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# EVOLUTION AND RECENT TRENDS IN FRICTION DRILLING TECHNIQUE AND THE APPLICATION OF THERMOGRAPHY

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**Abstract:**Friction drilling is a new trend of hole making process in which the frictional force between the tool and work material is used for hole making, by thrusting of the tool into the work material without chips formation as like conventional drilling.During friction drilling ductility of the material increases with heat, which causes the material to extrude on the front and backsides of the hole, which forms the boss and bush respectively on the work piece, so it provides the required projection for threading. The damage to the surface occurring during the hole making, takes place at high temperature, which could be monitored using thermography. By using this technique damages occur during manufacturing can be monitored and minimized.Due to high temperature during drilling various phenomena like thermal phase transition, plastic flow of material and extrusion may occur, which directly influences mechanical properties and may cause plastic material from the hole surface.Friction drilling is used for hole making process of aerospace, automotive, commercial and industrial products.
***Keywords*:**Friction Drilling, Extrusion, Thermography, boss, bush.

## 1. INTRODUCTION

In conventional drilling the main defects and damages are at the plate entrance and exit in the hole wall. These type of errors happen mainly due to anisotropy of the material[1]. Recent technological development over conventional drilling is friction drilling. Friction drilling is a new trend of hole making without chips, with maximum of 12mm thickness and the friction drilling needs high force for hole making[2]. Rotating a conical tool at high speed causes work material to soften and the tool to penetrate to penetrate the work

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piece,due to the heat generated by friction and thus making a hole on the work piece. While heat increases ductility of material extrudes itself on front and back side of the hole[3].

The extruded work material forms boss and bush on the work piece, where bushing is formed 3 times the size of work material. The advantages of friction drilling is bushing increases depth for the threading, its clean and chip less hole making process[4].Major concern during machining of composites is delaminating, mainly at plate entrance and exit[5]. Delamination factors are characterized by the damages caused at the entrance and exit. Major role for reducing damages at the entrance and exit is by high speed cutting or by minimizing point angle and low feed rate[6]. Several investigation have studied the damages caused during drilling by using thermograph, these thermography technique can help in avoiding manufacturing related damages[2].

Several investigators have used different materials for research, on hole making through conventional friction drilling. Different work piece material used are carbon/epoxy, woven composite, glass epoxy laminate, carbon fiber reinforced plastic etc. Tools with coated and non-coated have been studied and it is observed that coating on the tool plays a major role in reducing damages[7]. Quality of drilled hole can be improvedby using optimization techniques and suitable parameters and tool material can be established[8, 9]

## 2. EXPERIMENTAL SETUP

Friction drilling experimental are generally carried out by using a three axis computer numerical controlled vertical machining center. Typical setup of friction drilling has a work piece held rigidly on top of a piezo electric drilling dynamometer. The fig 1 shows the difference stages of friction drilling process, for making hole.

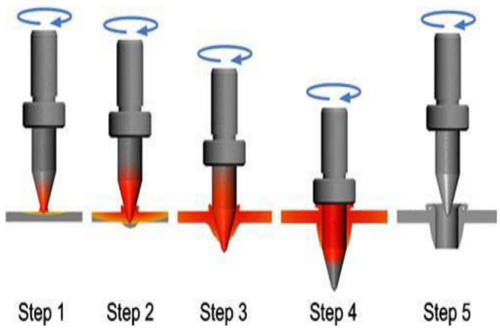


**Figure 1** Stages of tool position infriction drilling[9]

In stage 1 the work piece and tool comes in contact, in stage 2 the conical tool is penetrate the work piece due to the heat which developed by the frictional force. In this stage thrust force on the tool is at its peak and extrusion of material can be also seen, due to the ductility of the work material[3]. In stage 3 bushing can be identified due to the extrusion of material in the exit side of the hole. In stage 4 back extrusion is formed on the work piece at the entry side of the hole[3]. Schematic diagram of CNC machining centreexperimental set up for friction drilling setup was shown in fig 2[8].

