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Research Paper

Evaluating the Delamination in the Drilling Process of a Melamine Coated Medium Density Fiberboard (MDF)

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Abstract. Medium density fiberboard (MDF) is an engineering product that is used in many industrial and general applications such as the furniture industry and kitchen cabinets. Generally, MDF products are generated by screw joints using the drilling process. However, the drilling process of the MDF panels leads to the delamination at the entrance and exit of the drill bit that should be controlled. In this work, the effect of the processing parameters including the feed rate and cutting speed on the delamination of melamine coated MDF is investigated. For this, two different tools with different tool geometry (a brad point drill bit and a commonly used twist drill bit) are examined. Image processing is used to measure the conventional delamination factor together with a new delamination factor referred to as area delamination factor for the drilled holes. It that the delamination value decreases with increasing cutting speed and increases with increasing feed rate. Though, there were some fluctuations in the results. The trend of changing the delamination respect to the investigated parameters was the same for both applied drill bits; however, the smaller value of delamination is obtained using the twist drill bit. Using the proposed area delamination factor, the effect of process parameters on the delamination is presented with higher magnitudes but with the same behavior. This, together with the ability of characterization of the water absorption of drilled holes has made the area delamination factor a more appropriate parameter to evaluate the delamination. The overall results are consistent with previously published works.

Keywords: Drilling; Medium density fiberboard (MDF); Delamination factor; Area delamination factor;

1. Introduction

Products made out of the medium density fiberboard (MDF) are widely used in general and engineering applications such as furniture industry and kitchen cabinets. Moderate density, good physical and mechanical properties, low cost and the reuse of waste wood in the manufacturing process are the main advantages of the MDF that make it a proper option in these applications. Generally, a plastic laminate is overlaid on the MDF panels to enhance the aesthetics of these panels and to protect them against water [1-3].

Usually, MDF panels are joined together by screw joints to produce the desired product. These panels are drilled prior to screw joining that is usually accompanied by the removing of the plastic layer around the drilled hole at the entrance and the exit of the drill bit. This is known as the delamination in MDF products. Since, the plastic laminate acts as a protection layer against the water; removing it can lead to water absorption by MDF panels.

Till now, the drilling process of the metals has been studied by multiple researchers [4-6]. Also, there are some works in the scope of the delamination of composite materials [7-10]; but, there are very low researches in the scope of the delamination of MDF panels. Kant and Jawalkar [4] modeled the influence of drilling parameters such as tool material,

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cutting speed, feed rate, drill diameter and work-piece material on surface roughness and hole diameter error during dry drilling of some die steels. They used the Taguchi method based response surface analysis for this purpose. Also, the effects of cutting conditions on cutting temperature and hole quality in the drilling of Inconel 718 have been reported by Uçak and ÇiÇek [5]. They found that good surface roughness and tool life can be achieved under wet conditions and the use of the coating material reduces the tool wear extremely. Rana and Lata [6] used a GA based Optimization procedure to identify the most important factors that affect the drilling performance of aluminum-based composites. The investigated parameters were spindle speed, feed rate, and drill diameter while the performance characteristics were temperature, dimensional accuracy and burr height [6].

Otherwise, there are some works in the scope of delamination in the drilling process of composite materials. Ragunath et al. [7] optimized the drilling Delamination behavior of GFRP/Clay Nano-Composites Using RSM and GRA Methods. In their work cutting speed, feed rate, size of the drill and the Nano-clay content were considered as influential parameters on delamination. They found that the feed rate is the most significant factor among the other parameters. In the other research, Tsao et al. [8] investigated the delamination in the drilling process of laminated composites by a core–saw drill. The proposed equivalent delamination factor and compared it with adjusted and conventional delamination factors. They found that the proposed equivalent delamination factor is more appropriate to characterize the delamination at the exit of a drilled hole. Also, Xu et al. [9] proposed a three-dimensional delamination factor considering the drilling damage volume formed by cross-ply delamination. It was shown that the proposed factor has a better performance than the other delamination evaluation methods for the quantitative assessment of out-of-plane damage during drilling of fiber-reinforced composites. They used three types of drills including twist drills, brad spur drills, and dagger drills. In the other work, Xu et al. [10] studied the drilling process of multilayer carbon/epoxy composite-Ti6Al4V stacks and their individual material layers using tungsten carbide drills. They investigated the drilling forces, cutting temperatures and hole quality attributes against the drill wear. They found that the drill wear has a more significant impact on the delamination damage in a stack configuration than in drilling of the CFRP plates independently.

