Asian Journal of Engineering and Applied Technology
ISSN: 2249-068X (P) Vol. 2 No. 2, 2013, pp. 29-34

DOI: https://doi.org/10.51983/ajeat-2013.2.2.685

Evaluation of Drilling Performance of Unsaturated Polyester Resin

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Abstract - **Unsaturated polyester resin (UPR) has the resistance against boiled water, acid and alkali, and hence, is widely used in corrosive environment and elsewhere, although fracture strength of polymeric materials is generally low relative to metals and ceramics. Despite the fact that polymer components are mostly produced near-net-shape, machining, particularly drilling, is often required to prepare it for assembly. In the present paper, drilling of unsaturated polyester resin is undertaken for the evaluation of machinability of unsaturated polyester resin (UPR). Observation of cutting force requirement, type of chip formation, and eccentricity of drilled holes produced are made. Formation of burr at the edge of drilled hole is also explored under varying cutting conditions.**

Keywords: **Resin, Unsaturated Polyester Resin, Drilling, Machinability, Burr.**

I. Introduction

Synthetic organic materials include plastics, lubricants, rubber, soap oils, synthetic fibres, etc. Plastics and synthetic rubbers are generally termed as polymers [1]. Polymers are mostly organic in origin and based on hydrocarbons. Usually polymers are broadly classified in three categories; they are plastics, fibres and elastomers. Mechanical strength of polymers increases with the degree of crystallinity. Crystallization considerably affects [2] mechanical property. Polymers are the basic materials of rubber and plastic industries and important to the textile, petroleum, automobile, paper, and pharmaceutical industries.

Unsaturated polyester resins (UPR) are formed by the reaction of dibasic organic acids and polyhydric alcohols. Polyester resins are used in sheet moulding compound, bulk moulding compound, etc. Wall panels fabricated from polyester resins reinforced with fibreglass, known as fibreglass reinforced plastic (FRP), are typically used in restaurants, kitchens, restrooms, etc. requiring low maintenance. Unsaturated polyesters are condensation polymers formed by the reaction of polyols, known as polyhydric alcohols, organic compounds with multiple alcohol or hydroxyl functional groups, with saturated or unsaturated dibasic acids. The use of unsaturated polyesters and additives, such as styrene, lowers the viscosity of the resin. Liquid resin is converted to a solid by cross-linking chains. Polyester resins are thermosetting, and, as with other resins, cure exothermally. The use of excessive catalyst can, therefore, cause charring or even ignition during the curing process [3,4].

II. Drilling of Polymers

Machining of fibre reinforced polymer is often needed and requires standardisation to facilitate process design and product manufacture [5]. Machining of FRP may take place before and after lay-up and curing. Machining before curing involves cutting the reinforcement material to proper size to fit the contour before it is laid into a mould and cured. Machining of cured FRPs is carried out by conventional or non-conventional material removal methods. Conventional methods used most frequently are edge trimming, milling, drilling, countersinking, turning, sawing, and grinding [6].

Drilling, cutting and tapping are some of the most conventional forms of plastics machining. Drilling larger holes require slower speed and a regular drill press is the best means of accomplishing this. Drill life is improved for all materials with resin [6]. The drilled holes of GFREC (Glass Fibre Resin Epoxy Composite) with lower speed ratio at lower feed have greater roughness than that drilled at higher feed. Drill diameter combined with feed has a significant effect on surface roughness. Cutting speed has insignificant effect on the thrust force, cutting temperature and surface roughness of epoxy resin [7,8]. Hence, drilling, cutting and machining composites in any post-processing operation to get to the final part shape or configuration is different. Conventional fluted steel cutters certainly exist and are used in fabricating final composite parts. These are the high-speed steel (HSS) and carbide cutters that are used quite often.

The anisotropy of fibre-reinforced plastics (FRP) affects chip formation and thrust force during drilling. Delamination is recognized as one of the major causes of damage during drilling of fibre reinforced plastics, which not only reduces the structural integrity, but also has the potential for long-term performance deterioration. Delamination mainly depends on the thrust force exerted by the drill point. Process parameters play a main role in determining the thrust force, and consequently the extent of delamination [9]. As high feed rate causes delamination, low feed rate is preferred. Composite materials generally have poorer conductive properties when compared to metals. This leads to increased temperature during machining. One of the main limitations when drilling PMC (Polymeric Matrix Composites) with the conventional HSS twist drill is the excessive wear experienced by the tool. Tool wear has a significant effect [10] on damaging of a hole, as thrust force naturally increases with the progress of tool wear.