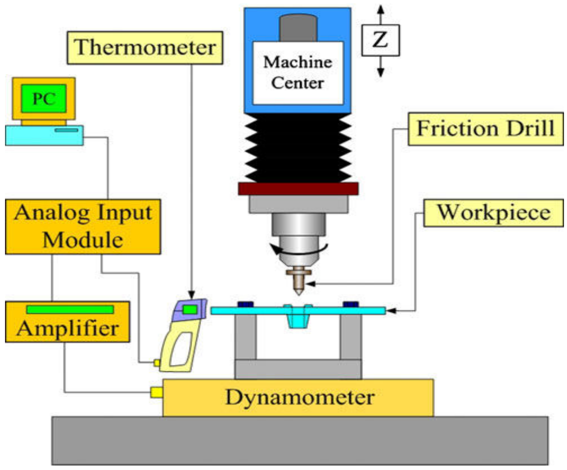


**Figure 2** Experimental setup of Friction Drilling[8]

During the friction drilling process the work piece is held on the dynamometer. Further to a thermometer/ sensor is fixed on the work piece while machining, for measuring temperature in drilling zone[8].

## 3. THRUST FORCE AND TORQUE

In [9]experimentally investigated ALSI 1020 steel, observed that peak thrust force of 700N occurs at a tool travel of 2.5mm from the starting contact with the work piece as shown in fig 3 at the initial position. Further torque rose to 1.5 N-m from 0.5 N-m with increase in torque, thrust force decrease to 300N.

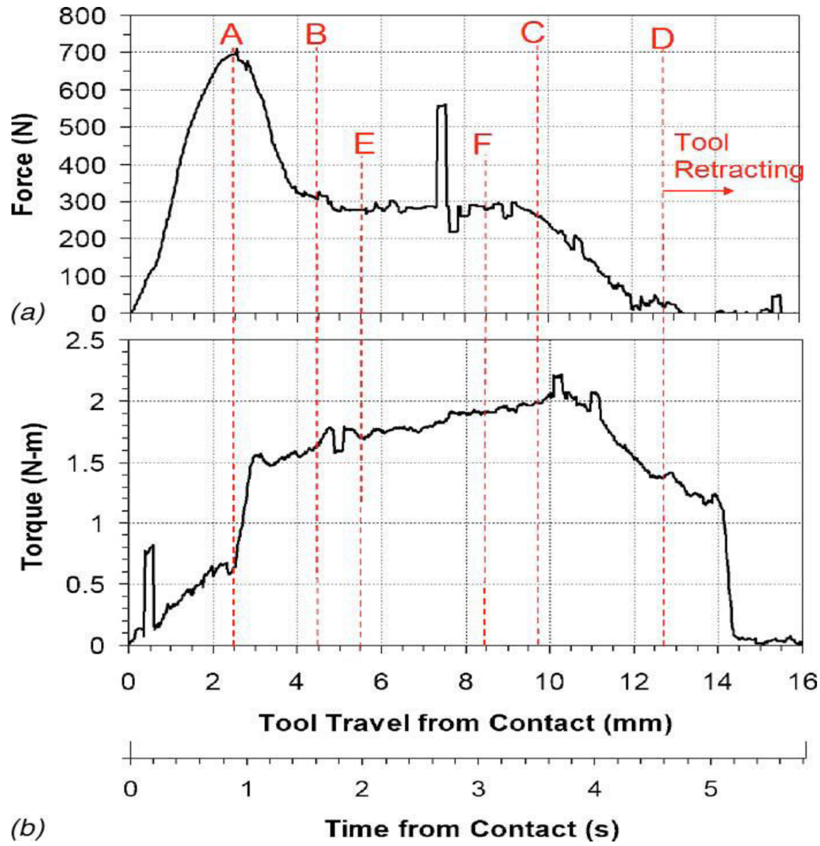


**Figure 3**. Torqueand Thrust Force in friction drilling[9]

In that position torque will be increased to 1.7 N-m. Suddenly after third position torque and thrust decreases, owing to this discoloring rings are found inside and outside of hole[9]

In [3]conducted experiment with spindle speed of 3000rpm and tool feed rate of 2.53 mm/s, 4.23mm/s and 5.93 mm/s, and measured tool thrust force and torque was measured using thermocouple with coefficient of friction of 0.7 at feed rate 5.95mm/s , 4.23 mm/s, 2.54mm/s, its observed that peek thrust force and torque are about 800N, 750N and 700N respectively as shown in fig 4. For the above paper its observed that during machining process, temp which is developed was about 400° C, 350° C, 270° C at 2.74mm, 3.48mm, 5.11mm respectively.

