KAUNAS UNIVERSITY OF TECHNOLOGY

MANUFACTURING ENGINEERING AND DESIGN FACULTY

Sebin Cheriyan Abraham

Experimental and statistical investigation of the friction drilling and tapping processes in thin-walled parts

Final project for Master degree

Supervisor
Assoc. Prof. Povilas Krasaukas

KAUNAS, 2015

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KAUNAS, 2015

KAUNAS UNIVERSITY OF TECHNOLOGY

MANUFACTURING ENGINEERING AND DESIGN

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ME M 3/9 INDUSTRIAL ENGINEERING AND MANAGEMENT

(Title and code of study programme)

EXPERIMENTAL AND STATISTICAL INVESTIGATION OF THE FRICTION DRILLING AND TAPPING PROCESSES IN THIN-WALLED PARTS

DECLARATION OF ACADEMIC HONESTY

29 May 20 15

Kaunas

I confirm that a final project by me, **Sebin Cheriyan Abraham**, on the subject " Experimental and statistical investigation of the friction drilling and tapping processes in thin-walled parts" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis. I understand that in case of a resurfaced fact of dishonesty penalties will be applied to me according to the procedure effective at Kaunas University of Technology.

(name and surname filled in by hand) *(signature)*

Cheriyan Abraham Sebin Eksperimentiniai ir statistinės tyrimas trinties gręžimo ir įsriegimo procesai plonasienių dalių magistras Pramonės inžinerijos ir vadybos galutinio projekto / vadovui doc. **Dr Povilas Krasauskas**; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultete, Pramonės inžinerijos ir vadybos katedra.

Kaunas, 2015 52 psl.

SANTRAUKA

Projektas yra apie eksperimentinės analizės Trintis Gręžimo procese. Trinties gręžimo galima paaiškinti kaip procesas, kuris naudoja trintį gaminti įvores ir metalų, tokių kaip DC 06 plieno ir 4301 nerūdijančio plieno.

Trintis gręžimas naujesnė netradicinė skylė priėmimo lustas mažiau procesas, kuris yra naudojamas, kad skylės medžiagų, kur ji gali būti naudojama aviacijos, automobilių, komercinių ir pramoninių produktų, elektroninių pakuotės, ir šilumos valdymu. Be trinties gręžimo, sukasi kūgio formos įrankis yra taikomas įsiskverbti darbu medžiagą ir sukurti į vieną žingsnį ir detales dėl proceso medžiagos ir įrankiai bus aptarti literatūros apžvalgos skylę.

Mes aptarti mechaninius ir galią, sukimo momentų aspektus trinties proceso šioje sesijoje.

Šiame tyrime, kamienas įtakos medžiagų savybes ir grūdų mikrostruktūra medžiagos aplinkinių nuo trinties gręžimo skylę. Pavyzdžiai kryžminių suskirstyta skyles buvo poliruoti ir išgraviruotas pagal krovimo analizės DC 06 plieno ir 4301 Nerūdijančio Steel.Experimental nuomonių buvo padaryta, siekiant turėti trumpą supratimą apie tyrimų, susijusių su projekto. Šiame skyriuje mes aprašome eksperimentinę analizę trinties gręžimo proceso ir analizės jėga ir sukimo momentas lemiantys įvorės ir sriegimo kokybę. Ir taip pat aš padariau regresinę analizę jėgos ir sukimo momento ir palyginimus su eksperimentiniais duomenimis, apskaičiuota duomenis.

Raktiniai žodžiai: trinties gręžimo, plonasienių dalys, išorinių arba vidinių sriegių procesas,jėga,sukimomomentas,regresinėanalizė

Cheriyan Abraham Sebin Experimental and statistical investigation of the friction drilling and tapping processes in thin-walled parts *Master of industrial engineering and management* final project / supervisor **Assoc. Prof. Dr Povilas krasauskas**; Kaunas University of Technology, Mechanical Engineering and Design faculty, Industrial Engineering and Management department.

Kaunas, 2015. 52 pages.

SUMMARY

The project is about Experimental analysis of Friction Drilling Process. Frictional drilling can be explained as a process that uses friction to produce bushings in metals like DC 06 steel and 4301 Stainless Steel.

Friction drilling is a newer non-traditional hole-making chip less process, which is used to make holes in materials where it can be used in aerospace, automotive, commercial and industrial products, electronic packaging, and thermal management. In friction drilling, a rotating conical tool is applied to penetrate work-material and create a hole in single step and the details regarding the process, materials and tools will discuss in the literature review.

We discuss the mechanical and Force, Torque aspects of friction process in this session.

In this study, strain affect material properties and grain microstructure of the material surrounding a hole from friction drilling. Samples of cross sectioned holes were polished and etched for material analysis in DC 06 steel and 4301 Stainless Steel.Experimental reviews had been done in order to have a brief understanding of the researches related to the Project. In this chapter, we describe the experimental analysis of friction drilling process and analysis of force and torque influencing the quality of the bushing and threading. And also I have done regression analysis of force and torque and comparison with the experimental data and the calculated data.

***Keywords**: friction drilling, Thin walled parts, tapping process, force, torque, regression analysis*

KAUNAS UN IVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Approved:
Head of
Production engineering
Department

____
(Signature, date)

____
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Experimental and statistical investigation of the friction drilling and tapping processes in thin-walled parts

Approved by the Dean 2015 may.11 Order No. ______________

2. Aim of the project

The aim of the project is the experimental and statistical analysis of force and torque in related to the spindle rotation, feed rate and the mechanical properties of the materials.

3. Structure of the project

The final work will consist of Introduction part, overview of friction drilling process and tapping process, materials and work pieces, data calibration and the experiment and the result discussion with the help of graph and the regression analysis

4. Requirements and conditions

The materials selected for the experiment should be used in the manufacturing industry and analysis should be done . The result should be discussed and recommendations are to be made for the same.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2015 June 1st.

Given to the student SEBIN CHERIYAN ABRAHAM

Task Assignment received ______________________________ ______________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor ______________________________ ______________________
(*Position, Name, Surname*) (*Signature, date*)

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ABSTRACT

The project is about Experimental analysis of Friction Drilling Process. Frictional drilling can be explained as a process that uses friction to produce bushings in metals like DC 06 steel and 4301 Stainless Steel. Frictional heat is created by the combined rotational and downward force of our special Friction Drilling tool bit.

Friction drilling is a newer non-traditional hole-making chip less process, which is used to make holes in materials where it can be used in aerospace, automotive, commercial and industrial products, electronic packaging, and thermal management. In friction drilling, a rotating conical tool is applied to penetrate work-material and create a hole in single step and the details regarding the process, materials and tools will discuss in the literature review.

We discuss the mechanical and Force, Torque aspects of friction process in this session.

In this study, strain affect material properties and grain microstructure of the material surrounding a hole from friction drilling. Samples of cross sectioned holes were polished and etched for material analysis in DC 06 steel and 4301 Stainless Steel.. Two ideas of pre-heating the work piece and high speed friction drilling were investigated. With the increased work piece temperature, the thrust force and torque was decreased and the bushing shape was improved. Thrust force, torque, and temperature in FEM were compared to experimentally measured values .Experimental reviews had been done in order to have a brief understanding of the researches related to the Project. In this chapter, we describe the experimental analysis of friction drilling process and analysis of force and torque influencing the quality of the bushing and threading. And also I have done regression analysis of force and torque and comparison with the experimental data and the calculated data.

INTRODUCTION

The friction drilling technique used to create a bushing on sheet metal, tubing, or thin walled profiles for joining devices in a simple, efficient way, is also known as Flow drilling .Such a bushing that is created through frictional drilling is usually two to three times as thick as the original work piece. This added thickness can be threaded, providing a more solid connection for attachment than attempting to thread the original sheet.

Friction drilling can also be known as thermal drilling, flow drilling, form drilling, or friction stir drilling. It is a nontraditional hole-making method. The friction between a rotating conical tool and the work piece, generates heat that softens the work material and penetrates a hole in it. Friction drilling uses a conical bit made of very heat-resistant material such as cemented carbide. This device is pressed against a target material with both high rotational speed and high pressure. That way, there is a high local production of heat which softens the object, making it plastic. The tool then sinks through the object, which makes a hole in it. Lubricants can help prevent the work-material from adhering to the bit. Unlike drilling, material that flows out is not lost but forms a sleeve around the hole. The length of that sleeve will be up to 3 times the original thickness of the material. The presence of this metal lip around hole edges makes connections stronger.

Several options are available with this technology. Bits may include a cutting device that removes the typical collar of plasticized material that flows upwards, so that an even top surface is the result. The required axial force can be reduced by the use of Drilled starter holes and it also leaves a smooth finish in the bushing's lower edge. Internal screw threads may be cut with taps or rolled with dies.

In this section, we study the mechanical aspect of friction drilling. The research on the mechanics of the friction drilling process, particularly the measurement of thrust force, torque, of the tool and work piece, is lacking and has become the goal of this research. The experimentally measured thrust force and torque are finalized under the constant tool feed rate.

Friction drilling provides a cost and quality replacement to traditional fastening methods. When you have thin walled material the only option to create strength is through a traditional fastener or thicker material, besides having disadvantages in the form of cost and failures in the production process. The thermal friction drill eliminates the need for expensive fasteners by having a two-step process capable of 1000's of repetitions.

Friction drilling is:

- A chip less process capable of strong threaded connections for metric, imperial and gas threads.
- Capable of drilling steel, stainless steel, copper, aluminium and brass.
- Environmentally friendly, no waste, no single fasteners, and recyclable.

An important step of friction drilling process is the thread forming taps. These taps form the threads by displacing the metal rather than cutting it. The resulting threads are smoother and stronger than cut threads. Since they do not have flutes, the taps are a lot stronger. They can be run faster and don't bind up with chips. It looks like the combination of thermal drilling and thread form taps creates a very clean operation.

Employing taps to fabricate internal threads is a widely used machining process. However, the sudden breakage of taps and a residue of broken tap pieces in the hole of the work piece is one of the most undesirable things that one may encounter during fabricating internal threads. It is particularly true when small size taps are used to fabricate internal threads for blind-holes, where breakage of tools occurs the most frequently. The reasons for this occurrence may include: inaccurate tap geometric sizes, blockage of chip material and improper lubrication.

The chip-free process provides a clean environment. Higher forming speeds as compared to thread cutting creates a better surface quality Greater tool lifetimes because thread formers are less susceptible to breaks. Increased pull out strength and torque of the formed threads as the process reforms the material in the bush without cutting into the natural grain structure of the material Suitable for most tapping machines Suitable for most tapping machines.

The tapping process creates formed threads by material displacement. The material flows into the thread depression and crest of the tap.

By the comparison of force and torque with the constant feed rate and spindle rotation, we could find the more influencing parameter for the better quality of the material as well as the life of the tool. We used different spindle rotation speed such as 2000 rpm, 2500 rpm, 3000 rpm and feed rate such as 60 mm/min, 100 mm/min, 140mm/min. Different thickness of the material is used in this study. It helps to identify the mechanical parameters which are influencing the experiment.

The materials with higher strength should require more thrust force for the hole penetration. Thermal property measurement provides information on how the work material responds to the friction heating at the tool-work piece interface. The experiment was performed on a CNC milling machine "DMU-35M" with controller "Sinumerik 810D/840D", using tungsten carbide tool with diameter of 6 mm.

And later we studied the experimental data and have done regression analysis. By using the regression analysis, we study the relationship between the one variable and several other factor And here y is called the dependent variable and the independent variable. Here we have done with experimental values and predict the calculated value

The research on the mechanics of the friction drilling process, particularly the measurement of thrust force, torque, of the tool and work piece, is lacking and has become the goal of this research. The experimentally measured thrust force and torque are finalized under the constant tool feed rate.

1. LITERATURE OVERVIEW

1.1. Friction drilling process

Friction stir welding is a concept similar to Friction drilling. FSW is a solid state joining process invented in 1991 by The Welding Institute in Cambridge, UK. In this process a rotating tool is used that generates frictional heat and creates a forging that facilitate continuous solid state joints. The tool consists of a pin, which protrudes from the lower surface of the tool, and the relatively large-diameter shoulder. Welding is initiated by first plunging the pin into the work pieces until the shoulder is in intimate contact with the component top surfaces. Friction heat is then generated as the shoulder rubs on the top surface under an apparent force. The tool is propelled forward, when sufficient heat is generated and conducted into the work piece. By the heating action of the shoulder, the material gets softened and is transported by the pin across the bond line, facilitating the joint. The only significant difference is that friction drilling heats and softens material to displace it and form a specific shape, while friction stir welding heats and softens material to mix and join it. (1)

The idea of rubbing two materials together to produce heat is as old as people learning to make fire in the Stone Age. However, applying the principle to drilling holes in metal is a more recent development. Most people who have worked in machine shops have at one time or another tried to drill a hole with a very dull bit. The result is a lot of smoke and heat. Jan Claude de Valliere, working on a little farm in the south of France some seventy-five years ago encountered the same problem . He recognized that if enough heat is generated he could melt and form a hole through the metal. (2)

With that thought in mind, he developed a special drill designed to increase friction. After many trials, he found a shape that worked. Jan Claude de Valliere's invention was not at the time commercially or practically viable. Publications on the subject of friction drilling are limited. Six patents have been awarded: first four by van Geffen 1976-80 and later by Head et al. and Hoogen boom in 1984. (4) France et al. investigates the strength characteristics of friction drilled holes in metal tubing. Overy and Bak discussed the design aspect of the friction drilled holes. Kerkhofs et al. studied the performance of coated friction drilling tools. These publications describe friction drilling tools, equipment needed, and evaluate performance issues of the tool and bushing created. (1)