Polymers and its composites have been steadily replacing metals as choice engineering materials for various applications. Although these can be manufactured to near-net-shape, holes are often needed for fabrication process. In the present experimental investigation, drilling performance of UPR using conventional HSS twist drills of 4mm and 6mm diameters is explored under varying environmental conditions.

III. Experimental Set-Up

Drilling of unsaturated polyester resin workpiece is carried out on an Energy Machine Tools Pvt. Ltd., Jamnagar, India made radial drilling machine. Drilling experiments are carried out under dry, water and water soluble oil conditions. Two different drill diameters, 4 mm and 6 mm, are considered in experiment set-I and set-II experiments respectively. Miranda, India made standard twist drills are used for this experimental investigation. Fig. 1 shows the set up for carrying out the drilling experiment. Details of experimental conditions are given in Table I.

During the operation, the thrust, i.e. normal force (Pn) is measured by a tool force dynamometer (Make: Sushma Pvt. Ltd., Bangalore, model: SA 116).

In experiment set-I, drilling operation is performed at cutting velocities (V_c) of 14, 22.5 and 35 m/min respectively with 4 mm diameter twist drills. At each cutting velocity, three different feeds of 0.032, 0.05 and 0.08 mm/rev are set.

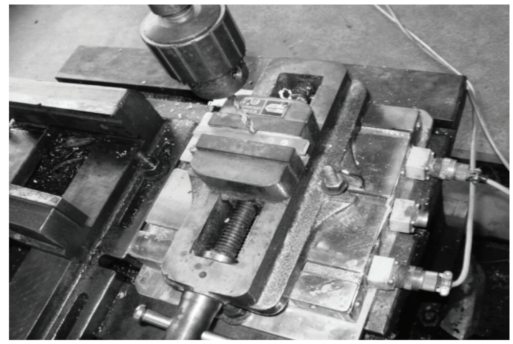

Fig. 1 Photograph of the drilling set up

Table I Experimental Conditions

Drill Dia. (mm)	V_C (m/min)	S_O (mm/rev)	Environment
4.0 (Experiment Set-I)	14.0	0.032	i) Dry, ii) wet with water and iii) soluble oil
		0.050	
		0.080	
	22.5	0.032	
		0.050	
		0.080	
	35.0	0.032	
		0.050	
		0.080	
6.0 (Experiment Set-II)	13.3	0.032	i) Dry, ii) wet with water and iii) soluble oil
		0.050	
		0.080	
	21.0	0.032	
		0.050	
		0.080	
	33.6	0.032	
		0.050	
		0.080	

Set-II drilling experiments are carried out using 6 mm diameter drills at three different cutting velocities (Vc) of 13.3, 21.0 and 33.6 m/min. At each speed, drilling is done with three different feeds of 0.032, 0.05 and 0.08 mm/rev similar to that of experiment set-I.

Both the sets of experiments are conducted at dry and wet conditions of water and water soluble oil. After drilling, the hole dimensions on X-axis and Y-axis have been checked under a tool makers microscope (make: Mitutoyo, Japan, model: T510) to check its cylindricity.

IV. Results and Discussions

A. Drilling at Dry Condition

At low feed under 14 and 22.5 m/min cutting velocities, more broken fan shaped chips are found. At high feed for all cutting velocities taken, conical helical chips are mostly found. In experiment set-I, the built-up edges (BUE) on HSS drill are not found at low cutting velocity, but at a cutting velocity of 22.5 m/min and 35.0 m/min, only loose BUEs are found at some cases. These loose BUEs are easily removed by rubbing with the nail. Table II shows detailed observation of chip forms and BUE under dry condition. At higher Vc, cutting temperature is higher and chips formed may become more sticky to form burrs.