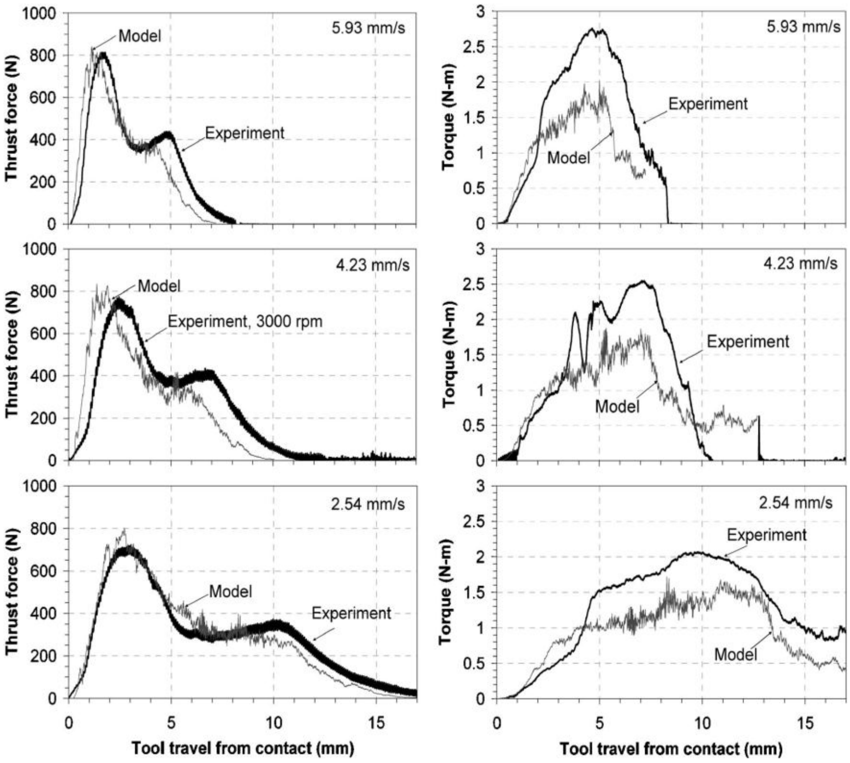


Fig 4 Comparison of the model predicted trust force and torque versus experiment in friction drilling (3000 rpm spindle speed and 5.93 mm/s, 4.23 mm/s and 2.54 mm/s ) for 0.7 coefficient of friction[3]

For the prediction of thrust force and torque in friction drilling process, it's purely based on pressure and contact area between tool and work piece.Boopathiet al[4] concluded in there paper that at constant feed rate, thrust force decreases linearly. This implies heat energy produced will be greater at higher speed and thus concluded that high tool speed, thrust decreases during penetration of hole. The investigators observed that for Aluminum peak thrust force is 1512N, for brass Peak thrust force 1798N, and Stainless steel peak thrust force 2745N for penetrating a hole.

## 4. MATERIAL SELECTION

A New generation material which is applied in aerospace, automotive etc was sandwich material, which is made by thin sheets and polymer/resin[11]. Sandwich material was prepared by using roll-joining process with the help of skin material and polypropylene, these will give good load bearing capacity[13].The tensile modulus and tensile strength of Glass fiber reinforced epoxy based composites increases with the tensile strength[10, 11].