A publication on the the International Advanced Technologies Symposium says that, Thread rolling is a cold or chipless forming process where a fluteless tap or a rolling head including rollers, having the reverse form of the thread, displace raw material to produce internal threads in blank holes with no material losses. Internal threading is produced by an action similar to thread rolling by deformation of material than cutting. The advantages are not only excellent surface finish but also a good surface hardness and increase in thread strength up to 40%. All ductile materials can be thread rolled internally with a good impact value. The primary reasons preferring rolled threads are lower unit cost, good surface hardness of threads, no chip formation hence blind holes can be threaded easily, good grain flow structure, reduced material utilization, and superior mechanical properties. As a consequence, thread rolling has virtually eliminated thread cutting as a competitive technique for fastener produced in quantity . By cold forming manufactured workpiece profiles are characterized by high accuracy, reliability and durability. Because of the rolling process, the formed threads and flanks allow an increased load to be applied in use . Although several threads forming by cutting have been created and performed on CNC machines, thread with rolling is still lower production time and lower labour and production cost due to formed completely in one pass of tap or rolling head. In cold forming, usually low-carbon steels are used. Thread rolling is primarily a cold forming process done at room temperature; it is possible to roll internal threads in both ferrous and non-ferrous metals provided that their hardness and tensile strength are not above 200 and 800 MPa, respectively, and it has an elongation of 10-40%. Areas of application include aluminum and its alloys, brass having copper %more than 62; and steel, stainless steel, free cutting steel. About 60 % of the materials used in industry nowadays can effectively be formed in this way. It is also established that there is an analytical relation between hardness and effective strain induced in a metal during cold working. (1) Most of the attempts to model the thread forming process to date have focused on external thread forming using dies. Hayama, developed a model, using the minimum energy method and partially plastic deformed thick walled cylinder theory to predict the maximum torque values experienced during the internal thread forming process. Ivanov and Kirov developed an empirical formula for finding the maximum value of torque experienced in internal thread forming. The each tooth tap or rollers of thread head come into contact with the work piece material deform the work material and deformed material flows upwards along the faces of the faces of the tooth or rollers. With the successive tooth or rollers forms the thread at desired depth of cut. During the rolling process the forces generated are both due to the deformation of workpiece and resulting flow of deformed material along the faces of the tooth (4). Plastic deformation also creates work hardening of work material. Knowing that inducing plastic deformation alters material's strength, different regions of cold formed part will have different strengths. Generally, cold formed parts are forged in a number of stages and in each stage the material undergoes additional permanent deformation (5). It has been considered that there is a close correlation between the hardness of a cold formed product and strain hardening because of cold forming. It is well known that the fatigue strength of rolled products increases than that of blank material in cold rotary forming, such as screw threads. While Kawai reported that the profile forming ratio in groove rolling affects the fatigue strength of groove-rolled products, it has been considered that the fatigue strength of rolled products is dependent on the strain-hardening of material and the residual stress built up during the rolling process. (1) An important utility for load reduction is the replacement of sliding friction by rolling friction This advantage is applied on thread rolling head which have rollers to deform blank materials.

1.2. *Friction tapping process overview*

An important step of friction drilling process is the thread forming taps. These taps form the threads by displacing the metal rather than cutting it. The resulting threads are smoother and stronger than cut threads. Since they do not have flutes, the taps are a lot stronger. They can be run faster and don’t bind up with chips. It looks like the combination of thermal drilling and thread form taps creates a very clean operation.

Employing taps to fabricate internal threads is a widely used machining process. However, the sudden breakage of taps and a residue of broken tap pieces in the hole of the work piece is one of the most undesirable things that one may encounter during fabricating internal threads. It is particularly true when small size taps are used to fabricate internal threads for blind-holes, where breakage of tools occurs the most frequently. The reasons for this occurrence may include: inaccurate tap geometric sizes, blockage of chip material and improper lubrication.

In view of this, the utmost important aspect is to increase the life of taps. From the knowledge of previous literature, there are three approaches to solve the problem of tap breakage; they are: improvement in the accuracy of the geometrical shapes of tap, usage of the attachment for safety taps and introduction of controllable vibration during tapping. Following the overall assessment of the preceding three approaches, the most efficient and effective solution is believed to be the introduction of control vibrator. As the trend to reduce aircraft weight and increase aircraft speed continues, the use of titanium alloys on aircraft components has rapidly increased. F-15 fighter for example, the use of titanium alloy accounts for 26.5% of the aircraft total components. The steel rivets used on the aircraft, is are huge in quantity, even though is small in physical volume. Normally, an aircraft may have tens to hundreds of thousands of steel rivets in it. If the steel rivets are to be replaced with titanium blind jack nuts, the weight of the aircraft can be considerably reduced. However, the manufacturability of titanium jack nuts is poor because of the difficulty of tapping internal threads for deep holes, particularly the deep holes. The reason for this is that the large spring back of the titanium metal due to its low elastic modulus would cause the relief face of the tap to generate a severe frictional torque, which is seven times that of medium carbon steel. The huge torque due to spring-back would in turn lock the tap from rotating and eventually break it in the hole during fabricating internal threads. This problem, which most frequently occurs when smaller size taps are used, cannot be solved even if the relief angle of the tap is enlarged.

From the preceding cited literature, it is can be seen that vibration-assisted tapping not only reduces the tapping torque but also prolongs the tap’s usable life. The application of ultrasonic vibration has both beneficial effects in reducing the tapping torque and improving the surface smoothness of the finished teeth. However, few researchers have applied ultrasonic vibration generated by magneto-striations vibrators to assist in internal thread tapping. As such, the present study was motivated to investigate the influence of high frequency vibration on tapping internal threads, utilizing a piezoelectric actuator to generate the high frequency. The experiment was performed with and without the introduction of cutting fluid. Internal threads tapping for titanium metal were assisted by high frequency vibration aiming at investigating the beneficial effects derived from both the introduction of cutting fluid and vibration. The optimal tapping process parameters were sought after as well.

In depth study of the friction drilling process is the purpose of this research. A complete analysis of the friction drilling process was performed for basic understanding of mechanics and details.

1.3. *Drilling method description*

A rotating punch-type tool is forced into the material and forms cylindrical hole without metal removal. The heat generated by the friction, heats the surrounding area, the material become plastic and the hole then is perforated pushing the tool to the material with feed rate approximately of 1 mm/s. The excess of the material forms the neck on the underneath side of the hole and bushing on the upside of the sheet, increasing the wall thickness and strength of the hole (Fig. 1)

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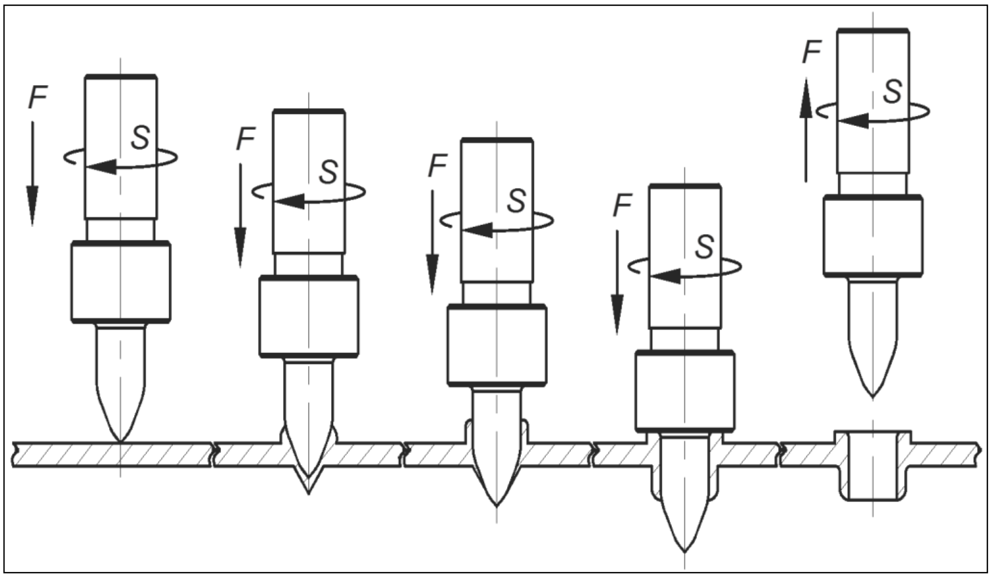


Figure 1 Friction drilling steps: a - initial contact; b- tool-tip penetration to the material; c - material flow; d - bush forming; e - tool withdrawal (source: Article of Prof. povilas krasauskas)

1.4. *Tapping method description*

Thread forming taps is an important step of friction drilling process. These taps form the threads by displacing the metal rather than cutting it. The resulting threads are smoother and stronger than cut threads. The taps are a lot stronger because they do not have flutes. The can be run faster and don't bind up with chips. It looks like the combination of thermal drilling and thread form taps creates a very clean operation.

a) b) (source: Google)

Figure 2 a – Tapping tool; b – Tapping tool and the material

Tapping process is doing with high quality tool and can be ordered with lubrication grooves and coatings for special applications.

Superior strength tapped threads are produced by the Friction drilling methods as compared to conventional methods. Formed threads avoid cutting the natural grain of the material. Higher pull-out strength and torque specifications are provided by the compressed structure. The chip-free process provides a clean environment. Higher forming speeds as compared to thread cutting creates a better surface quality Greater tool lifetimes because thread formers are less susceptible to breaks. Increased pull out strength and torque of the formed threads as the process reforms the material in the bush without cutting into the natural grain structure of the material Suitable for most tapping machines Suitable for most tapping machines. The Flow tap creates formed threads by material displacement. The material flows into the thread depression and crest of the tap.

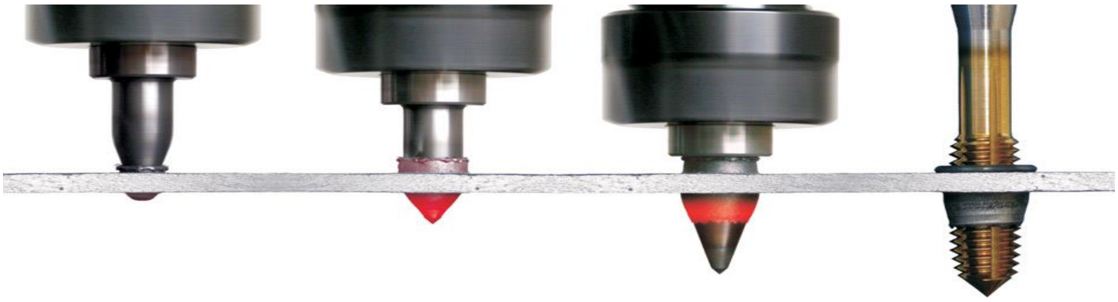


Figure 3 Tapping process (source: Google)

2. MATERIALS AND WORKPIECES

The experiment was performed using two various materials stripe: - stainless 4301steel and DC 06 STEEL. The Chemical composition, mechanical properties and dimensions of the materials is presented in Tables 1-3.

Table 1Chemical composition of as-received sheet metal

ELEMENTS	C	Si	Mn	Cr	Ni	Mg	Cu	Zn	P	Fe	Ci
DC 06 STEEL	0.02		0.25						0.02		
STAINLESS STEEL	0.07		2.0	18	8						

Table 2 Mechanical properties of the materials

Material	Ultimate strength $R_{m,}$, MPa	Yield limit $R_{p0,2}$, MPa	Elongation A_5 , %
DC 06 STEEL	270-350	170-180	41
Stainless 4301 steel	500-700	190	26

Table 3 Work pieces dimension

Material	Thickness (mm)	Length (mm)	Width (mm)
DC 06 STEEL	1.5	100	10
S Stainless 4301 steel	1	100	10

3. EXPERIMENTAL SETUP AND TECHNIQUE

3.1. *Tools*

The drill consists of five regions:

1. Center region: The cone-shape center has the angle α and height hc. The angle is usually blunt. The effect of blunting is to generate more force and, therefore, heat at the start of the drilling. The center region, like the web in a twist drill, provides the support in the radial direction for the friction drilling process and keeps the tool from walking at the start of the process.

2. Conical region: This region has a sharper angle than the center region. The drill in this region rubs against the work piece to generate the friction force and heat and pushes the work-material sideward to shape the bushing.

3. Cylindrical region: This region helps to form the hole and shape of the bushing. The length and diameter of this region are designated as hl and d, respectively.

4. Shoulder region: The shoulder of this region may touch the work piece to round the entry edge of the hole and bushing.

5. Shank region: This is the area of the tool gripped by the tool holder of the machine.

The experiment was performed on a CNC milling machine “DMU-35M” with controller “Sinumerik 810D/840D”, using tungsten carbide tool with diameter of 6 mm.

Table 4 Dimensions of the friction drill, mm

*D*1	*D*2	*D*3	*L*1	*L*2	*L*3	*L*4	*L*5	*R*	α^o
5.4	8	11	11	14	7	5	6	0.5	25

Drilling program was written using “ShopMill” software, which enable to simulate drilling and tapping time and to change forming regimes in expeditiously manner.

3.2. *The overview of milling machine and drilling device*

CNC vertical machining center was used for the friction drilling process of, stainless steel and DC 06 steel. Overview of the setup is shown in Fig.8.The work piece was held on the top of the drill tool dynamometer using the vise. The drill tool dynamometer is used for the measuring the thrust forces involved in the drilling process. The tool was held by a standard tool holder. Two materials used for experiments in this friction drilling study of 1 mm thick and 1.5mm .

The materials with higher strength should require more thrust force for the hole penetration. Thermal property measurement provides information on how the work material responds to the friction heating at the tool-work piece interface. The experiment was performed on a CNC milling machine “DMU-35M” with controller “Sinumerik 810D/840D”, using tungsten carbide tool with diameter of 6 mm.