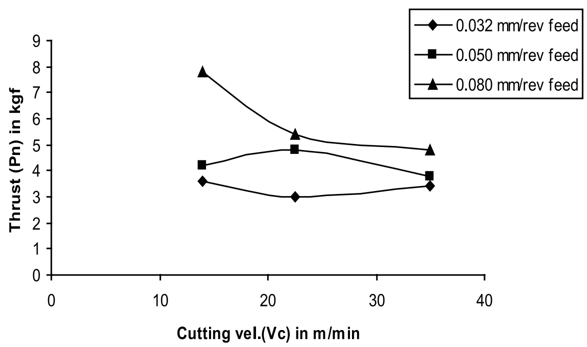

Fig. 2 Plot of variation of thrust with V_c at different feeds with 4 mm dia. drill at dry condition (experiment set-I)

Table II Chips and Bue Observed in Dry Environment in Experiment set-I with 4mm Diameter Drill

Sl. No.	V_C	S_O	Types of Chips	BUE
1	14.0	0.032	Broken-fan shaped	No
2		0.050	Thick, conical-`helical, open	No
3		0.080	Thick conical	No
4	22.5	0.032	Broken-fan shaped	One loose
5		0.050	Broken-fan shaped	No
6		0.080	Thick, conical-`helical, open	One loose
7	35.0	0.032	Thin, conical-`helical, open	No
8		0.050	Thick, broken-fan shaped	One loose
9		0.080	Thick, conical-`helical, open	One loose

Burrs observed through out the experiments at dry condition are found loose and easily removed by rubbing with finger. Exit burrs are found to be relatively higher than entry burrs in most of experiments.

The lack of cylindricity of the drilled hole has been checked along major axis (X-axis) and minor axis (Y-axis), and dimension of Y- axis varies from 3.850 mm to 4.020 mm, and along X-axis, they vary in between 4.005 mm and 4.110 mm.

Fig.2 represents the variation of thrust (P_n) with the change in cutting velocity at three different feeds for experiment set-I. In this experiment set-I, thrusts are naturally higher with the increase in feeds. However, no clear trend of the change in thrust is visible with the change in cutting velocity that may be due to the unstable BUE observed.

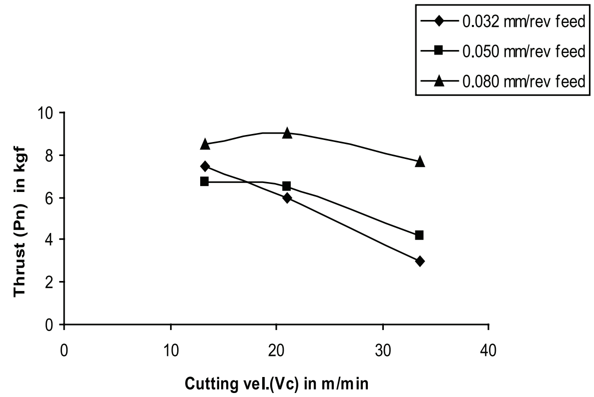

Fig. 3 Plot of variation of thrust with V_c at different feeds with 6 mm dia. drill at dry condition (experiment set-II)

Table III Chips and Bue Observed in Dry Environment in Experiment Set-II with 6mm Diameter Drill

Sl. No.	V_C	S_O	Types of Chips	BUE
1	13.3	0.032	Broken-fan shaped	Two loose
2		0.050	Thick, conical-`helical, open	No
3		0.080	Thick, conical-`helical, open	One loose
4	21.0	0.032	Broken-fan shaped	One loose
5		0.050	Wide, thick, conical	No
6		0.080	Broken-fan shaped	One hard
7	33.6	0.032	Broken-fan shaped	No
8		0.050	Long, wide conical	One hard
9		0.080	Wide, long conical	One hard

In experiment set-II, with 6 mm diameter drill, BUEs are found relatively higher than the previous set. Here, few hard BUEs are found which can not be removed by nail. At low feed with different cutting velocities, more broken fan shaped chips are found. At high feed, conical helical chips and broken fan shaped chips are found (Table III) at different V_c. Thrust (P_n) increases at higher feed at each velocity under dry condition for set-II (Fig.3).

The drilled hole diameters for experiment set-II are varying from 5.915 mm to 6.110 mm along X-axis and 6.010 mm to 6.100 mm along Y-axis. The eccentricity in the drilled hole is usual, and this is also observed in the present experiments with unsaturated polyester workpiece which have quite smooth surface promoting running of centre point of the drill chisel edge before start of drilling.

In experiment set-II with 6 mm diameter drill, the thrust (P_n) at higher feeds also show higher values on the whole. Only in case of 13.3 m/min cutting velocity at 0.08 mm/rev feed, thrust is lower than that at 0.05 mm/rev feed. Formation of unstable BUE may be the reason behind this. In aggregate, there is a decreasing tendency of thrust observed with the increase in cutting velocity. Similar observations were also made in an earlier work [8]. Thermal softening at higher cutting velocity may have resulted in this trend.