In[2] conducted friction drilling analysis with two different materials glass epoxy TSE-2 laminate and sandwich laminate,the author concluded that heat generated is more when compared with sandwich composite. While machining with Bosh drilling machine, HSS drill bit are used. R piquet et al[15]used thin carbon/epoxy.Drill bit made up of k20 rated micro grain tungsten carbide, but two different tool geometry i.e op1 and op2 both having 3 cutting edges, maximum cutting edge is 59°, minimum cutting edge is 0°, clearance angle is 0°, rake angle for both op1 and op2 in 0°, in op1 no chamfer angle is available, author concluded that if feed rate is decreased quality can be increased.

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In [7] investigated parameters of nano coated drilling on CFRP/ aluminum sandwich material. Tools used are tungsten carbide drill with nano coating and non nano coated tool. Author observed that during drilling on material aluminum and composites thrust force is reduced with the help of non-coated tool, while surface roughness is minimum for sandwich material. Scott f miller et al[16] studied microstructure alteration associated with friction drilling of Titanium, Aluminum, Steel it was observed that microstructure is affected by heat produced during friction drilling process. It was observed that while friction heat and temperature is also increased, results in material elongation and bushing.

Sanjay Rowat et al[30] investigated characteristics of High Speed drilling of woven composites and found that, chisel edge of drill cause hard graphite fiber fracture inside the soft epoxy material, this happened based on fracture mechanism, thrust force increases with low feed rate and medium speed. Jose Mathew et al[17], reviewed carbon fiber reinforced plastic composite material and concluded difference in thermal properties of the carbon fiber matrix of material in composites and the difficulties in maintaining good quality cuts to maintain high quality better focusing behavior of pulsed Nd: YAG laser and high beam intensity gives a smaller thrust load during cutting. This creates minimum defects concluded that damages are obtained by repetition rate, pulse duration, cutting speed and beam energy.

## 5. TOOL SELECTION

In Friction drilling drill bit is made up of cylindrical rod made up of Tungsten Carbide with grain size super finish. A diamond grinder is used for grinding into a conical shape for friction drilling tool as shown in fig 5 and fig 6. Fig 5 shows Friction Contact Area Ratio 100% Fig 6 shows FCAR of 50%. ie, friction contact area ratio in this drill four friction contact area shown in fig .FCAR was defined in friction contact area/ circumference area as shown in fig 5.

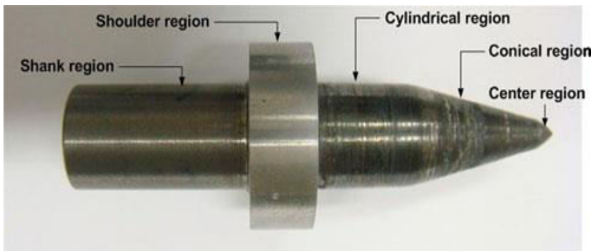


**Figure 5** FCAR of 100% [8]

**Figure 6** FCAR of 50% [8]

M Boopathi et al [4] investigated the use of tungsten carbide tool for making hole, they performed experiments on brass, aluminum and stainless steel, and concluded thatbrinell hardness for each metal

Aluminum, Brass, Stainless steel is 122,208,477 respectively and incase of aluminum high adhesion of work piece and material transfer on microstructure. Very less material transfer on brass and no evidence of melting of brass, no evidence for work material transfer and melting for stainless steel.

Redouanezitoune et al [7] experimentally investigated the use of Nano coated cutting tool and withoutNano coated tool, two types of tungsten carbide tool were used for the study. The author concluded that thrust force for coated drill is (10-15)% lesser compared with uncoated drill while machining on a composite plate. Similarly thrust force for coated drill is 50% lesser compared with uncoated drill while machining on aaluminum plate.

R Piquet et al [15] investigated specific cutting tool is shown in fig 7 op1 and op2 tool is made up of double fluted twist drill uses micrograin tungsten carbide than carbides which are tougher. Tool is made with tough and wear resistant in tool op1 chamfer angle with zero clearance angle in op2 tool also chamfer on cutting edge.

