to the workpiece [13].

2.3. Bushing length

The primary goal of the thermal drilling process is to increase joining strength through bushing formation. As a result, the bushing formation and shape are quite interesting. The friction between the revolving part and the metal heats the metal throughout this production process. As the temperature rises, the workpiece in the drilling zone softens. The softened material is then forced lower by the thermal drill in the direction of the spinning, the thermal drill continuing into the workpiece to form the bush, which increases the joining strength in sheet metals. As a result, the primary goal of the thermal drilling operation is bushing creation. The busing formed is shown in Figure 2. However, the bush's microstructure has changed due to the deformation impact during the procedure. As a result, the bushing form has a microstructure with finer grains than the underlying material. When the flowing material's strength rises as it gets too close to the surface of the thermally drilled hole. The clamping load is increased by a bushing with a cylindrical shape and no cracks or petal development. Furthermore, increased bushing length results in a larger screwing surface as well as increased sheet materials connection strength.

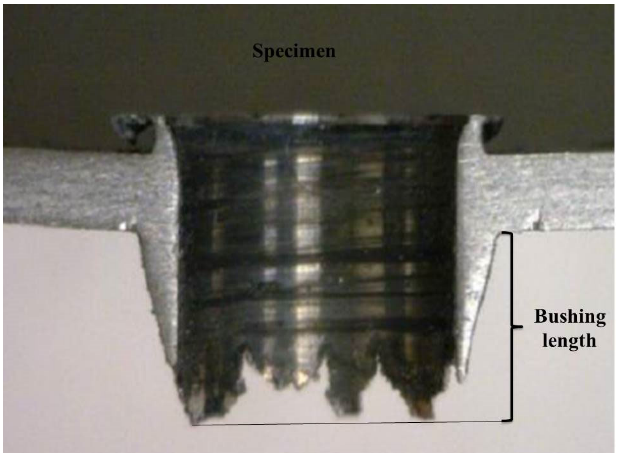

Fig. 2. Bushing length occurred during friction drilling

The bushing's capacity is to improve strings thickness and cinch load accessibility. Friction drilling is most appropriate for ductile materials. The petals and cracks are framed at the bushing resulting from the thermal drilling of delicate cast metals. The advancement of petals brings about the development of a bushing with limited burden limit with respect to string attaching. Fragile and malleable workpieces change because weak work material doesn't make a bushing with the vital shape, though pliable occupation has a smooth, round and hollow bushing with satisfactory length [14]. In frictional penetrating, the workpiece thickness (t) to instrument measurement (d) proportion is significant. The critical commitment of bushing at high t/d demonstrates that an impressively longer measure of material is uprooted. Materials of higher elasticity require more push power to exist infiltrated. The bushing shape, cylindricality, petal arrangement, bushing divider thickness, and surface harshness are utilized to evaluate the nature of the erosion-penetrated opening. The bushing structure becomes round and hollow as the workpiece temperature rises and has less breakage. For grinding boring of fragile cast metals, high shaft speed and pre-warming limit push power, force, energy, and power [10]. The frictional heat increases the material's ductility material for the workpiece that is ejected on both the front and rear surfaces of the material drilled. Because of the additional height of the bushing form, the length of the threaded portion of the hole might grow by a minimum of four times [15]. The bushing form is designed to enhance threading thickness and available clamp load [16].

3. Previous works

Friction Stud-Welding [17-22], Diffusion bonding [23-25], Friction Welding [26-31], Friction Drilling [24,25], and Friction Riveting [32,33] are a few processes employed for the joining of dissimilar metals. One of them is, the Friction Drilling process is a promising candidate. Tool wear in friction stir drilling is investigated by Scott F. Miller et al. [11] (2007) utilizing a CMM to recognize vacillations fit as a fiddle, elements of hardware wear are assessed by estimating device body weight and form modifications, and wear absconds are identified utilizing checking electron microscopy. The varieties in instrument surface synthetic pieces inferable from erosion were analyzed utilizing energy dispersive spectrometry. Force and push powers are likewise recorded regularly during warm penetrating, just as the size of the opening, to evaluate for instrument wear impacts. About 11000+ openings, the bushing's width was diminished by 0.29 mm at the bottom. On the funnel-shaped and round and hollow locales, ostensible device wear happened after 11000 openings.