B. Drilling at Wet Condition with Water

Fig.4 and Fig.5 show variation of thrust at different feeds and cutting velocities under wet condition with water with 4 mm and 6 mm diameter of drill.

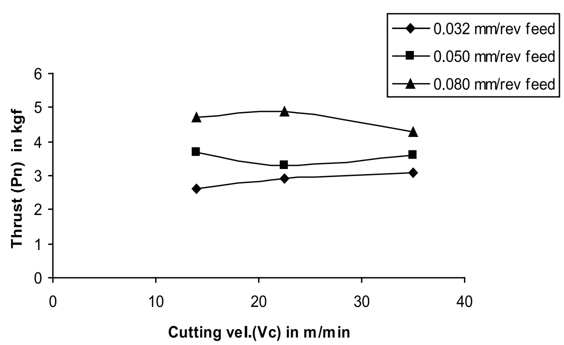

Fig. 4 Plot of variation of thrust with V_c at different feeds with 4 mm dia. drill at wet condition with water (experiment set-I)

The thrust (P_n), at different cutting velocities at their respective feeds (SO) of 4 mm diameter drill (set-I) at wet condition using water is plotted as shown in Fig. 4. It shows only slight variation of the thrust (P_n) at different feeds with the increase in cutting velocity (V_C). At higher feeds P_n is higher naturally.

Fig.5 shows the variation of thrust (P_n) at different feeds (S_O) with varying cutting velocities (V_C) at experiment set-II for wet condition with water. No distinct trend is observed in this case.

At 0.032 mm/rev feed, Pn increases first up to 21.0 m/min velocity, and then decreases up to 33.6 m/min. But at 0.05 mm/rev feed, thrust (P_n) first decreases slightly, and then increases up to 8.0 kgf.

Table IV Chips and Bue Observed in Wet Environment Using Water in Experiment Set-I With 4mm Diameter Drill

Sl. No.	V_C	S_O	Types of Chips	BUE
1	14.0	0.032	Thin, conical-helical-open	No
2		0.050	Thin conical	No
3		0.080	Thin, broken-fan shaped	No
4	22.5	0.032	Thin, conical-helical-open	No
5		0.050	Thin, conical-helical-open	No
6		0.080	Narrow, conical-helical	One loose
7	35.0	0.032	Broken-fan shaped	No
8		0.050	Broken-fan shaped	One loose
9		0.080	Soft conical- helical-open	No

In both the sets of experiments in water cooled wet condition, thrusts observed are expectedly lesser than that at dry condition due to better cooling and lubrication effects.

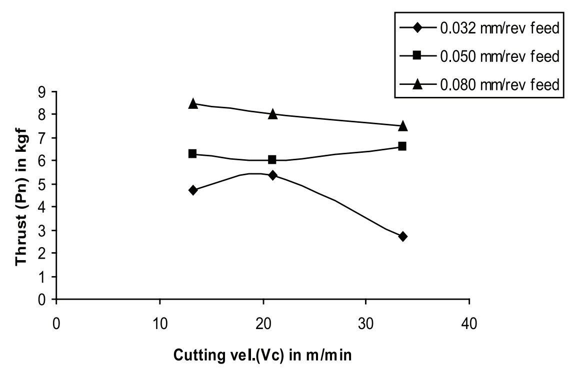

Fig. 5 Plot of variation of thrust with V_c at different feeds with 6 mm dia. drill at wet condition with water (experiment set-II)

Thin, narrow chips are found more in this wet condition with water (Table IV and Table V) irrespective of their speeds and feeds. No built-up edges (BUE) on HSS tool are seen mostly. Only under few high speed-feed conditions, loose BUEs are found. Effect of water to suppress BUE formation is clearly observed when compared with dry condition.

It has been noticed that mostly no burr is formed during drilling when water is used as a cutting fluid, and in few high-speed and feed condition. Few loose burrs are obtained that can be removed by rubbing finger easily. Mainly the entry and exit burrs are found at high cutting velocities of 33.6 m/min and 35 m/min.