References [1-3] are the main works performed in the scope of the delamination of MDF panels. Davim et al. [1] investigated the relationships and parametric interaction between two controllable variables, namely, feed rate and cutting speed on the delamination factor at entry and exit of the holes in the drilling of MDF. They performed the experiments on two types of MDF panels, one with a melamine coating layer and the other with a wood coating layer. They used a cemented carbide drill bit and reported the main and the interaction effects of the examined drilling parameters. In the other report, Davim et al. [2] stated that the delamination factor decreases with the increase of cutting speed and increases with the feed rate for both the MDF panels with a melamine coating layer and the MDF panels with the wood coating layer. In the other research, Prakash et al. [3] used the desirability function-based approach to optimize the drilling parameters for minimizing the delamination factor at entry and exit in the drilling of MDF boards. According to the results obtained, they expressed that the feed rate is the main parameter influences the delamination factor in the drilling of MDF. The experimental results also indicated that the increase of spindle speed (that is in direct relation with the cutting speed) reduces the delamination factor and the increase of feed rate and drill diameter increases the delamination factor.

In this research, the effect of processing parameters including the feed rate and cutting speed on the delamination in the drilling process of melamine coated MDF are investigated. For this, two completely different drill bit, one a brad point drill bit and another a commonly used twist drill bit are used. Image processing is used to measure the delamination factor for the drilled holes. Also, as it will be explained later, a new area delamination factor is proposed to complete the assessment of the delamination. Also, the results are compared with the previously published related works [1-3].

2. Material and Experiments

The drilling process of MDF panels was performed on a vertical machining center (VMC) with 19 kW spindle power and a maximum spindle speed of 6000 rpm (Fig. 1). The tests were conducted on a melamine coated MDF panel produced by the Foumanat industrial group with a thickness of 16mm and the melamine coating thickness of 0.1mm. The mechanical and physical properties of the tested MDF panel are listed in Table 1.

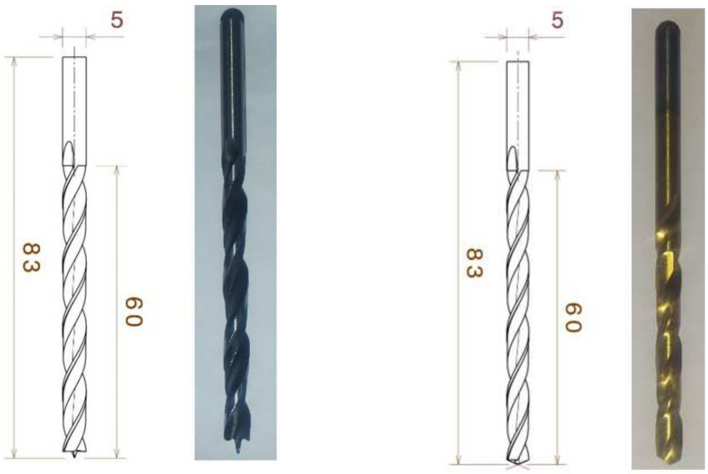
Two that different 5mm in diameter drill bits were used; a brad point drill bit and a commonly used twist drill bit. The geometry of the drill bits used in this research is presented in Figs. 2(a and b). It should be mentioned that the helix angle of both the brad point drill bit and the commonly used twist drill bit is equal to 30º. However, the point angle is 30º for the brad point drill bit and is equal to 120º for the latter.

The appearance of the delamination generated around a drilled hole at the entrance or exit of the drill bit is presented in Fig. 3.

Table 1. Mechanical and physical properties of the examined MDF panel (produced by Foumanat industrial group).

Density (kg/m^3)	Elasticity modulus (GPa)	Bending strength (MPa)	Humidity (%)
730	2.8	34	4.2

Fig. 1. The drilling process of the MDF panel on a vertical machining centre.



(a) (b)

Fig. 2. The drill bits used in this research; a) a brad point drill bit and b) a commonly used twist drill bit.