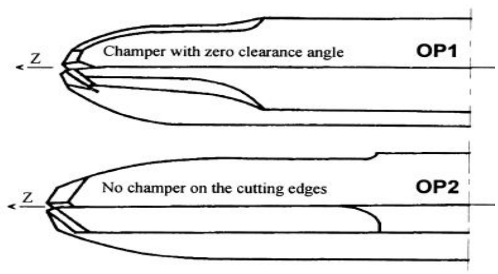


**Figure 7** Specific tool geometry for op1 and op2 tool [15]

Geometric comparison between f2 and op1, working section shown in fig 8. Author concluded that op1 tool has less damage than f2 drill tool, at plate entrance and exit while experiment done on carbon/epoxy plate. Op1 too has excellent result. Experiment carried out at constant feed rate of 0.5 to 62.5 micron.

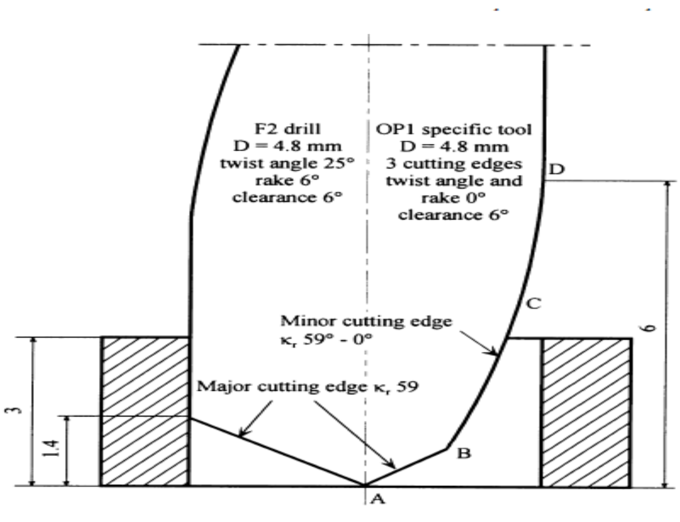


**Figure 8** Geometric comparison between f2 and op1[15]

## 6. DELAMINATION

Delamination is the main problem during drilling process in composite material. Due to deforming forces and temperature. Delamination occursnon optimal due to process parameters[2]. Delamination mainly occurs at both entrance and exit. Mechanism which is responsible for delamination is push out at exit and peel up at entrance as shown in fig 9

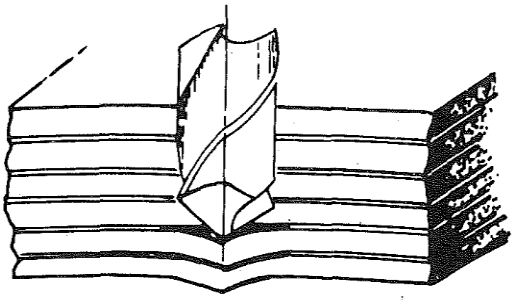

**Figure 9** Push out delamination at exit [5]

Where push out happens when drill bit when it approaches the end, uncut thickness become smaller and the deformation resistance decreases, so at this point delamination occurs due to the load exceeds the inter laminate bond strength. Peel up at entrance happens due to the downward acting trust force as shown in fig 10[5].

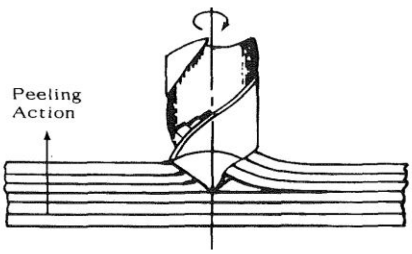


**Figure 10** Peel up at delamination entrance [5]

For getting higher quality holes without delamination the use of special drill and feed method [27]. Schema of the visualization of delamination is shown in fig 11[18].

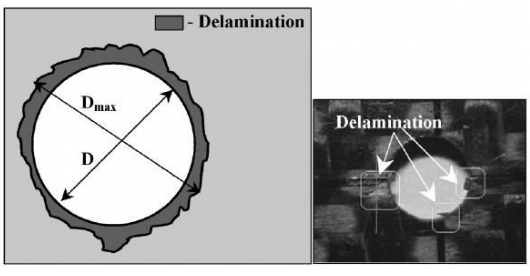


**Figure 11** Schema of the visualization of the delamination [18]

From the study it is concluded that delamination at exit is lesser when compared with entrance damages. For higher cutting speed and higher feed delamination increases with cutting parameters in composite plate. While comparing Brad n Spur drill with straight shank drill delamination is less in Brad n Spur drill. Major focus for reducing delamination was cutting velocity [18]. The layered component have a good agreement with model prediction and used for minimize delamination defects [19].