M. Boopathi et al [6] (2013). Thermal Drilling on Brass, Stainless Steel, and Aluminium was focused likely. In Friction infiltrating, the best push power for Stainless Steel material is gotten at a speed of 2500 rpm and a feed speed of

80 mm/min. It is well indeed, and it tends to be considered that if the feed rate is expanded, the push power will result in everyday augmentation at a predictable speed of 2500 rpm. At speeds of 3000 rpm and 3500 rpm, relative effects of limits were taken note. The temperature flow is assessed using an infrared thermometer. Aluminium, metal, and treated steel independently have the best temperatures of 468, 252, and 164°C. A 2.5 mm indenter is utilized to indent the balls. The Brinell hardness test is finished on a grouping of metals in various regions. Metal, treated steel, and aluminium, for example, have top hardness potential gains of 120, 166, and 359, independently. Under SEM, strong material trade and the workpiece's grip are seen under minute evaluation. There is practically no indication of the relaxing of metal and only a bit of proportion of material trade, and there is no indication of dissolving of metal, aluminium materials, and material workpiece trade in treated steel.

Experimentation made in SUS 304 Stainless Steel by Wei-Liang Ku et al. [7] (2011) by Thermal Drilling on Investigating the Process Parameter Optimizing this work made use of circumstances, with paces of 3,600 and 1,200 rpm and penetration paces of 75,125 mm/min. The impacts of SR and Bush length in warm rubbing penetrating utilizing the Taguchi method on SUS304 tempered steel are examined in the upcoming test. Friction Drilling broadened the apparatus life and worked on the nature of the drill opening surface while keeping away from instrument wear. The ideal machining variable values for BL and SR were determined in this experiment with Spindle Speed=3600 RPM, FACR(Friction Contact Area Ratio)=50 per cent, FA(Friction Angle)=30° and FR=100 mm/min, after 60 runs of SUS 304 stainless steel. FR=75 mm/min, FACR (Friction Contact Area Ratio) =50% and Spindle Speed=1,200 rpm.

Kaya et al. [34] (2014) examine the impacts of drilling parameters like surface temperature, thrust force, and torque during friction drilling of ST12 material, which includes friction angle, friction contact area ratio (FCAR), feed rate, and spindle speed. The tool is made of tungsten carbide with a TiN coating. According to research observations, the thrust force and torque steadily rise as the feed rate, friction angle, and FCAR increase. But from the other extreme, the thrust force and torque decrease when drilling speed increases. It is observed that drilling speed has a considerable influence on the workpiece surface temperature. The temperature of the workpiece's surface rises as drilling speed does. The workpiece surface temperature is not significantly affected by changing the friction angle or FCAR.

Modern lightweight vehicle design has a significant potential for implementing the thermomechanical assembly technique known as "flow drill screw (FDS) drive," which enables single-sided access to multi-material joining. A discussion of lightweight joining in a combination of a thermomechanical procedure, flow drill screwdriving (FDS), is an introduction to join lightweight materials. This method is used since it is reliable, takes little time to install, and only provides access to one side. The procedure combines the three concurrent partially overlapping steps for flow drilling, thread formation, and tightening. Aslan et al. [35] (2019) examine the impacts of the process parameters on the flow drilling operation of thin sheets with a thickness of 2.5 mm for AA5182-O and 1.4 mm for DP600. There is a correlation between certain control parameter ranges and drilling problems. Mechanical testing has revealed that the drilling flaws did not affect the assembly's mechanical strength when subjected to static stress. The ideal joining parameters and the reliable process window were chosen based on these findings. Over the open process window, the fluctuation of every mechanical quantity related to the process was noted. These data might also be used to validate process simulations, or they could be used to build data-driven meta-models.

Skovron et al. [36] (2015) investigate the study of the impact of material temperature on process time, installation torque, and other joint measurables using varied pre-process material temperatures of Al6063-T5A. With the help of the thermal aid, it was possible to cut the processing time by up to 52% and the installation torque by 20%. The thermal assistance during the Flow Drill Screwdriving has the highest pre-process material temperature did not exceed the tempering temperature, and the rise in pre-processing material temperature had no effect on the material's hardness beyond the least heat-affected zone.

Krasauskas [37] (2011) analyses and investigates the thermo-mechanical friction drilling process through experimentation. Thermo-mechanical friction drilling experiments for hot-rolled S235 steel, AISI 4301 stainless steel, and Al 5652 aluminium alloy are given, detailed, and the study results are reviewed. In order to assess how drilling speeds, workpiece thickness, and mechanical qualities of the materials affected the maximum drilling force and torque variation, a quantitative five-variable linear regression analysis was carried out. Models of multivariable linear regression are suggested for optimising the drilling operations.

Playing out Experimental Research on the Effect of Pre-penetrating Depth and Diameter on Initial Deformation, Bushing Shapes, and Temperature by Demir [38] (2016), Friction Drilling is carried out on A7075-T651 is pre-drilled widths and profundities had an essential connection at the finished measurement and the length of device's tip, the primary misshaping was taken out or altogether decreased, and the interaction temperature was made consistently. Pre-penetrating measurement's consistency changed depending on axle speed as per the temperature condition. At 40 mm/min feed and 3000 rpm, the most elevated temperature esteems were 368.5°C and 346.1°C, separately. The bushing's shape is improved in a round, hollow structure, with fewer breaks and petal development. In rubbing boring, where examples were not pre-bored, the length of breaks on the bushing structures expanded because of early mutilation.