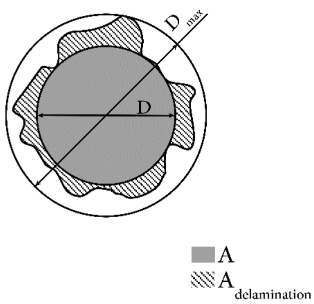


Fig. 3. The appearance of the delamination generated around a drilled hole at the exit of the drill.

Conventionally, the delamination factor is defined as [11]:

$$Delamination\ factor = \frac{D_{max}}{D} \tag{1}$$

where D is the diameter of the drill bit and D_{min} is the diameter of the peripheral circle on the delamination area (see Fig. 3). According to the definition above, if there is no delamination, the value of the delamination factor becomes equal to one. In the occurrence of the delamination, this value becomes a number larger than 1. In other words, the conventional delamination factor value is equal to or larger than 1.

As, the water absorption can be taken place through the delamination area (removed melamine layer during the drilling process) and the distribution of the delamination around the drilled hole may be inhomogeneous; here, a new delamination factor, referred to as area delamination factor, is defined:

$$Area\ delamination\ factor = \frac{A_{Delamination} + A}{A} \tag{2}$$

where A is the area of the drilled hole and $A_{Delamination}$ is the delamination area. Similar to what described the conventional delamination factor, the area delamination factor value is equal to or larger than 1. The main idea of this definition is that the area delamination factor can be a better parameter to characterize the water absorption in drilled holes of MDF products. Especially, consider the condition in which narrow delamination around the drilled hole is taken placed or in other words the distribution of the delamination around the drilled hole is inhomogeneous (Fig. 4). In this condition the delamination may be characterized by a large value using the conventional delamination factor; while, the area exposed to water absorption is the same as what for the homogeneous delamination. The area delamination factor defined here can be used to overcome this problem.

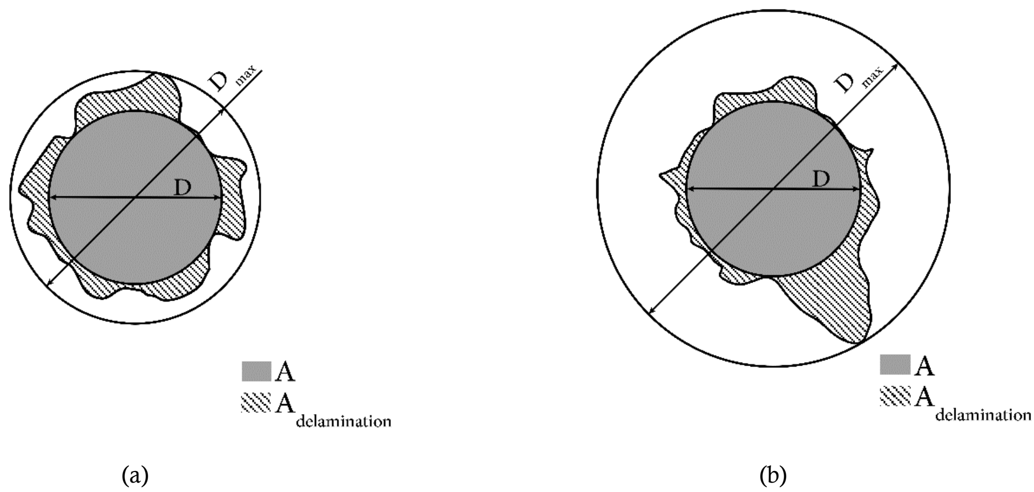


Fig. 4. A comparison between a) homogeneous and b) inhomogeneous distributions of delamination around a drilled hole.

Here, the image processing technique was used to determine the conventional and area delamination factors. The details are presented and discussed further in section 3.1 of the paper.

The experiments presented in table 2 were conducted to investigate the effects of two processing parameters including the cutting speed and the feed rate on the delamination around the drilled holes. These are the main parameters that affect the delamination in the drilling process of MDF panels [1-3]. The experiments were conducted using a brad point drill bit and a commonly used twist drill bit.

Also, it should be mentioned that to apply the desired cutting speed in each experiment the proper revolution speed (revolution per minute (rpm)) of the machine spindle was determined using the following equation:

$$\text{Cutting speed (m/min)} = \frac{D(mm)\times\pi\times n(rpm)}{1000} \tag{3}$$

where D is the diameter of the drill bit (as defined in equation (1)) and n is revolution speed of the machine spindle (rpm).