Delamination factors can be studied by evaluating cutting speed, feed rate, and point angle. More over by low feed rate and point angle damages can be reduced [6]. For machining high quality drilled hole following areas should be analyzedhole diameter, peel up delamination, circularity, push out delamination. For mainly these parameters major role is played by spindle speed and feed rate [20]. Major problem for delamination caused to the geometry, with decrease of feed rate delamination size also decreased [21]. U In[22] experimentally investigated delamination on different materials like cross winding/polyester, continues winding with filler/polyester, woven/ polyester, chopped /polyester and woven /epoxy composite. Machining done on all the materials, the author observed that push out delamination is lower in both in chopped/composite and woven composite with the reduction of thrust force [22].

Industries are in greater importance to thermo mechanical tool loading because hole geometry and surface integrity are affected greatly[23].In [24] developed a new method for reducing delamination using Artificial Neural Network(ANN) method as shown in fig 12.

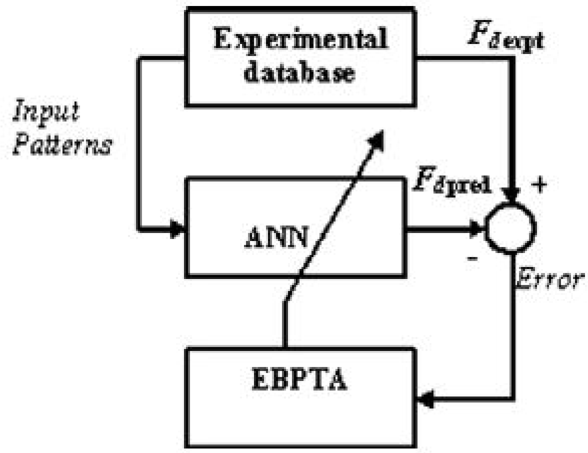


**Figure 12** Methodology of ANN modeling[24]

Concept of friction/ heating is adopted both in friction drilling and Flow Drill Screw driving process (FDS). In normal friction drilling process tool penetrates and forms a extrusion, so surface area of treading is also formed. So again it need high torque for tightening and clamping. FDS used thread tool as shown in fig 13.

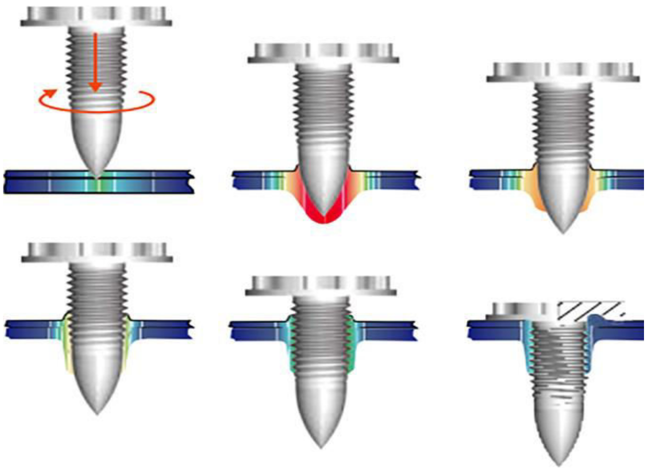

**Figure 13** Six steps FDS process [14]

Steps involved are same as of Friction drilling, but its limited to light weight [14].During FDS process heat generated follows columbic friction law, which depends on following parameters coefficient of friction between tool and work material and velocity reduction of sliding contact.

## 7. SURFACE ROUGHNESS

Micro fiber fracture, fiber pull outs and matrix cracking are the main problem during machining process this may affect surface roughness. By low feed rate and reduction of thrust force surface roughness can be improved, with low feed and high speed temperature increases the low coefficient of thermal conductivity and low transition of plastics [26].