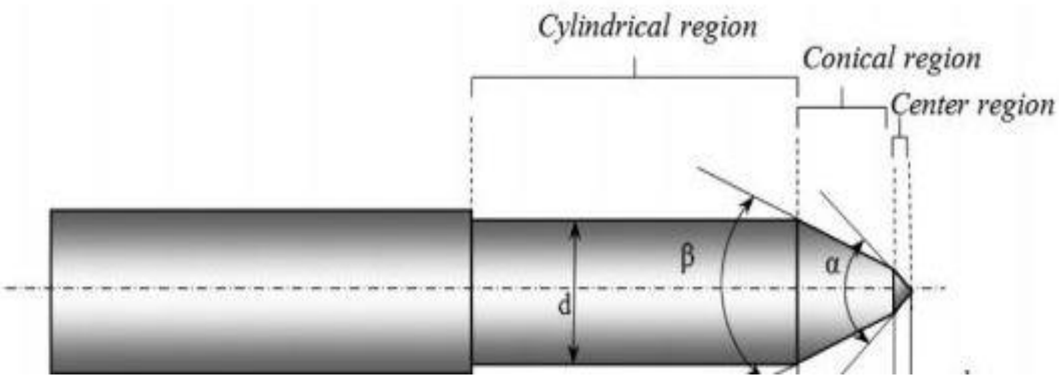


Figure 4 Shape of the friction drilling tool (source: Google)

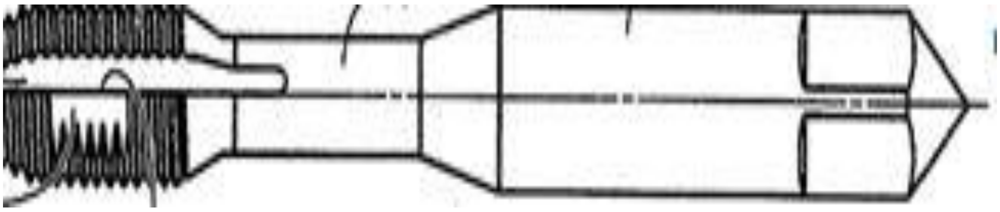


Figure 5 Shape of the tapping tool (source: Google)

a **b**

Figure 6 a- Friction drilling experimental setup; b- drilling device

Drilling force during the experiment was measured using Kistler dynamometer mod, the measurements were recorded to the computer via oscilloscope “PICO ADC-212 and given graphs were transformed to the graphs in force and torque.

a b

Figure 7 a- Kistler dynamometer ; b- Kistler amplifier (source: Kistler catalogue)

3.3. Test equipment arrangement

In the CNC machine, the dynamometer is connected to record the force and torque while doing the experiment. From the dynamometer, the charge amplifier amplifies the force and torque from the component sensor. Using Pico scope software, we will get the force and torque graph.

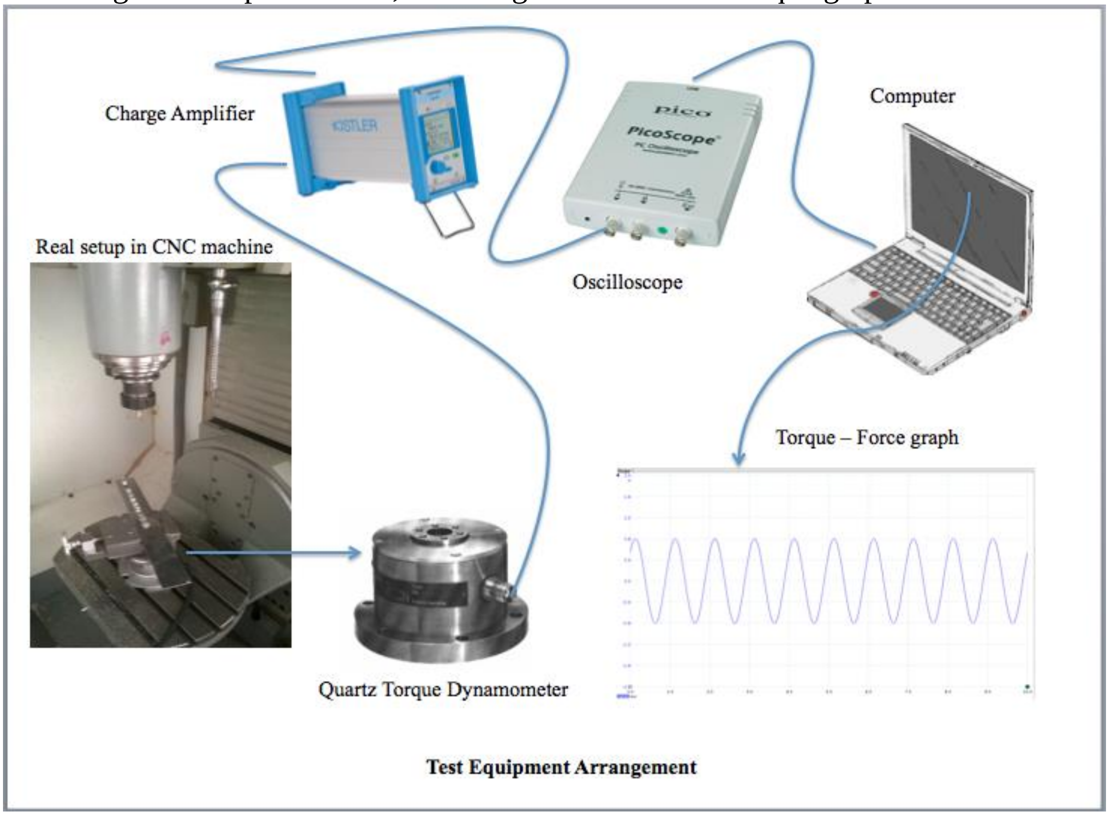


Figure 8 Test equipment Arrangement

CNC vertical machining center was used for the friction drilling process of, stainless steel and DC 06 steel. Test equipment is shown in Fig.2.The work piece was held on the top of the drill tool dynamometer using the vise. The drill tool dynamometer is used for the measuring the thrust forces involved in the drilling process. The tool was held by a standard tool holder. Two materials used for experiments in this friction drilling study of 1 mm thick. The materials with higher strength should require more thrust force for the hole penetration. Thermal property measurement provides information on how the work material responds to the friction heating at the tool-work piece interface.

4. DATA CALIBRATION AND VERIFICATION

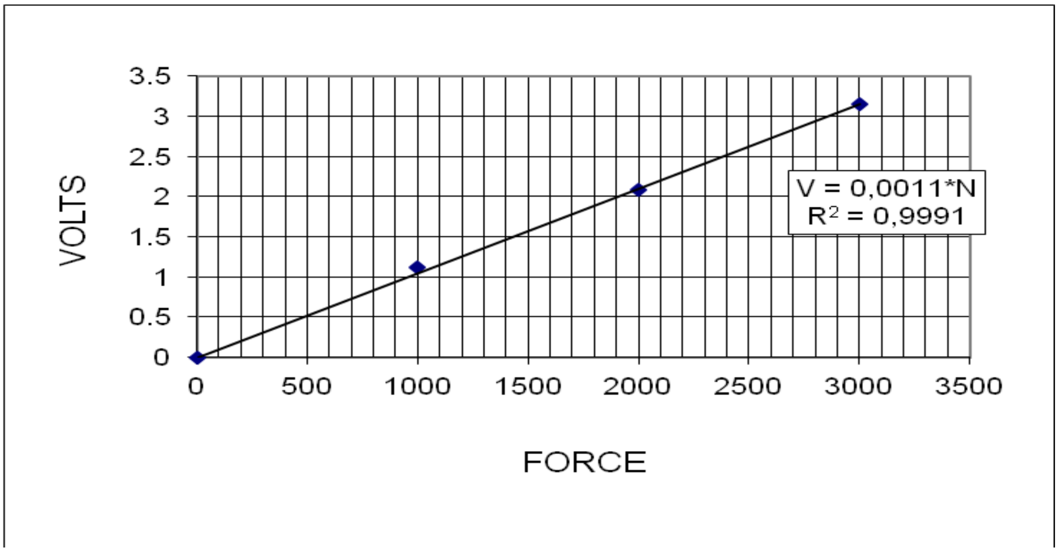


Figure 9 Force calibration

From the graph we can know that, 2 volts=1900 N and thus we got mF= 1900/2 = 950 N for the force and in the fig: we can know that 2V = 4.6, thus we got mT= 4.6/2= 2.30 Nm/v

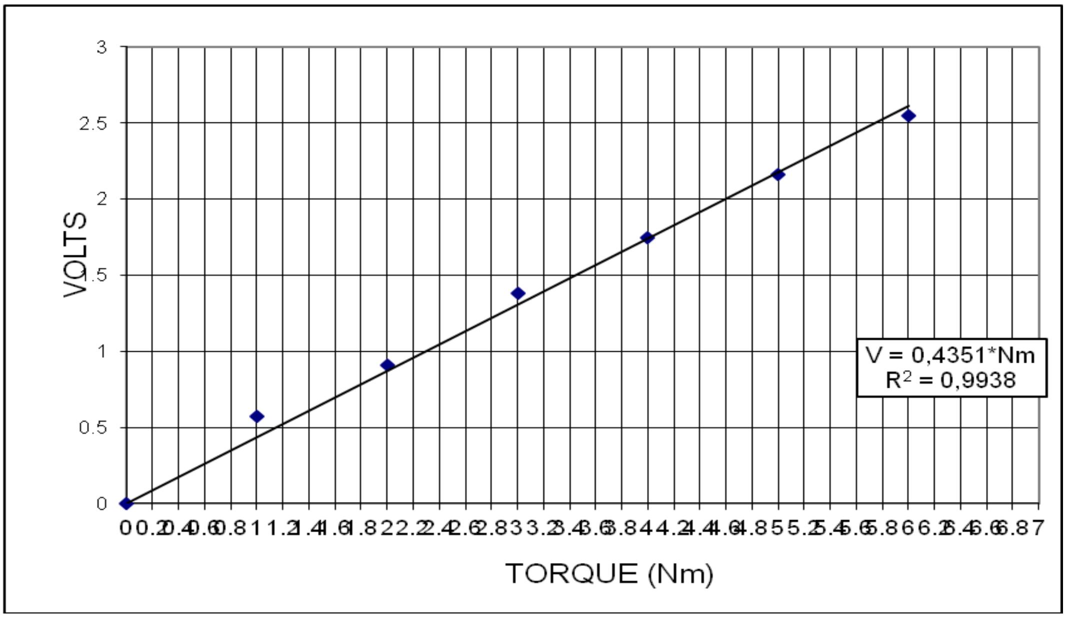


Figure 10 Torque Calibration

5. EXPERIMENTAL RESULTS AND DISCUSSION

The experiment was planned according the course: spindle rotation speed set of 2000, 2500 and 3000 rpm was selected and for each ones drilling feed ratio set of 60, 100 and 140 mm/min was assigned.

Table 5 Friction drilling experiment table

MATERIAL	Thickness (mm)	SPINDLE SPEED (rpm)	FEED RATE, mm/min	FORCE (N)
	1	2000	60	550
	1	2000	100	650
	1	2000	140	790
	1	2500	60	650
DC 06 STEEL	1	2500	100	640
	1	2500	140	690
	1	3000	60	500
	1	3000	100	550
	1	3000	140	600
	1.5	2000	60	800
	1.5	2000	100	650
	1.5	2000	140	850
	1.5	2500	60	650
4301 STAINLESS STEEL	1.5	2500	100	1240
	1.5	2500	140	890
	1.5	3000	60	650
	1.5	3000	100	1200
	1.5	3000	140	850

Table 6 Tapping experiment table

MATERIAL	Thickness (mm)	SPINDLE SPEED (rpm)
DC 06 STEEL	1.5	350
4301 STAINLESS STEEL	1	350

5.1. DRILLING FORCE

5.1.1. DC 06 STEEL

The thickness of the material is 1.5mm. spindle speed and feed rate changed to analyze the difference and to test the influence of feed rate and spindle rotation in the experiment. The spindle speed changes 2000 rpm , 2500 rpm and 3500 rpm and feed rate changes 60 mm/min , 100 mm/min , 140 mm/min respectively.

Table 7 DC 06 Steel drilling experiment

Thickness (mm)	SPINDLE SPEED (rpm)	FEED RATE, mm/min	FORCE
1.5	2000	60	800
1.5	2000	100	650
1.5	2000	140	900
1.5	2500	60	650
1.5	2500	100	1240
1.5	2500	140	890
1.5	3000	60	650
1.5	3000	100	1200
1.5	3000	140	850

Here the feed rate is 60 mm/min and the spindle rotation changed and done three experiments as 2000 rpm, 2500 rpm , 3000 rpm.