Table V Chips and Bue Observed in Wet Environment Using Water in Experiment set-II Using 6mm Drill

Sl. No.	V_C	S_O	Types of Chips	BUE
1	13.3	0.032	Wide, thick open conical-helical	No
2		0.050	Wide thick open conical-helical	No
3		0.080	Wide and thick	No
4	21.0	0.032	Thick, hard open conical-helical	No
5		0.050	Thick, hard open conical-helical	No
6		0.080	Wide, broken-fan shaped	No
7	33.6	0.032	Wide, broken-fan shaped	No
8		0.050	Long, soft conical-helical	One loose
9		0.080	Wide, broken- fan shaped	One loose

In experiment set-I, the hole diameters along major axis vary from 4.030 mm to 4.080 mm, but along minor axis, they are varying between 3.985 mm and 4.090 mm. The drilled hole diameters for experiment set-II vary from 5.905 mm to 6.025 mm along major axis, and 5.975 mm to 6.035 mm along minor axis.

C. Drilling at Wet Condition with Soluble Oil

Thin, soft conical helical and broken fan shaped chips are found (Table 6) more at wet condition of water soluble oil. Only few loose BUEs are found at 35 m/min velocity under 0.08 mm/rev feed.

In experiment set-I, the thrust (P_n) at higher feeds shows an increasing trend naturally. At high feed (0.080 mm/rev), Pn is decreased from 5.7 kgf to 4.0 kgf with the increase in V_C, but at low feed (0.032 mm/rev), Pn does not show noticeable variation with varying cutting velocities (Fig. 6).

Fig. 6 shows that in experiment set-II, at low velocity (13.3 m/min), values of thrust (Pn) at different feeds (SO) are high, and they are decreasing with the increase in velocity.

There is no burr at entry and exit sides for 4 mm drilled holes; only burr is found at the exit edge at 13.3 m/min cutting velocity with 6 mm drill and is removed by rubbing finger. The lack of cylindricity of the drilled hole has been checked along X-axis and Y-axis. Similar observations were also made in some other works done previously [7,8].

Table VI Chips and Bue Observed in Soluble Oil Environment in Experiment Set-I With 4mm Drill

Sl. No.	V_C	S_O	Types of Chips	BUE
1	14.0	0.032	Thin, open conical-helical	No
2		0.050	Thin and soft	No
3		0.080	Thin, broken fan shaped	No
4	22.5	0.032	Thin, broken fan shaped	No
5		0.050	Thin, broken fan shaped	No
6		0.080	Narrow, open conical–helical	No
7	35.0	0.032	Thin, broken fan shaped	No
8		0.050	Thin, broken fan shaped	No
9		0.080	Broken fan shaped	One loose

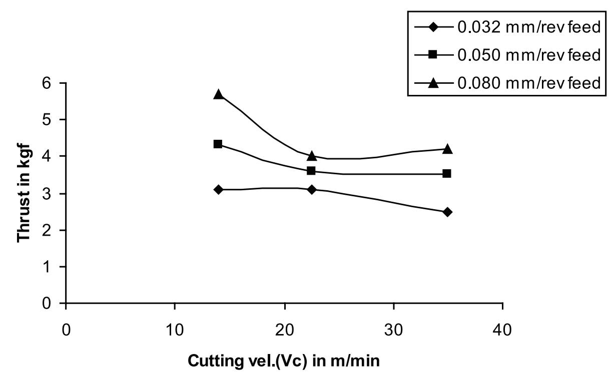

Fig. 6 Plot of variation of thrust with cutting velocity at different feeds in wet with soluble oil environment with 4 mm drill in experiment et i

In experiment set-I, hole diameters along Y-axis vary from 3.975 mm to 4.080 mm, and along Y-axis, they are varying between 4.005 mm and 4.120 mm. The drilled hole diameters for experiment set-II vary from 6.005 mm to 6.050 mm along major axis and 6.005 mm to 6.080 mm along minor axis. Smooth surface of the unsaturated polyester may be the reason for the variation of hole sizes.

Various chip forms observed in experiment set-I and set-II experiments under soluble environment are shown in Table VI and Table VII respectively for 4 mm and 6 mm diameter drills. Fan shaped and conical helical chips are seen at varying conditions of drilling. Similar chip forms are commonly observed during drilling of polymeric materials [2,4,6,7,10].