## 8. FAILURE MECHANISM

Mechanical behaviour of sandwich composite structure or any other material can be experimentally studied by using tensile testing and 3 point bending test. Failure behaviour of tested structure obtained from stress- strain curve were under various loading condition. Shear failure and elastics and plastic zone failure were identified using above testing method, a new model was be developed from obtained results [31].

## 9. THERMOGRAPHY

Mechanical damages of the structure are monitored by using thermography technique. The study of the critical temperature analyzed by the heat during drilling process and can be used to predict the mechanical damages and hence avoided by applying suitable techniques like selection of appropriate drill bit, cooling of drillbitetc[2]. While friction drilling process measuring work material deformation and temperature is difficult. FEM technique also can be adopted for this process as shown in fig 14, shows deformation in meshed form, plastic strain, temperature and von-mises stress at feed rate 4.23mm/s, speed 3000rpm, coefficient of friction 0.7etc[3].

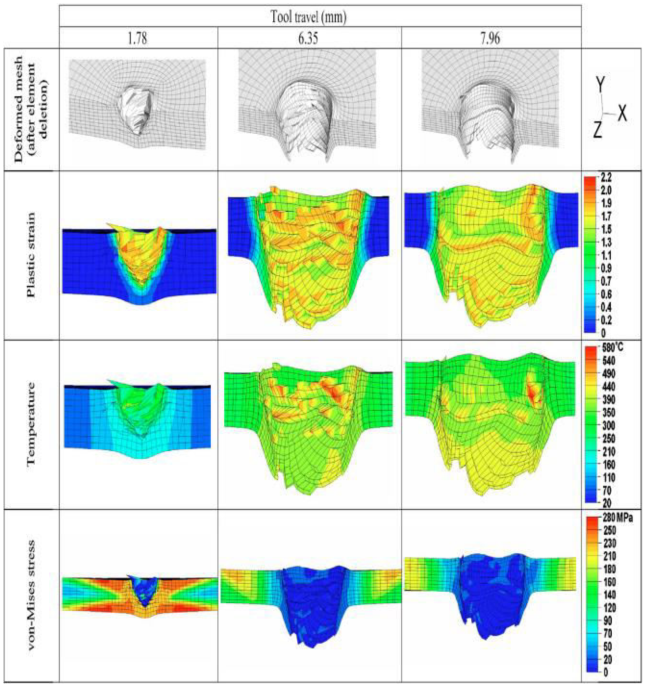


**Figure 14** Deformed mesh and plastic strain, temperature and von mises stress [3]

While doing friction drilling process temperature in work piece and tool is high,for measuring temperature Infrared(IR) camera is used for the thermography study. The range of IR camera is about 3 to 5 microns. Minimum detecting temperature is about 250°C and max of about 1000°C and it varies with IR camera. Fig 15 shows picture of thermography.