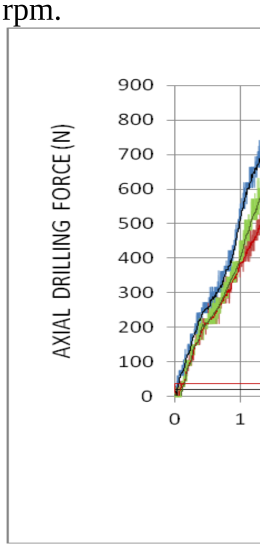


Figure 11 Feed rate 60 mm/min (DC steel)

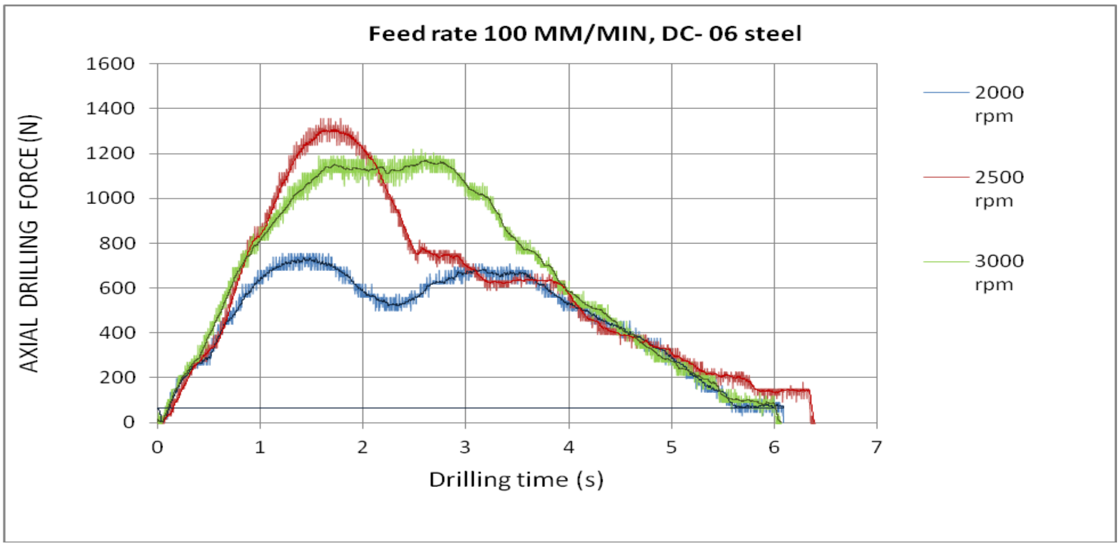


Figure 12 Feed rate 100 mm/min (DC steel)

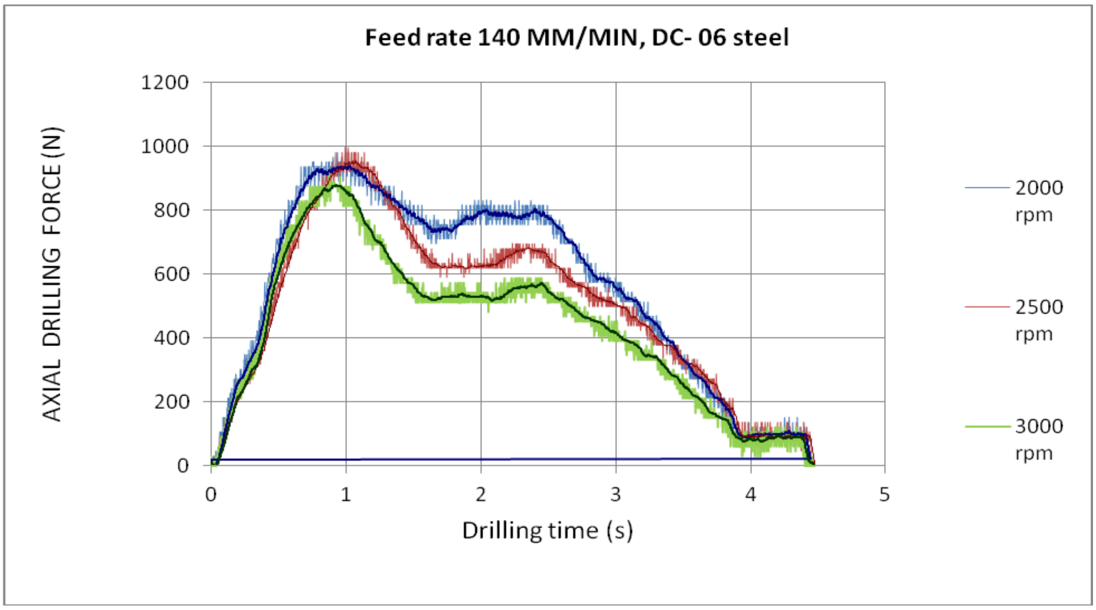


Figure 13 Feed rate 140 mm/min (DC steel)

From the above three graph shows the 60 mm/min , 100 mm/min , 140 mm/min feed rates influencing the force of the drilling processes. Feed rate 100 mm/min made the biggest force and the we can see that the forces are varying according to the changes in the feed rate and the spindle rotation speed.

Here the feed rates are constant as 60 mm/min, 100 mm/min and 140 mm/min and the done three experiment and the spindle rotation changed as 2000 rpm, 2500 rpm and 3000 rpm.

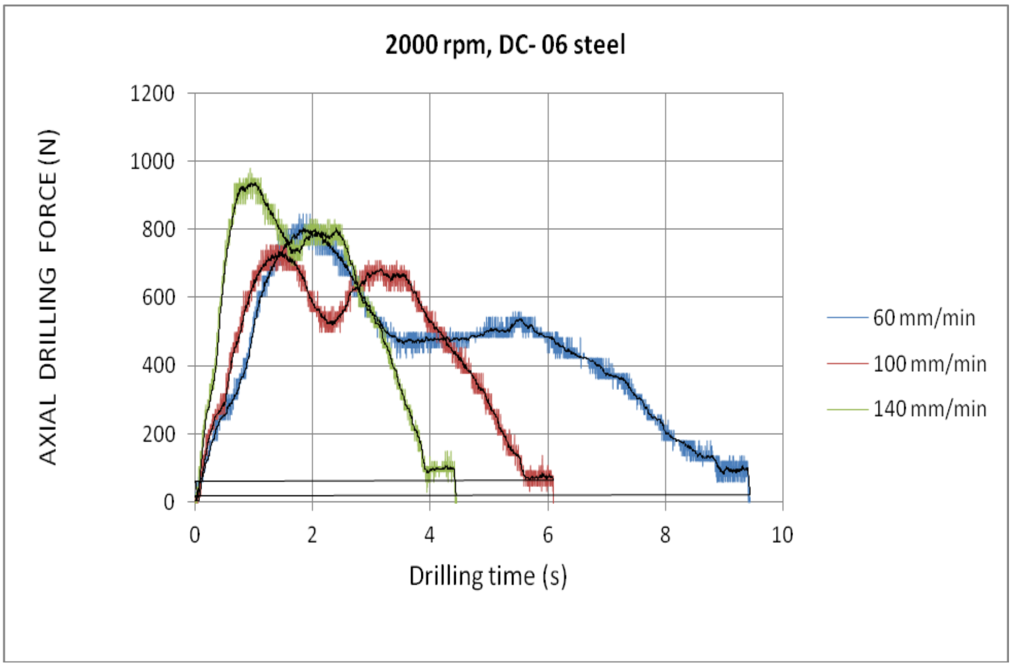


Figure 14 Spindle rotation speed 2000 rpm (DC 06 Steel)

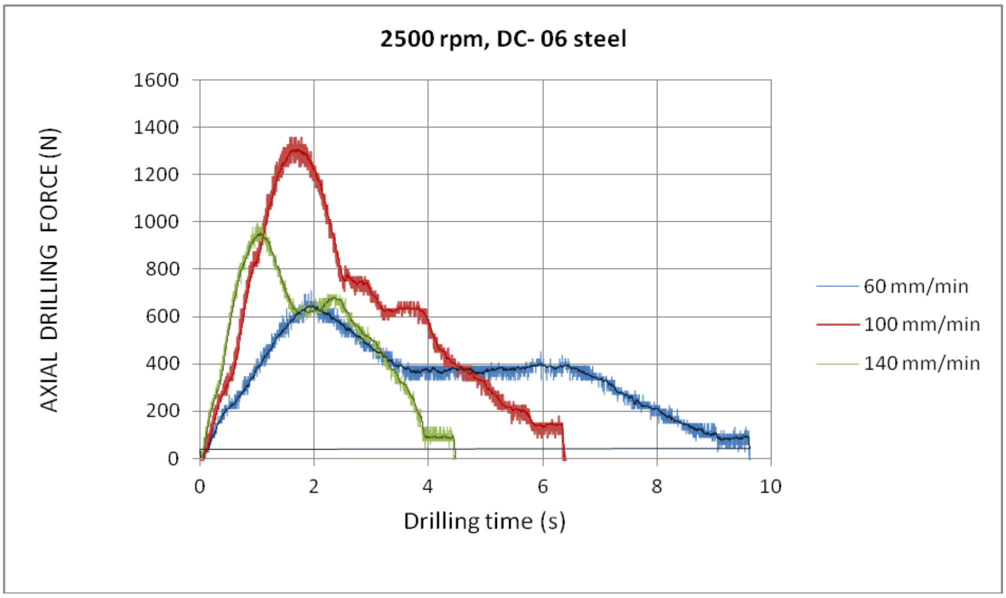


Figure 15 Spindle rotation speed 2500 rpm (DC 06 Steel)

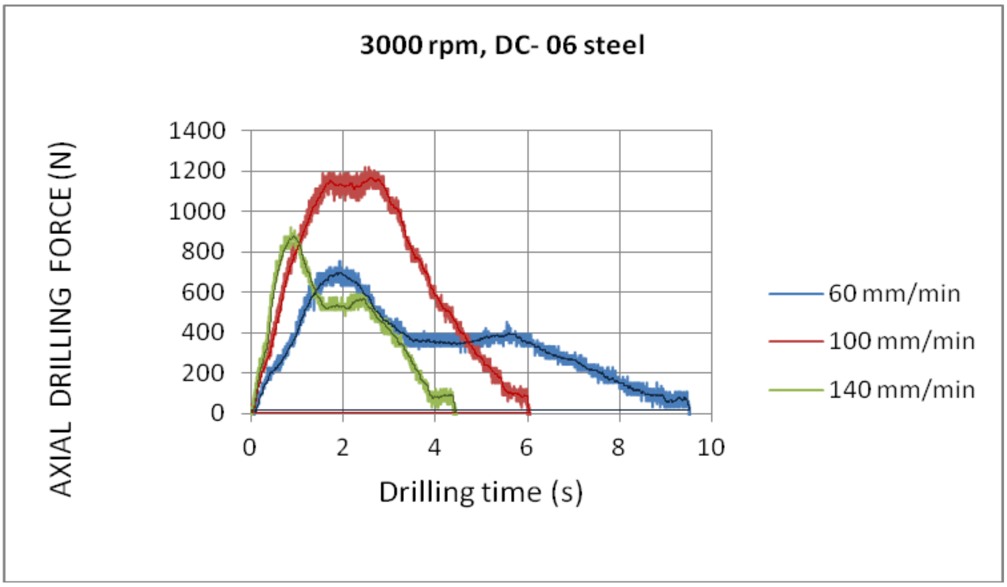


Figure 16 Spindle rotation speed 3000 rpm (DC 06 Steel)

5.1.1.1. DC 06 steel tapping force v/s tapping torque

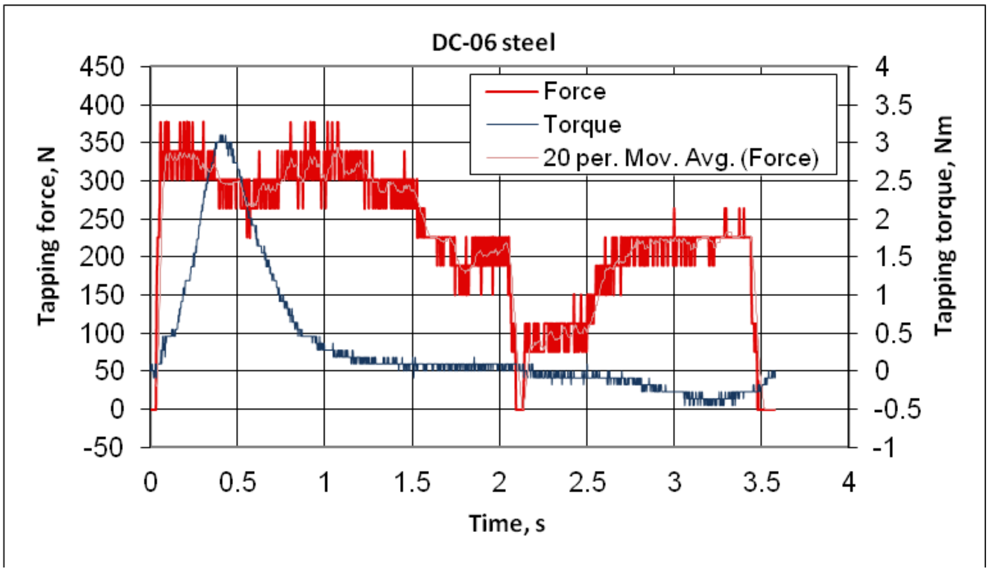


Figure 17 DC 06 steel tapping force v/s tapping torque

The measured thrust force and torque in tapping of DC 06 steel are shown in Fig. 17 The tool feed rate is 1 mm/min and the speed of the spindle is 350 rpm. A peak thrust force of nearly 350 N occurs at 1.5 mm of tool travel from the initial contact with the workpiece. The torque rapidly rose to 3N m after the tool reached position . The thrust force drops rapidly to 50 N, less than half of the peak value. Force remains at about 300 N and the torque gradually decrease to the maximum at 0 N m and then to - 0.5.

5.1.2. 4301 STAINLESS STEEL

The experiment performed with 4301 stainless steel material with feed rate of 60 mm/min, 100 mm/min and 140 mm/min. And the spindle rotation speed also done with 2000 rpm, 2500 rpm and 3000 rpm respectively.