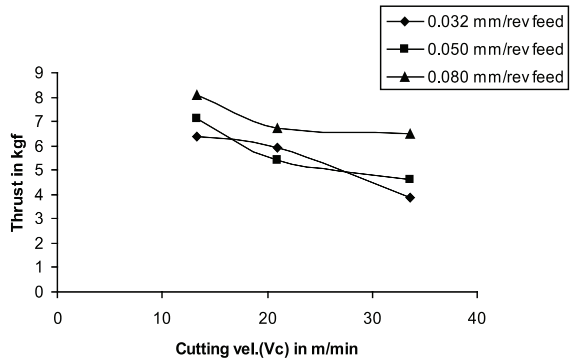

Fig. 7 Plot of variation of thrust with cutting velocity at different feed in soluble oil environment with 6mm drill at experiment set-II

Table VII Chips and Bue Observed in Wet With Soluble Oil Environment in Experiment Set-II With 6Mm Drill

Sl. No.	V_C	S_O	Types of Chips	BUE
1	13.3	0.032	Wide, thick, broken conical-helical-open	No
2		0.050	Wide, thick, open conical-helical	No
3		0.080	Thick, broken fan shaped	No
4	21.0	0.032	Thick ribbon	No
5		0.050	Wide, thick, open conical-helical	No
6		0.080	Broken-fan shaped	No
7	33.6	0.032	Broken-fan shaped	No
8		0.050	Long and soft, open conical-helical	One loose
9		0.080	Broken-fan shaped	No

V. Conclusion

From the experimental results under varying conditions, following conclusions may be made during drilling of unsaturated polyester resin.

- Thrust at dry condition is high and it is expectedly reduced on the whole to some extent by the application of water and water soluble oil for lubrication and cooling action.
- Formation of long conical helical chip is reduced with the application of cutting fluid. Thick and hard chips are found at dry condition, but at wet condition with water, hard chip is absent, and with water soluble oil, thin, narrow and small broken fan shaped chips are produced. The built-up edges (BUE) have also become reduced considerably due to cooling effect of cutting fluid.
- Burrs formed with HSS drill at dry condition are greatly reduced by applying cutting fluid. So, the burrs on HSS tool are remarkably controlled by applying both the cutting fluids, and are greatly reduced when water soluble oil is used.
- Size and eccentricity of drilled hole can also be controlled by using water and water soluble oil.

Acknowledgement

The authors are indebted to Mr. Sushanta Halder, Mr. Goutam Chakraborty, Mr. Ramapada Soren and Mr. Ashis Kumar Bhattacharya for extending their co-operation in utilization of various facilities in Workshop and laboratories of Department of Mechanical Engineering, Kalyani Government Engineering College, during this work. Authors also acknowledge active support rendered by Dr. Bijoy Mandal, a Visiting Faculty of the college.

References

[1] Sperling, L.H. (2006), 'Introduction to Physical Polymer Science', Hoboken, N.J. Wiley, pp. 10-30.

[2] Ahmad, J.Y.S. (2008), 'Machining of Polymer Composites', Springer Publication.

[3] Callister, W.D. (2007), 'Material Science and Engineering– An Introduction', 6th Edition, Wiley Higher Education, pp. 557-558.

[4] Eriksson, P.A., Albertsson, A.C., Boydell, P., Eriksson, K., Manson, J.A.E. (1996), 'Reprocessing of fibreglass reinforced polyamide 66: influence on short term properties', *Journal of Polymer Composites*, Vol. 17(6), pp. 823-829.

[5] Gupta, V.B., Kothari, V.K. (1997), 'Manufactured Fiber Technology', Chapman & Hall Publication, p. 225.

[6] Beckwith, S.W. (2009), 'Drilling, cutting, machining composite materials and structures', *SAMPE Journal,* Vol. 45(2).

[7] Krishnaraj, V.; Vijayarangan, S.; Nazrudeen, M.M.; Suresh, G. (2005); 'Analysis of temperature rise in drilling of GFRP composite material with various drill profiles', *Proceedings of the 21st AIMTDR conference, Vellore Institute of Technology,* Vellore, India, pp. 9-14.

[8] May, C.A. (1987); 'Epoxy Resins', Chemistry and Technology (2nd ed.), New York, p. 794.

[9] Davim, J.P., Rubio, J.C., Abrao, A.M. (2007), 'A novel approach based on digital image analysis to evaluate the delamination factor after drilling composite laminates', *Journal of Composition Science Technology,* Vol. 67, pp. 1939–1945.

[10] Zhang, H., Chen, W., Chen, D., Zhang, L. (2001), 'Assessment of the exit defects in carbon fiber-reinforced plastic plates caused by drilling', *Journal of Key Engineering Materials,* Vol. 196, pp. 43–52.