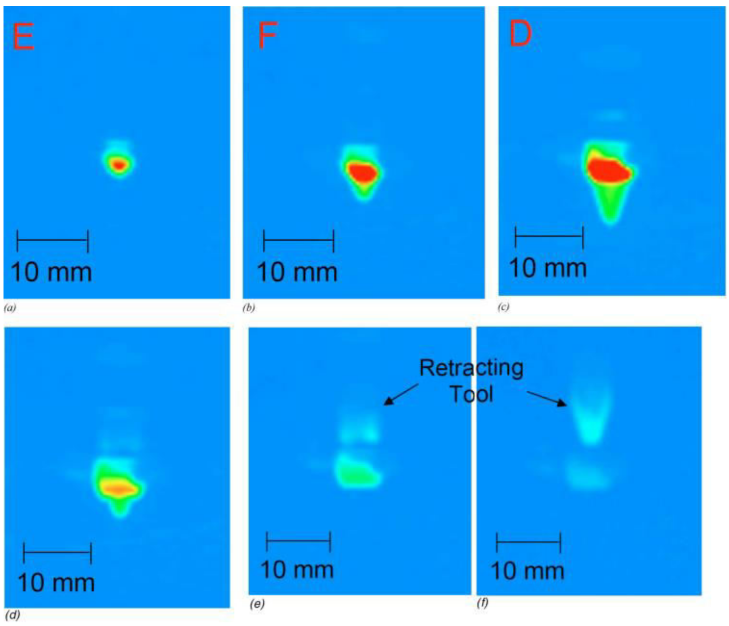

**Figure 15** Infrared Camera image of friction drilling [9]

Work piece used in the study is AISI1020 cold rolled carbon steel plate and db mate of wc in co matrix. In fig 15(e) and 15 (f) tool is retracted, high intensity with bright spot on 15(c) in fig 16 stress max temp and min temp which is noted by thermography technique [9].

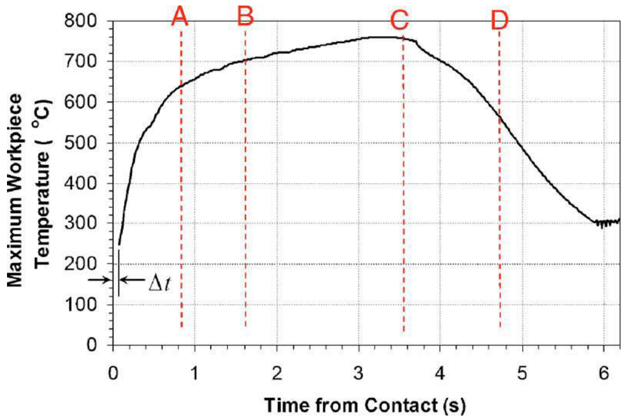


**Figure 16** Maximum and Minimum work piece temperature detected by infrared camera [9]

How thermo grams are important are studied as experimental process in the paper image processing and data analysis [28]. In Scanning Electron Microscope(SEM) images are shown fig 17, where thermal damage of the carbon fiber composite material is visibility seen. These damages are happened due to the raise in temperature during machining process.

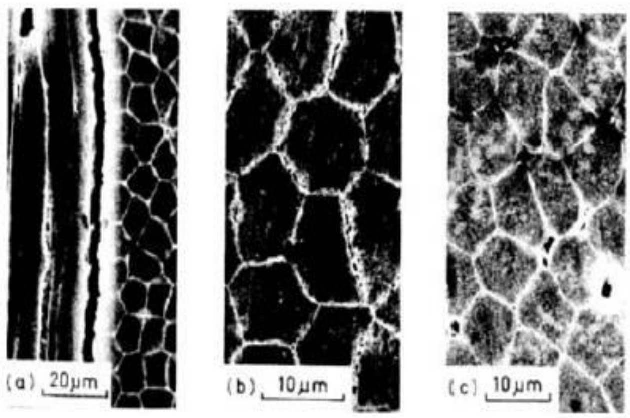


**Figure 17** SEM image carbon fiber composite material [29]

## 10. OPTIMIZATION TECHNIQUE

Optimization technique is a powerful tool for reducing mechanical damages by optimizing the process parameters. After conducting different number of experiment trials, these trials were examined by Analysis of Variance (ANNOVA). For thermal friction drilling process using optimization techniques are carried out. Design of experiments is adopted by taguchi method and analysis of variance by Annova[8].

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## 11. CONCLUTION

Friction drilling is a non –traditional process for holemaking, this technique is the most recent trend in hole making which currently applied in all major mechanical industries. Friction drilling is used in all sectors like Automobile, Aeronautical etc. Thermography is the new technique for identifying machining damages these damages are happened due to the influence of high temperature. A Boss and Bush is formed on front and backside of the work piece, due to the increase in ductility of the work material increases. This literature review reveals that the sandwich material is suitable for friction drilling process, because sandwich material have advantages likevery low weight, high stiffness and durability. Friction drilling drill bit is made up of cylindrical bar made up of tungsten carbide with Nano coating FCAR of 100% and 50%. By reducing low feed rate, point angle and proper cutting speed delamination can be reduced.

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