Table 8 4301 Stainless Steel drilling force experiment

Thickness (mm)	SPINDLE SPEED (rpm)	FEED RATE, mm/min	FORCE (N)
1	2000	60	550
1	2000	100	650
1	2000	140	690
1	2500	60	650
1	2500	100	600
1	2500	140	690
1	3000	60	450
1	3000	100	550
1	3000	140	600

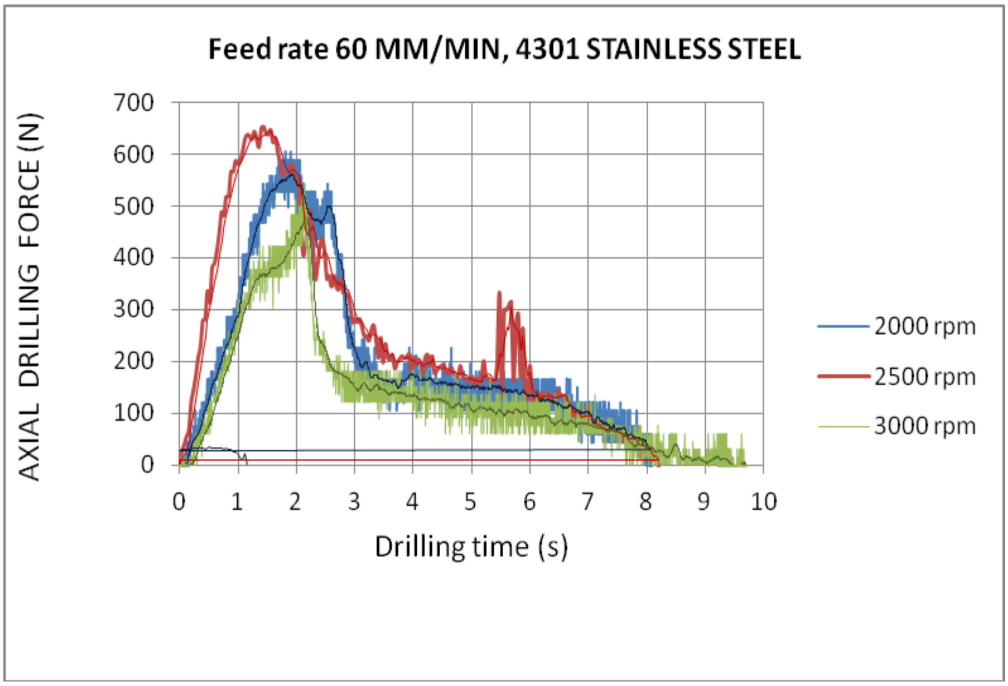


Figure 18 Feed rate 60 mm/min (4301 SS)

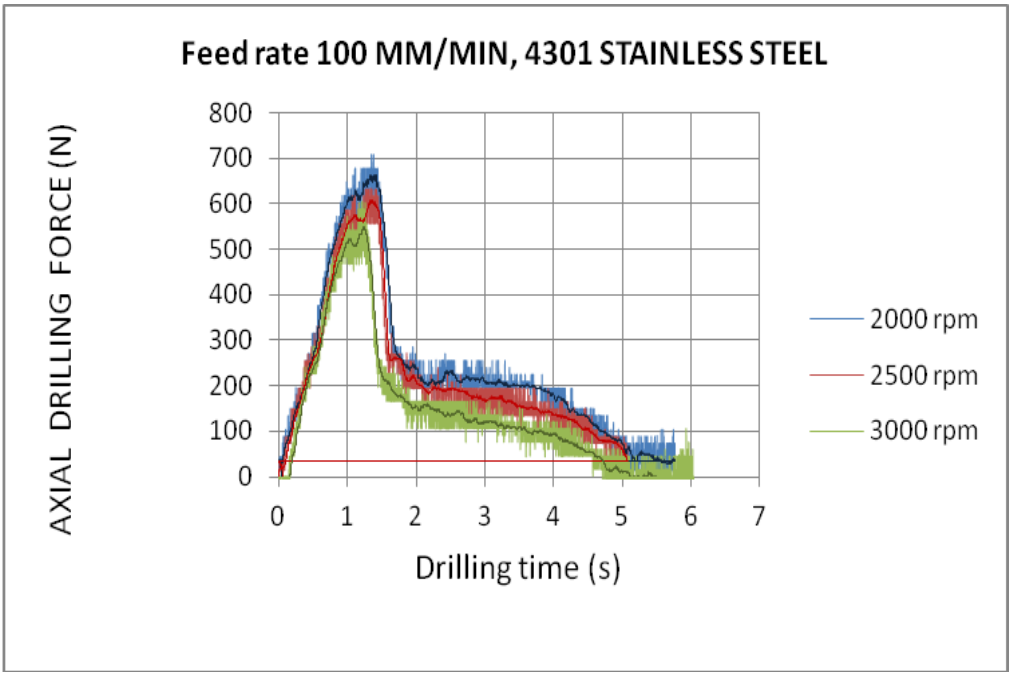


Figure 19 Feed rate 100 mm/min (4301 SS)

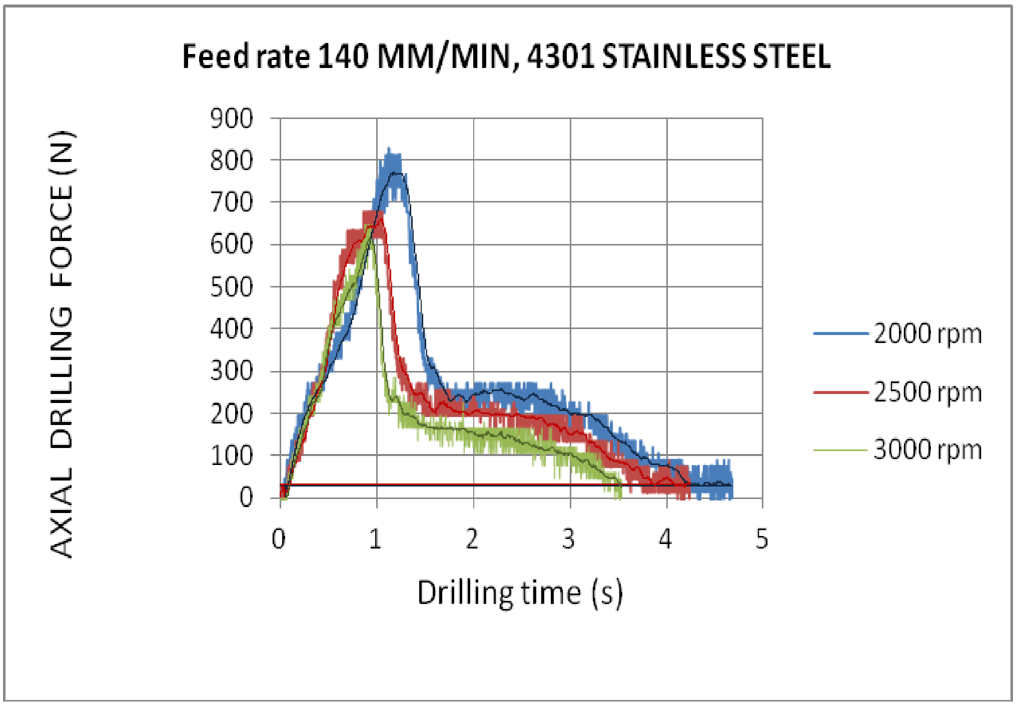


Figure 20 Feed rate 140 mm/min (4301 SS)

Here the feed rates are constant as 60 mm/min, 100 mm/min and 140 mm/min and the done three experiment and the spindle rotation changed as 2000 rpm, 2500 rpm and 3000 rpm.

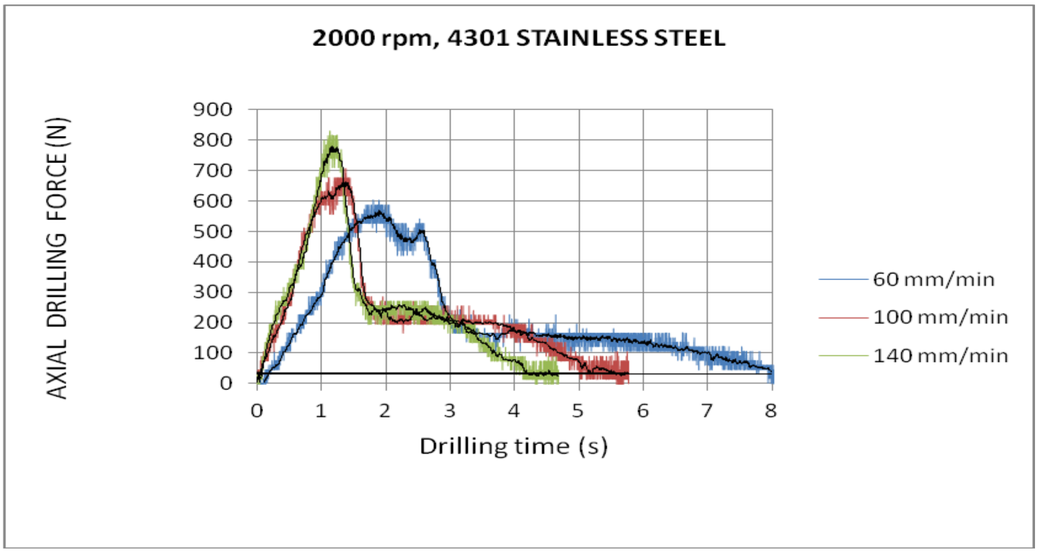


Figure 21 Spindle rotation speed 2000 rpm (4301 SS)

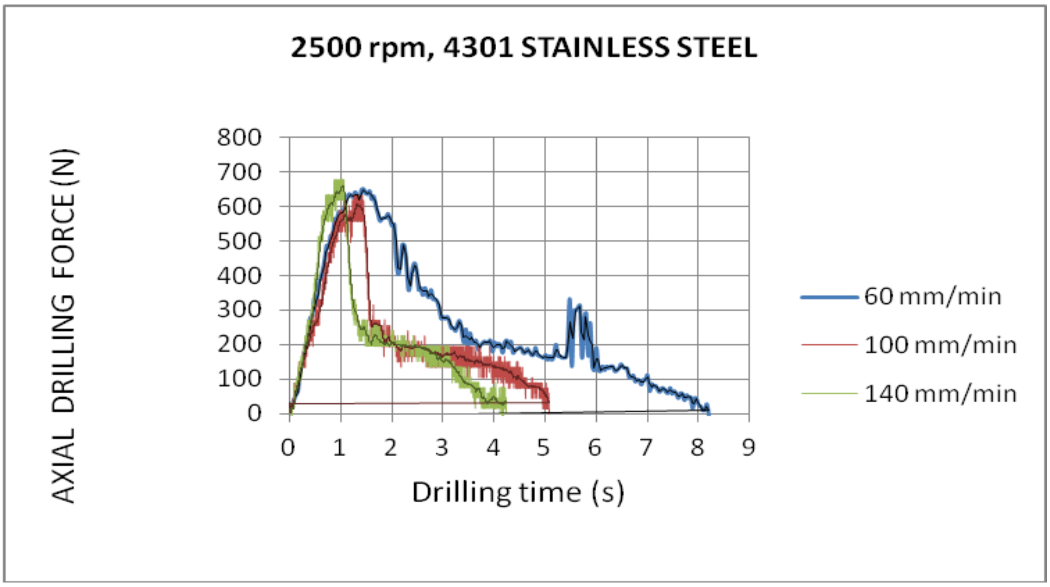


Figure 22 Spindle rotation speed 2500 rpm (4301 SS)

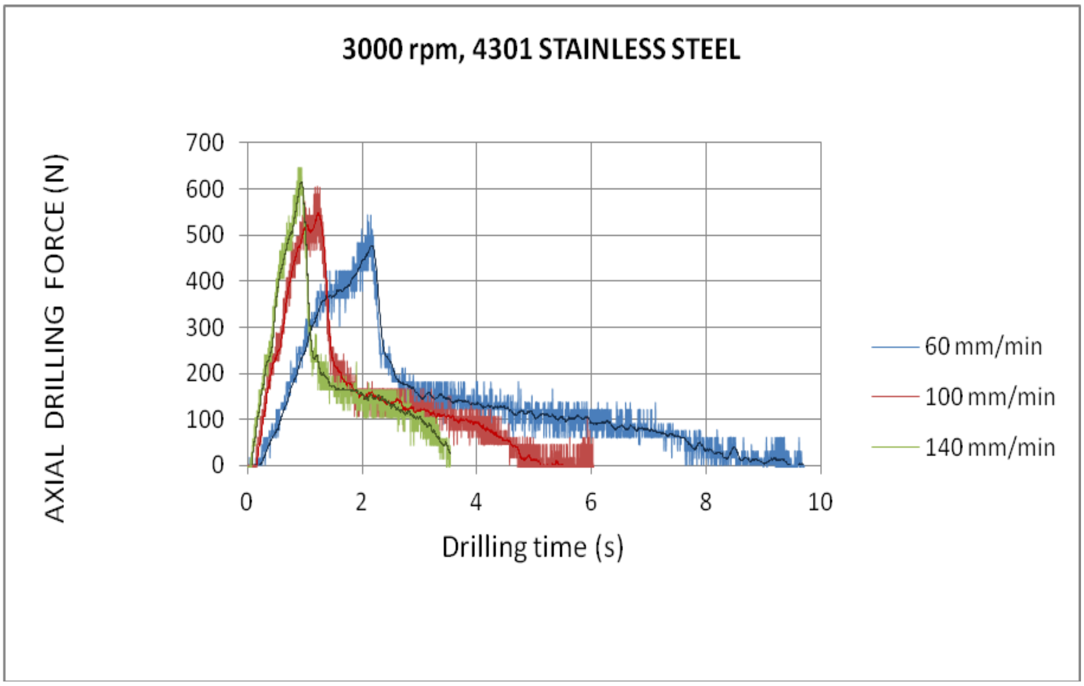


Figure 23 Spindle rotation speed 3000 rpm (4301 SS)

And thus the thrust force of the DC 06 steel aand the 4302 stainless steel are measured and from the graphs we get an idea that the force changing according to the changes in the feed rate and the spindle rotation speed. The Mechanical properties of the material also affects the experiment. The force needed for the drilling is different for the two materials as even the feed rate and force are changing respectively.By analysing the graphs we know that the feed rate is affecting the force more than that of the spindle rotation speed.

And here there is only a small changes of spindle rotation speed happened and the variation of the force is also very small. And there is a surface roughness happened as we increased the feed rate of the tool. The conical region of the tool has perforated the workpiece and pushed the work-material aside to form a bushing. Rings of discoloration were observed inside and outside the hole, indicating the further increase of workpiece temperature. Both the force and torque start to decrease after 3 seconds , that means it comes up to the retracting point. And the force is reduced to almost zero or even negative.

5.1.2.1. THRUST FORCE AND TORQUE IN FRICTION DRILLING OF STAINLESS STEEL

The measured thrust force and torque in friction drilling of STAINLESS STEEL are shown in Fig.24 The tool feed rate is 140 mm/min and the speed of the spindle is 2000 rpm. A peak thrust force of nearly 800 N occurs at 1.5 mm of tool travel from the initial contact with the work piece.