Cebeli et al. [39] (2013) inspect the thickness and height of the bushing sheet, similar as surface cruelty reliant upon pipe formed point, material thickness, pivot speed, and invasion rate in disintegration infiltrating of St37 Steel and A7075-T651. While simultaneously cutting down both the cone point and the feed rate. Increased hub speed lessened surface hardness while extending instrument pipe formed point and feed rate diminished bushing height and extended bushing sheet thickness. Since the working temperature was under 600°C, St 37 steel was not reasonable for crushing exhausting.

Sara et al. [40] (2018) tentatively explored the ideal boundaries of the friction drilling process on hardened steel AISI 304, utilizing an examination of change methods and the DOE approach joined with fluffy rationale. The outcomes uncover that with a pivoting velocity of 3500 rpm, a feed pace of 60 mm/min, an erosion contact region proportion of half, a grating point of 30 and an apparatus breadth of 9.2 mm, the cycle boundaries blend will be great. An extra bearing surface can be strung to get a more extended shrub length. When the hub power is brought down, the machining current is restricted.

Nwankiti et al. [41] (2022) adopted a novel technique of combined Taguchi-Pareto-grey wolf-desirability function analysis applied to the AISI 304 stainless steel, and the optimization of the drilling operation process is taken into account. The mean signal-to-noise values generated from the Taguchi method's response table were used to create an optimal solution. Additionally, in order to evaluate the results of the linear programme created in accordance with the objective function and some systemic limitations, the ranks of the variables through the response table are taken in the reciprocal mode. Mouthpiece thickness, feed rate, friction angle, friction contact area ratio, tool cylindrical region diameter, and reciprocal speed were six input factors that were taken into consideration. The output responses are axial and radial forces, hole diameter dimensional error, roundness error, and bushing length. These data were examined for the optimisation process of the inputs and outputs. The best value converges with a beginning value of 1699.2 in iteration 8, according to the C++ software's solution results. After six cycles (iterations two through seven), Iterative process 1 falls to 11016.3, and in Iterations eight through twenty, it ultimately converges at 11015. The effort's significance lies in its assistance to process engineers in the execution of energy-saving decisions that can be reached utilising optimal thermal friction values.

<u>Microstructural characterisation</u>

Dehghan [42] (2019) examined the microstructure of workpieces and instrument wear during the grinding penetrating of tempered steel, titanium combinations, and nickel-based compounds. The exploration adds to the improved microstructural portrayal of workpiece and instrument conditions, distinguishing material conduct and exhibiting what it means for bushing arrangement exactness and penetrating apparatus productivity. Information of workpiece microstructural changes and apparatus wear to support distinguishing material conduct and what it means for bushing arrangement quality and boring device execution for rubbing boring of intense materials. The examination discoveries show that nickel-based composites and hardened steel have many unrivalled bushing shapes, the opening divider's surface nature, and petal development than titanium compounds. Titanium compounds' helpless hotness conductivity and nickel-based combinations' solid shear strength and work-solidifying greatly affect item quality and device wear. Moreover, rough wear is generally seen in the tapered space of the boring device, which has the most contact with the opening divider. The microstructure and synthetic nature of the boring device exhibit that the instrument wear on the penetrating apparatus utilised generally for grinding boring of Titanium compounds is considerably more limited than most different devices. The grating wear on the device that penetrated Stainless Steel is material disposal, yet the rough wear on the device that bored Titanium composites is apparatus harm. Moreover, the apparatus that bored the Nickel-based composite has grating wear looking like round grooves. Titanium compounds because more glue wears to the penetrating device, while nickel-based composites cause less cement wear to the boring instrument. The most elevated oxidative wear is likewise seen on the penetrating instrument used to bore nickel-based alloys.

4. Conclusions

Friction drilling is a fast, financially savvy, and novel strategy for making openings in sheet metal. Future examination in the vehicle regions has been perceived as a need by this survey:

- The friction drilling process is optimised by taking essential machining factors into account. The machining factors include spindle speeds, feed rate, tool angles, thrust force, Torque, surface roundness, bushing height, frictional heat and tool diameter.
- The exploration adds to the improved microstructural characterisation of workpiece and device conditions, recognising material conduct and exhibiting what it means for bushing arrangement quality and boring instrument execution. The outcomes show that grating wear is generally observable in the funnel-shaped space of the device, which has the most contact with the opening divider. Besides, the restricted warm conductivity of Titanium amalgam increases frictional hotness age, bringing down item quality and device life.
- Also, this review influence the cost-effective method in optimising the friction-drilled values.

Additional information

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