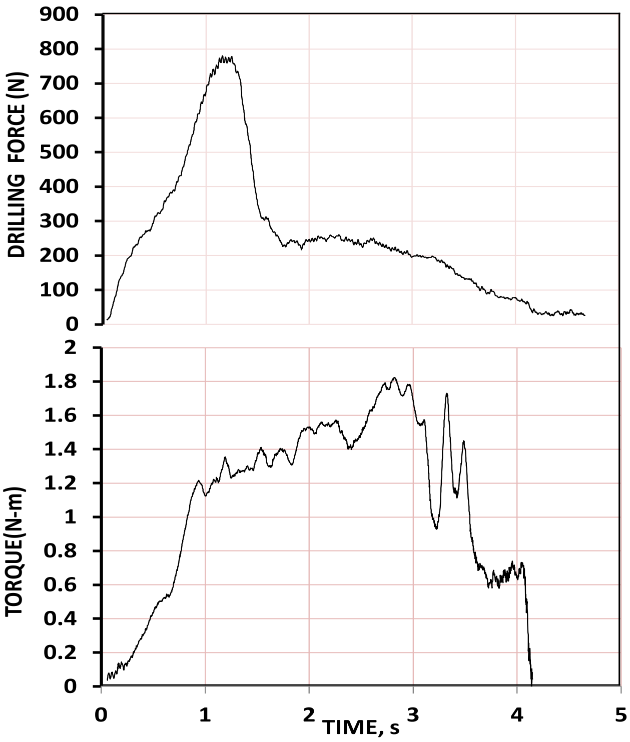


Figure 24

Thrust force and torque in friction drilling of STAINLESS STEEL

The torque rapidly rose to 1.2 N m after the tool reached position A. The thrust force drops rapidly to 250 N, less than half of the peak value. The center of the drill contributes a majority of the thrust force. Change in color was observed inside the hole due to the increased temperature. the thrust force remains at about 300 N and the torque gradually increases to the maximum at 1.8 N m. The conical region of the tool has perforated the work piece and pushed the work-material aside to form a bushing. Rings of discoloration were observed inside and outside the hole, indicating the further increase of work piece temperature. Both the force and torque start to decrease after 3 seconds, which means it comes up to the retracting point. And the force is reduced to almost zero or even negative.

5.2. FRICTION DRILLING TORQUE

5.2.1. DC 06 STEEL

Table 9 Friction drilling torque experiment of DC 06 steel

Thickness (mm)	SPINDLE SPEED (rpm)	FEED RATE, mm/min	TORQUE (kN)
1.5	2000	60	2.7
1.5	2000	100	2.3
1.5	2000	140	2.6
1.5	2500	60	1.7
1.5	2500	100	1.9
1.5	2500	140	2
1.5	3000	60	2
1.5	3000	100	1.5
1.5	3000	140	1.9

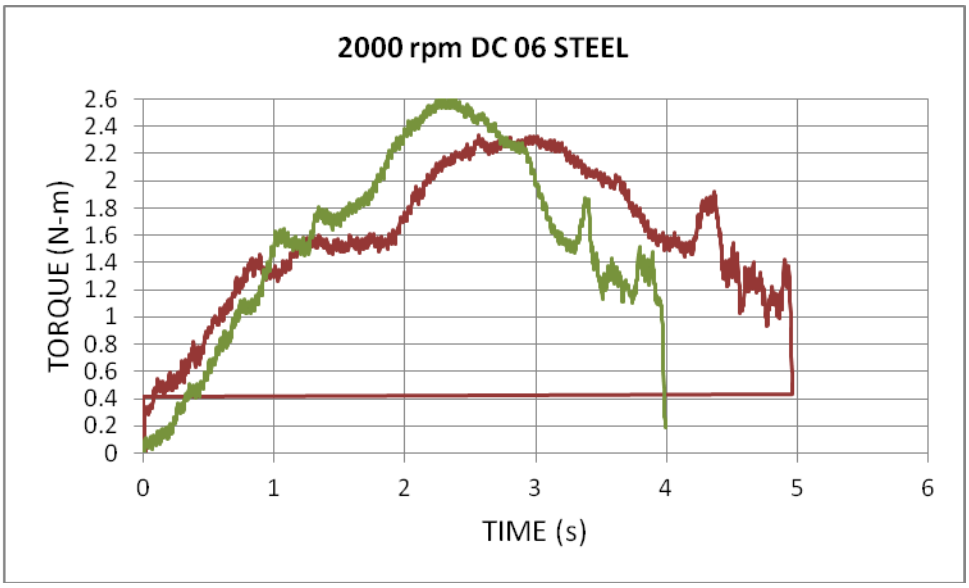


Figure 25 Spindle rotation speed 2000 rpm (torque) DC 06 steel

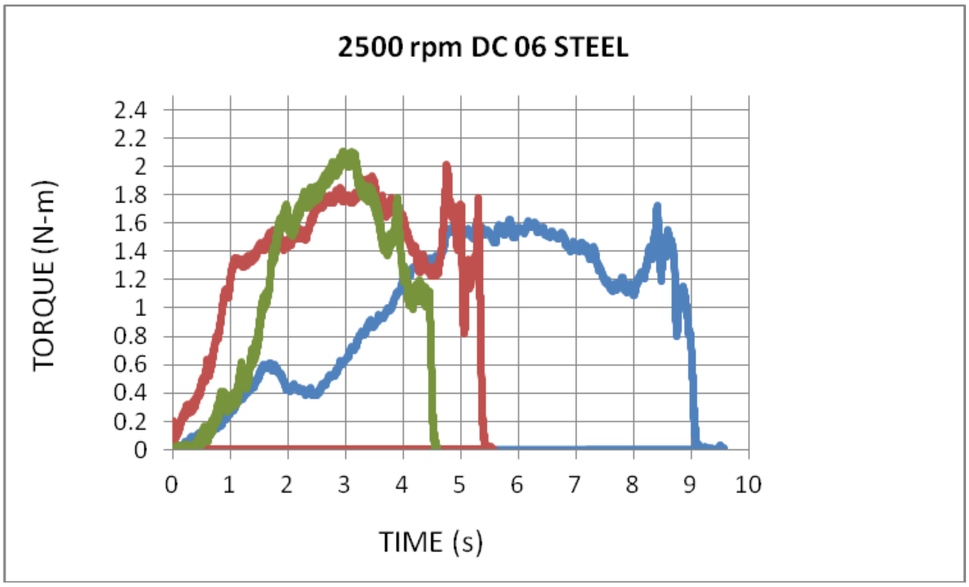


Figure 26 Spindle rotation speed 2500 rpm (torque) DC 06 steel

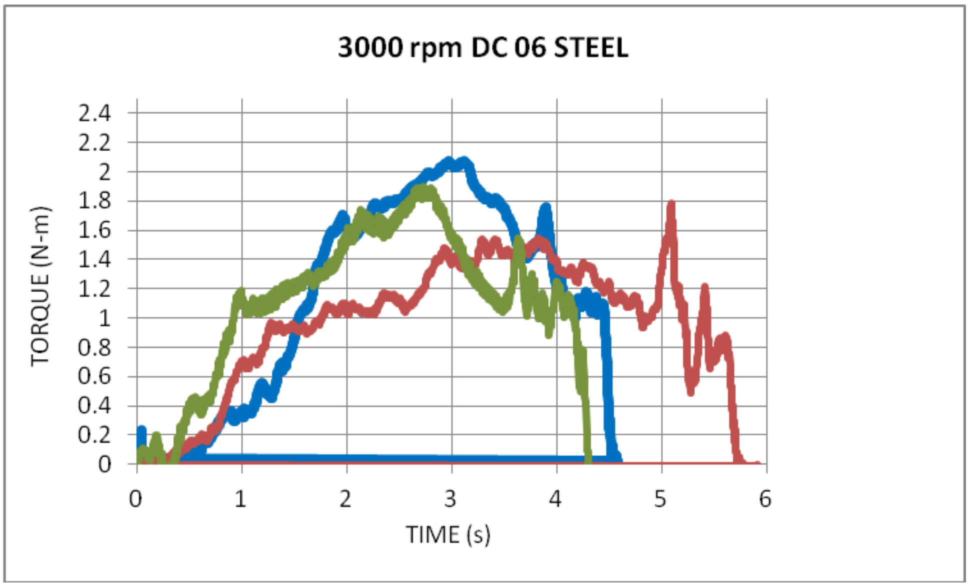


Figure 27 Spindle rotation speed 3000 rpm (torque) DC 06 steel

5.2.2. 4301 STAINLESS STEEL

Table 10 Friction drilling torque of 4301 Stainless Steel

Thickness (mm)	SPINDLE SPEED (rpm)	FEED RATE, mm/min	TORQUE (kN)
1	2000	60	1.2
1	2000	100	1.4
1	2000	140	1.8
1	2500	60	1
1	2500	100	1.2
1	2500	140	1.3
1	3000	60	0.9
1	3000	100	1.1
1	3000	140	1.2

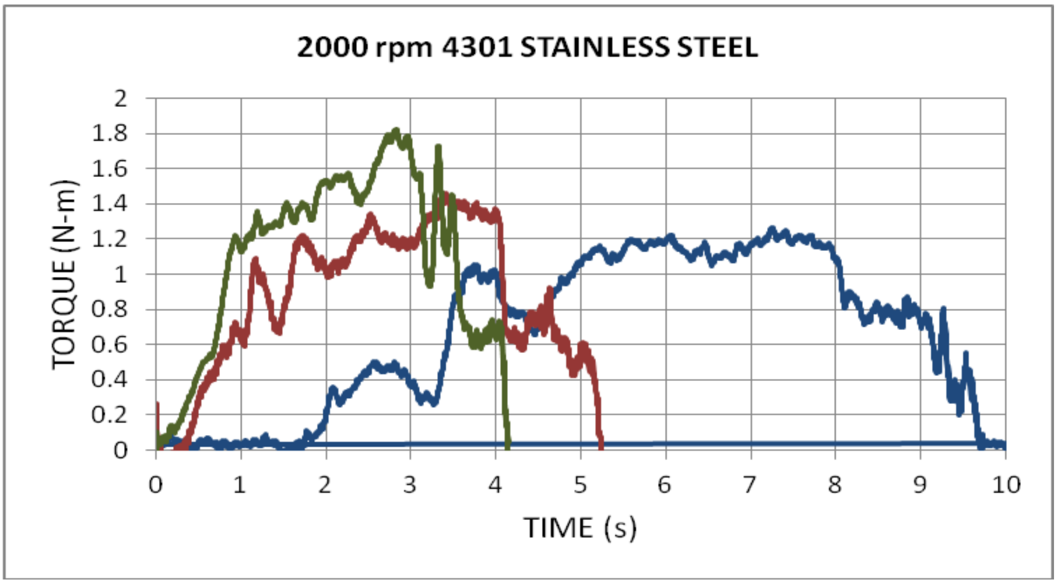


Figure 28 Spindle rotation speed 2000 rpm (torque) 4301 SS

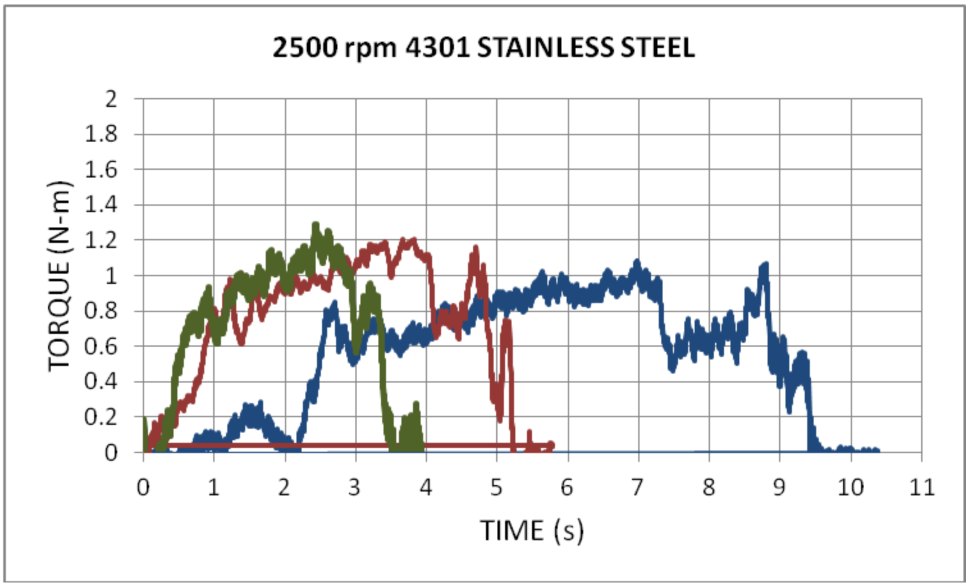


Figure 29 Spindle rotation speed 2500 rpm (torque) 4301 SS

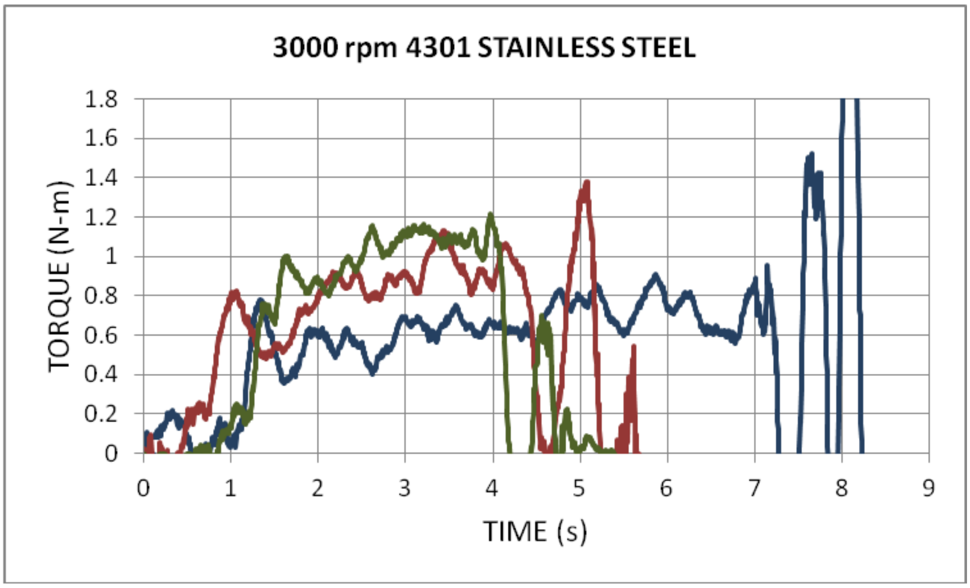
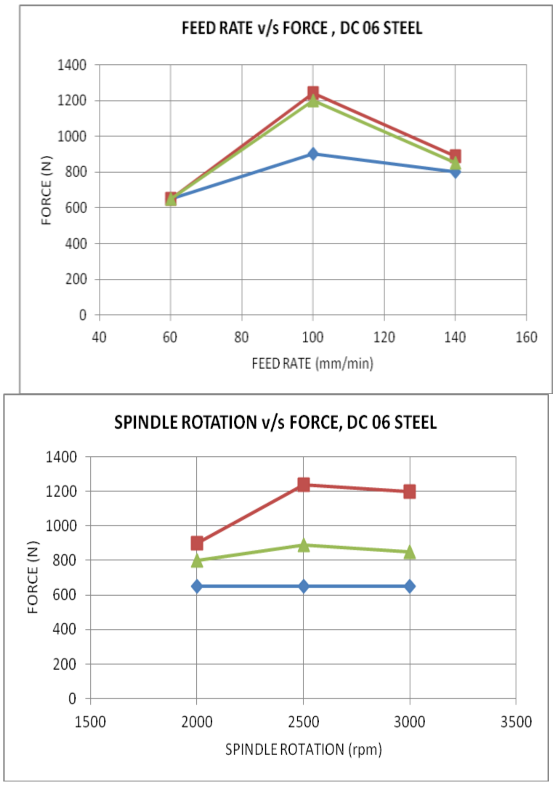


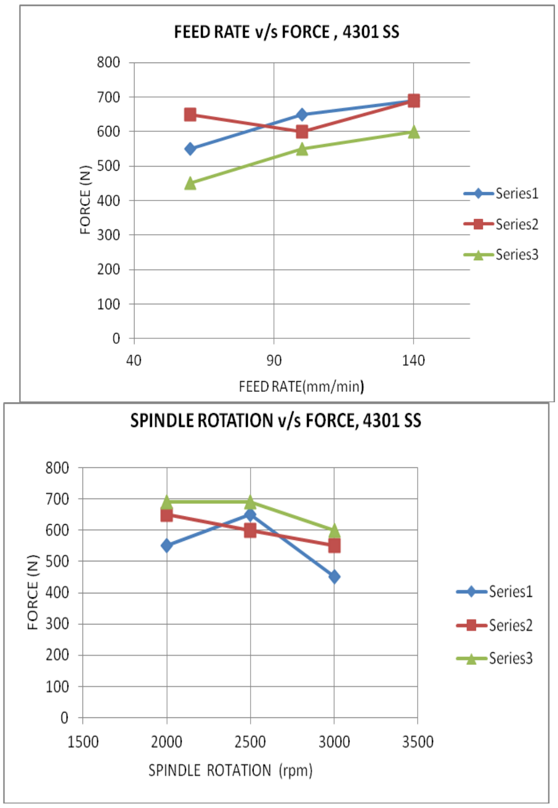
Figure 30 Spindle rotation speed 3000 rpm (torque) 4301 SS

6. ANALYSIS OF FORCE ANALYSIS AND TORQUE ANALYSIS

6.1. FORCE ANALYSIS OF DC 06 STEEL AND 4301 STAINLESS STEEL



a . b



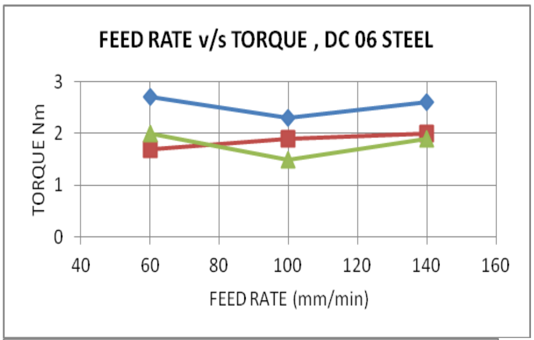
c d

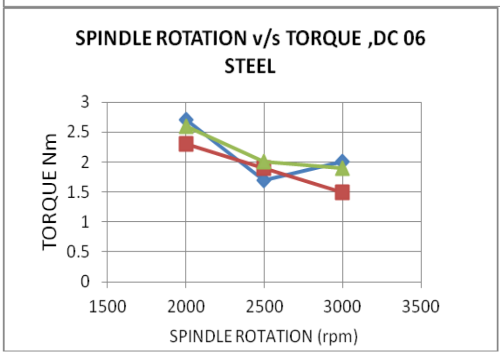
Figure 31 a) Spindle rotation v/s Force, dc o6 steel b) Feed rate v/s Force, dc 06 steel

c) Feed rate v/s Force, 4301 SS d) Spindle rotation v/s Force, 4301 SS

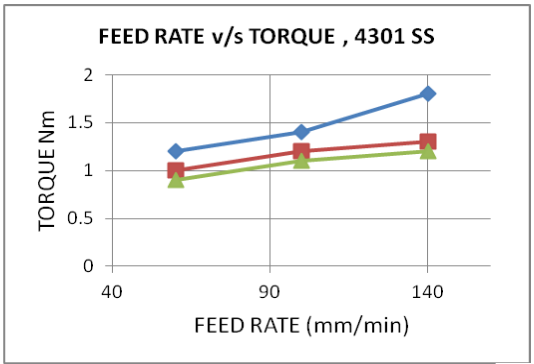
In the figure 31 we can see that the spindle rotation is influencing more than that of the feed rate for DC 06 Steel Force is almost same for the different feed rate . But in the case of 4301 stainless steel , cudnt find out which is influencing more ,because both the feed rate and spindle rotation made the force which is very close as we can see in the graph.The thickness of the 4301 stainless steel is 1mm and thus we can come into a conclusion that the here the thickness influenced a lot for the force produced for the drilling. And in the figure 31.d the outputs are almost same for 2500 rpm and thus for the feed rate of 100 mm/min also made the force almost near to other.

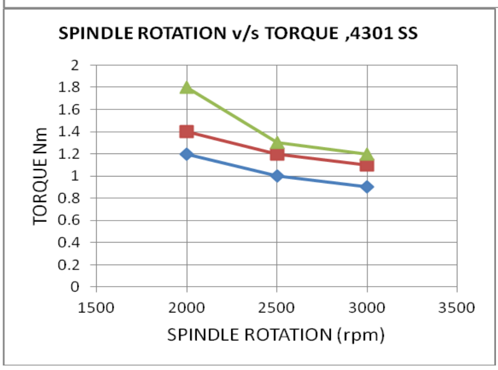
6.2. TORQUE ANALYSIS OF DC 06 STEEL AND 4301 STAINLESS STEEL





a b





c d

Figure 32 a) Feed rate v/s Torque, dc o6 steel b) Spindle rotation v/s Torque, dc 06 steel c) Feed rate v/s Torque, 4301 SS d) Spindle rotation v/s Torque, 4301 SS

Here the feed rate is influencing more for the DC 06 Steel and spindle rotation is not much influencing the torque. But there are .some little changes, In the 100 mm/min feed rate the torque is coming closer and it is almost between 2.5 N-m and 1. 5 N-m. So we can finalize that the feed rate And here the thickness of the material also is the reason for the changes in torque according to the feed rate and spindle rotation. The mechanical characteristics of the materials are different and it place a major role in the quality of the bushing and threading more over its feed rate and spindle rotation. And the quality of the tool also influence the quality of the threading

7. STATISTICAL INVESTIGATION OF FRICTION DRILLING PROCESS

7.1. Regression analysis

In modern science Regression analysis is a necessary part of virtually almost any data reduction process. We are done regression analysis by using Microsoft office Excel. Here the regression analysis is explained in the linear regression model. However the description of the output is minimal and is often a mystery for the user who is unfamiliar with certain statistical concepts. In statistics, linear regression is a form regression analysis observational data are modeled by a function which is linear combination of the model parameters and depends on one or more independent variables. The statistical tool , regression analysis helps to estimate the value of one variable from the given value of another.

By using the regression analysis, we study the relationship between the one variable y and several other factors xi. And here y is called the dependent variable and xi is called the independent variable. Regression function also involves a set of unknown parameters bi. If a regression function is linear in the parameters, we will call its as linear regression model. Linear regression model with more than one independent variable are referred to as multiple linear models, as opposed to simple linear models with one independent variable.

Model selection

To determine the best set of parameters bi, such that the model predicts the experimental values of the dependent variables as possible. Here the calculated values should be close to the experimental values.

$$Y = a_0 + a_1X_1 + a_2X_2 + \cdots + a_nX_n$$

where Y is independent function (force or torque); a_0 ... a_n are regression model coefficients; X_1 ...X_n are independent variables.

X_1 – plate thickness, X_2 –S (drilling speed, rpm), X_3 –F (drilling feed, mm/min).

ANOVA

Analysis of Variance is popularly known as ANOVA. It can be used in cases where there are more than two groups. When we have only two samples we can use the test to compare the means of the samples but it might become unreliable in case of the more than two samples.

Different factors affect the responses to a different degree. The relative magnitude of the factor effects could be judged from their factor levels, which gives the average efficiency for each level. And it is commonly called analysis of variance. It is also helpful for estimating the error variance for the factor effects and variance of the prediction error. These aspects are used in my study. Here the present research is an effort to investigate the influence of process parameters such as spindle rotation and feed rate and also the mechanical properties of the materials. Analysis of variance is used here to investigate the influence of process parameters such as spindle rotation and feed rate and also the mechanical properties of the materials.

F-distribution

F- Distribution is a continuous probability distribution. It is used most commonly in analysis of variance. Each distribution has specific degrees of freedom in the numerator and the denominator. In this type of distribution, the numerator degrees of freedom are always giving at the first as changing the order of degrees of freedom changes the distribution. And confidence level is the interval in which a measurement to given probability.

7.2. Statistical result using MS office Excel for drilling force (spindle rotation and feed rate)

Regression Statistics					
Multiple R	0.84042372				
R Square	0.70631203				
Adjusted R Square	0.6433789				
Standard Error	122.594311				
Observations	18				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	506033.3333	168677.778	11.2232138	0.000510296
Residual	14	210411.1111	15029.3651		
Total	17	716444.4444			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-238.888889	246.6739841	-0.9684397	0.34925863	-767.9519647
X Variable 1	480	115.5830248	4.15285896	0.00097611	232.0990678
X Variable 2	0.01	0.070779858	0.14128313	0.8896591	-0.141807698
X Variable 3	3.58333333	0.88474823	4.05011642	0.00119298	1.685737112
			Upper 95%	*Lower 95,0%*	*Upper 95,0%*
Intercept			290.174187	-767.95196	290.1741869
X Variable 1			727.900932	232.099068	727.9009322
X Variable 2			0.1618077	-0.1418077	0.161807698
X Variable 3			5.48092955	1.68573711	5.480929554

7.3. Statistical result using MS office Excel for drilling force (Mechanical Properties)

Regression Statistics					
Multiple R	0.60148699				
R Square	0.3617866				
Adjusted R Square	0.19689826				
Standard Error	169.049631				
Observations	18				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	259200	86400	9.06998445	0.001375145
Residual	16	457244.444	28577.7778		
Total	19	716444.444			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	1824.44444	360.815263	5.05645029	0.00011681	1059.550261
X Variable 1	0	0	65535	#NUM!	0
X Variable 2	-5.3333333	1.77090579	-3.0116415	0.00827601	-9.087485867
X Variable 3	0	0	65535	#NUM!	0
			Upper 95%	*Lower 95,0%*	*Upper 95,0%*
Intercept			2589.33863	1059.55026	2589.338628
X Variable 1			0	0	0
X Variable 2			-1.5791808	-9.0874859	-1.579180799
X Variable 3			0	0	0

7.4. *Statistical result using MS office Excel for drilling torque (spindle rotation and feed rate)*

Regression Statistics					
Multiple R	0.92666825				
R Square	0.85871404				
Adjusted R Square	0.82843848				
Standard Error	0.22294031				
Observations	18				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	4.229166667	1.40972222	28.3632735	3.30552E-06
Residual	14	0.695833333	0.04970238		
Total	17	4.925			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.7125	0.448581778	1.58833915	0.13453146	-0.249612223
X Variable 1	1.66666667	0.210190138	7.92932857	1.5182E-06	1.215853658
X Variable 2	-0.0005667	0.000128715	-4.4025034	0.00060191	-0.000842732
X Variable 3	0.00270833	0.001608933	1.68331011	0.11447187	-0.000742485
			Upper 95%	*Lower 95,0%*	*Upper 95,0%*
Intercept			1.67461222	-0.2496122	1.674612223
X Variable 1			2.11747968	1.21585366	2.117479676
X Variable 2			-0.0002906	-0.0008427	-0.000290601
X Variable 3			0.00615915	-0.0007425	0.006159152

7.5. *Statistical result using MS office Excel for drilling torque (Mechanical Properties)*

Regression Statistics				

Multiple R	0.796566235				
R Square	0.634517766				
Adjusted R Square	0.486675127				
Standard Error	0.335410197				
Observations	18				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	3.125	1.04166667	27.77777778	3.7416E-06
Residual	16	1.8	0.1125		
Total	19	4.925			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	5.4	0.715891053	7.54304719	1.17923E-06	3.882378773
X Variable 1	0	0	65535	#NUM!	0
X Variable 2	-0.018518519	0.003513642	-5.2704628	7.61696E-05	-0.025967106
X Variable 3	0	0	65535	#NUM!	0
			Upper 95%	*Lower 95,0%*	*Upper 95,0%*
Intercept			6.91762123	3.882378773	6.917621227
X Variable 1			0	0	0
X Variable 2			-0.0110699	-0.025967106	-0.011069931
X Variable 3			0	0	0

7.6. ANOVA RESULTS AND CALCULATION OF AXIAL DRILLING FORCE

Table 11 ANOVA results of cutting regimes influence on axial drilling force variation

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	506033.3	168677.8	11.22321	0.00051
Residual	14	210411.1	15029.37		
Total	17	716444.4			

From the Table we have:

f_1=3 *(regression)*

df_2=14*(residual)*

From the F distribution table, we will get, $F_{(0.05)} = 3.5874$.

And we know that the Experimental value is F_{exp}=11.22321

So $F_{exp} > F_{(0.05)}$

Conclusion: if $F_{exp} > F_{(0.05)}$, we reject the null hypothesis is rejected and with 71% probability regression model explains cutting regimes influence on axial drilling force variation

Table 12 Regression Coefficients

Intercept	-238.889
X Variable 1	480
X Variable 2	0.01
X Variable 3	3.583333

$$F_{max} = -238.9 + 480 \cdot t + 0.01 \cdot S + 3.583 \cdot F$$

7.7. Comparison of experimental and predictable drilling force

Table 13 Comparison of experimental and predictable drilling force

Thickness(mm)	Spindle rotation,rpm	Feed rate, mm/min	F_{exp}, N	$F_{predict}$, N
1.5	2000	60	650	716
1.5	2000	100	800	859
1.5	2000	140	850	1002
1.5	2500	60	650	721
1.5	2500	100	890	864
1.5	2500	140	1240	1008
1.5	3000	60	650	726
1.5	3000	100	850	869
1.5	3000	140	1200	1012
1	2000	60	550	477
1	2000	100	650	620
1	2000	140	790	763.52
1	2500	60	650	481.88
1	2500	100	640	625
1	2500	140	690	769
1	3000	60	500	487
1	3000	100	550	630
1	3000	140	600	773.52

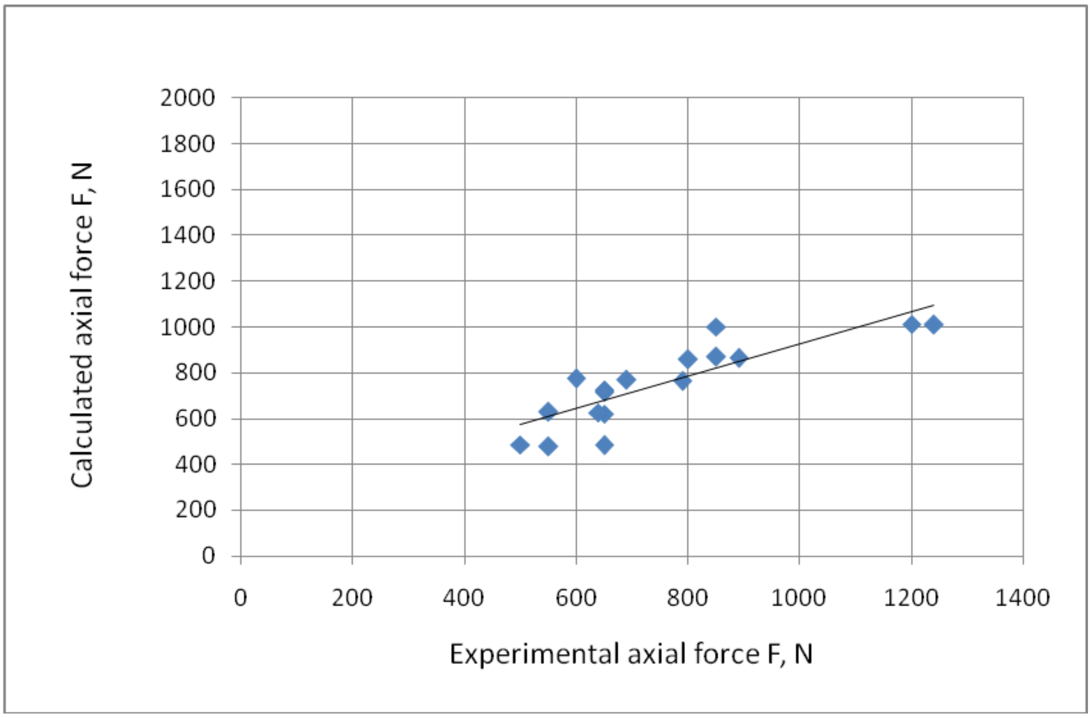


Figure 33 Experimental axial force v/s Calculated axial force

In the figure 33, we can see the experimental force values and the calculated or the predicted value. The error percentage is very low here and only a small changes in the value. The co efficient of the axial drilling force that we got it from the regression analysis through the statistical analysis by the help of Microsoft spreadsheet. And from the graph we can get into the conclusion that in the experimental axial drilling force values are also affected by the mechanical and chemical characteristic of the materials. Because we only add the thickness of the material for the regression analysis.

By analyzing the table 13, we get an idea that there is only a little bit changes in the calculated values and the experimental values. And the error percentage is small and it has positive increase for the calculated values.

7.8. *ANOVA RESULTS AND CALCULATION OF DRILLING TORQUE*

Table 14 ANOVA results of cutting regimes influence on axial drilling torque variation

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	4.229167	1.409722	28.36327	3.30552E-06
Residual	14	0.695833	0.049702		
Total	17	4.925		`	

From the Table we have:

f_1=3 *(regression)*

df_2=14*(residual)*

From the F distribution table, we will get, $F_{(0.05)} = 3.5874$

And we know that the Experimental value is F_{exp}=28.36327

So $F_{exp} > F_{(0.05)}$

Table 15 Regression Coefficients

Intercept	0.7125
X Variable 1	1.666667
X Variable 2	-0.00057
X Variable 3	0.002708

$$F_{max} = 0.7125 + 1.67 \cdot t - 0.00057 \cdot S + 0.002708 \cdot F$$

7.9. Comparison of experimental and predictable drilling Torque

Table 16 Comparison of experimental and predictable drilling Torque

t, mm	Spindle rotation,rpm	Feed rate, mm/min	T_{exp}, N-m	$T_{predict}$, N-m
1.5	2000	60	2.7	2.24
1.5	2000	100	2.3	2.35
1.5	2000	140	2.6	2.46
1.5	2500	60	1.7	1.95
1.5	2500	100	1.9	2.06
1.5	2500	140	2	2.2
1.5	3000	60	2	1.7
1.5	3000	100	1.5	1.8
1.5	3000	140	1.9	1.9
1	2000	60	1.2	1.4
1	2000	100	1.4	1.5
1	2000	140	1.8	1.6
1	2500	60	1	1.1
1	2500	100	1.2	1.23
1	2500	140	1.3	1.05
1	3000	60	0.9	1.4
1	3000	100	1.1	1.2
1	3000	140	1.2	1.1

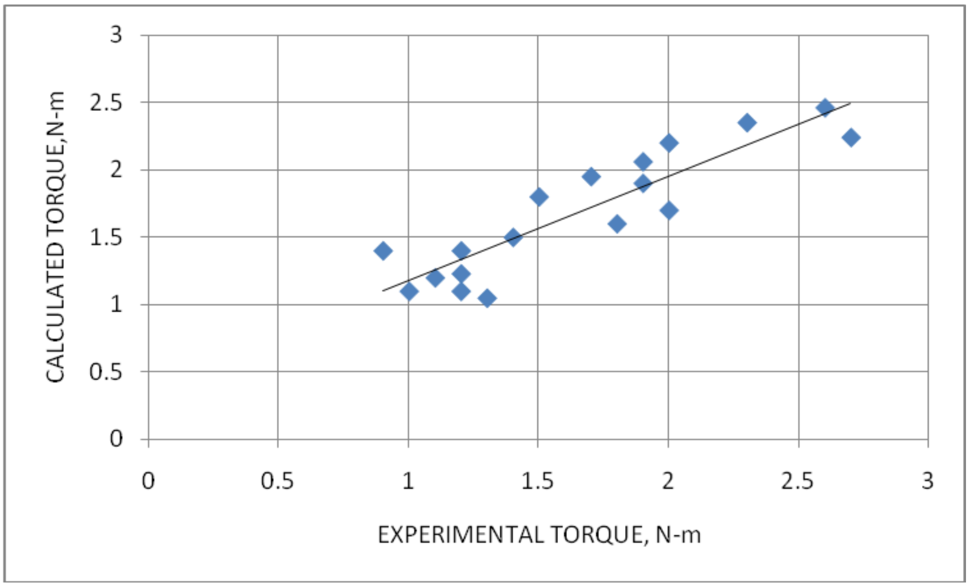


Figure 34 Experimental axial torque v/s Calculated axial torque

In the table 16, the comparison between the calculated torque and experimental torque values are showing and it has only a little bit of changes when compared to the experimental values of the two materials such as DC 06 steel and 4301 Stainless steel respectively. From the fig 34 also we will come into a conclusion that the percentage of error is very small and thus we can easily predict the force and torque according to the thickness, feed rate and spindle rotation speed. And we know that the quality of the products is according to these parameters mainly and the characteristics of the material.

CONCLUSION

This study investigates the thermal friction drilling effects on surface temperature, thrust force and torque. Experimental data support the following conclusions:

- Thrust force and torque increases gradually with increasing friction angle, feed rate an
- Thrust force and torque decreases with increasing spindle speed.
- As the spindle speed increases, the work piece surface temperature increases.
- Increasing or decreasing the friction angle and FCAR has no significant effect on work piece surface temperature.
- There is an increase in surface roughness as the feed rate increases.
- The bushing length decreases as the feed rate increases

Bibliography

1. *Friction drilling of cast metals. –International Journal of Machine Tools and Manufacture.* **Scott F. Miller, Jia Tao, Albert J. Shih.** 2006.

2. *Experimental and numerical analysis of the friction drilling process. –Journal of Manufacturing Science and Engineering.* **Scott, F. Miller, Rui Li, Hsin, Wang, Albert, J. Shih.** 2006.

3. *http://www.sciencedirect.com.*

4. *http://www.formdrill.com.*

5. *http://www.flowdrill.com.*

6. *http://wumrc.engin.umich.edu/wp-content/uploads/sites/51/2013/08/MillerScott_Friction_Drilling_Dissertation6.pdf.*

7. *http://www.mcsshop.com/Pages/FlowForming_Definition.aspx.*

8. *http://www.tcsme.org/Papers/Vol38/Vol38No3Paper4.pdf.*

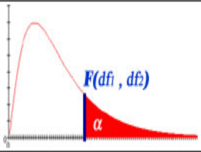
9. *"Some investigations in friction drilling AA6351 using high.* **Krishna, P.V., Kishore, K. and Satyanarayana, V.V.**

10. *Experimental and statistical investigation of thermo-mechanical friction drilling process .* **Krasauskas, P.**

APPENDIX

1) F Table

F Table for α = 0.05



/	df_1=1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
df_2=1	161.4476	199.5000	215.7073	224.5832	230.1619	233.9860	236.7684	238.8827	240.5433	241.8817	243.9060	245.9499	248.0131	249.0518	250.0951	251.1432	252.1957	253.2529	254.3144
2	18.5128	19.0000	19.1643	19.2468	19.2964	19.3295	19.3532	19.3710	19.3848	19.3959	19.4125	19.4291	19.4458	19.4541	19.4624	19.4707	19.4791	19.4874	19.4957
3	10.1280	9.5521	9.2766	9.1172	9.0135	8.9406	8.8867	8.8452	8.8123	8.7855	8.7446	8.7029	8.6602	8.6385	8.6166	8.5944	8.5720	8.5494	8.5264
4	7.7086	6.9443	6.5914	6.3882	6.2561	6.1631	6.0942	6.0410	5.9988	5.9644	5.9117	5.8578	5.8025	5.7744	5.7459	5.7170	5.6877	5.6581	5.6281
5	6.6079	5.7861	5.4095	5.1922	5.0503	4.9503	4.8759	4.8183	4.7725	4.7351	4.6777	4.6188	4.5581	4.5272	4.4957	4.4638	4.4314	4.3985	4.3650
6	5.9874	5.1433	4.7571	4.5337	4.3874	4.2839	4.2067	4.1468	4.0990	4.0600	3.9999	3.9381	3.8742	3.8415	3.8082	3.7743	3.7398	3.7047	3.6689
7	5.5914	4.7374	4.3468	4.1203	3.9715	3.8660	3.7870	3.7257	3.6767	3.6365	3.5747	3.5107	3.4445	3.4105	3.3758	3.3404	3.3043	3.2674	3.2298
8	5.3177	4.4590	4.0662	3.8379	3.6875	3.5806	3.5005	3.4381	3.3881	3.3472	3.2839	3.2184	3.1503	3.1152	3.0794	3.0428	3.0053	2.9669	2.9276
9	5.1174	4.2565	3.8625	3.6331	3.4817	3.3738	3.2927	3.2296	3.1789	3.1373	3.0729	3.0061	2.9365	2.9005	2.8637	2.8259	2.7872	2.7475	2.7067
10	4.9646	4.1028	3.7083	3.4780	3.3258	3.2172	3.1355	3.0717	3.0204	2.9782	2.9130	2.8450	2.7740	2.7372	2.6996	2.6609	2.6211	2.5801	2.5379
11	4.8443	3.9823	3.5874	3.3567	3.2039	3.0946	3.0123	2.9480	2.8962	2.8536	2.7876	2.7186	2.6464	2.6090	2.5705	2.5309	2.4901	2.4480	2.4045
12	4.7472	3.8853	3.4903	3.2592	3.1059	2.9961	2.9134	2.8486	2.7964	2.7534	2.6866	2.6169	2.5436	2.5055	2.4663	2.4259	2.3842	2.3410	2.2962
13	4.6672	3.8056	3.4105	3.1791	3.0254	2.9153	2.8321	2.7669	2.7144	2.6710	2.6037	2.5331	2.4589	2.4202	2.3803	2.3392	2.2966	2.2524	2.2064
14	4.6001	3.7389	3.3439	3.1122	2.9582	2.8477	2.7642	2.6987	2.6458	2.6022	2.5342	2.4630	2.3879	2.3487	2.3082	2.2664	2.2229	2.1778	2.1307
15	4.5431	3.6823	3.2874	3.0556	2.9013	2.7905	2.7066	2.6408	2.5876	2.5437	2.4753	2.4034	2.3275	2.2878	2.2468	2.2043	2.1601	2.1141	2.0658
16	4.4940	3.6337	3.2389	3.0069	2.8524	2.7413	2.6572	2.5911	2.5377	2.4935	2.4247	2.3522	2.2756	2.2354	2.1938	2.1507	2.1058	2.0589	2.0096