Table 2. The experiments conducted to investigate the effects of the cutting speed and the feed rate on the delamination.

Experiment No.	cutting speed (m/min)	feed rate (m/min)
1	15	0.1
2	15	1.25
3	15	2.5
4	15	3.75
5	15	5
6	30	0.1
7	30	1.25
8	30	2.5
9	30	3.75
10	30	5
11	60	0.1
12	60	1.25
13	60	2.5
14	60	3.75
15	60	5

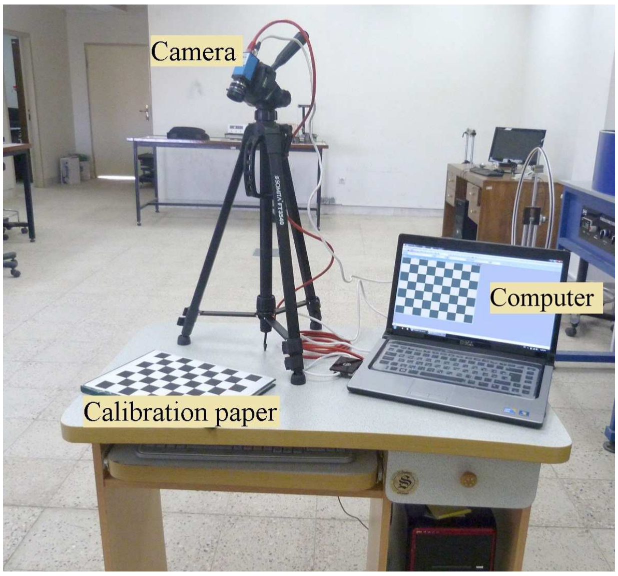


Fig. 5. The hardware setup of the camera calibration.

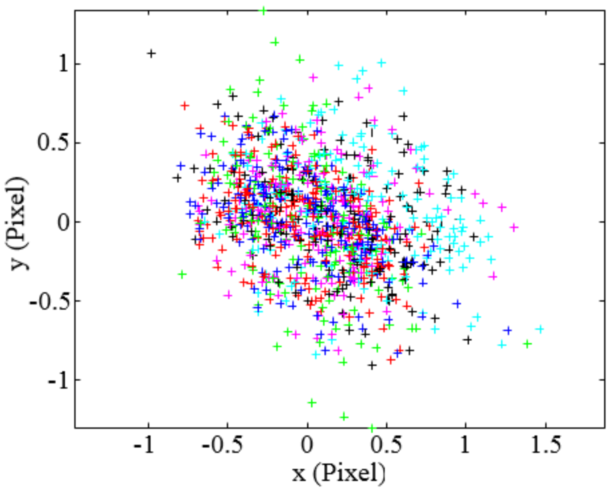


Fig. 6. The hardware setup of the camera calibration

3. Results and Discussion

In this section, first, the application of image processing to determine the delamination factor/ area delamination factor is explained in detail. Then, the results are presented and compared with the other previously published works.

3.1 Image processing for determination of conventional and area delamination factors

To determine the conventional and area delamination factors using the image processing the camera calibration was conducted, firstly [12]. The camera calibration refers to the determination of the extrinsic and intrinsic camera parameters. The intrinsic parameters include focal length, image sensor format, principal point, and lens distortion; while, the extrinsic parameters include the translation vector and the rotation matrix denote the coordinate system transformations from 3D world coordinates to 3D camera coordinates. Here, the camera calibration was conducted in a manner similar to that described in detail in Refs. [13, 14]. A CMOS 1280×960 color camera (DFK23GM021, GigE Company) with a pixel size of 3.75 µm was used. The camera lens was C-mount type (M1614-MP2, Computer) with the focal length of 12 mm. Accordingly, as depicted in Fig. 5, a planar checkerboard was used as a calibration plane in the measurement space.

Knowing the exact 3D position of the points in the calibration plane corresponding to the projected points in the image, the camera calibration parameters were computed and the projection error for points of the calibration plane was obtained (as depicted in Fig. 6). The mean value of projection error that is the mean error between the actual location of the image points and the calculated points of the calibration plane was obtained as 0.43 and 0.41 pixel for x and y directions, respectively.

In order to measure the drilled holes dimensions, the calibration plane was replaced with the drilled MDF panel in the same position, as shown in Fig. 7.

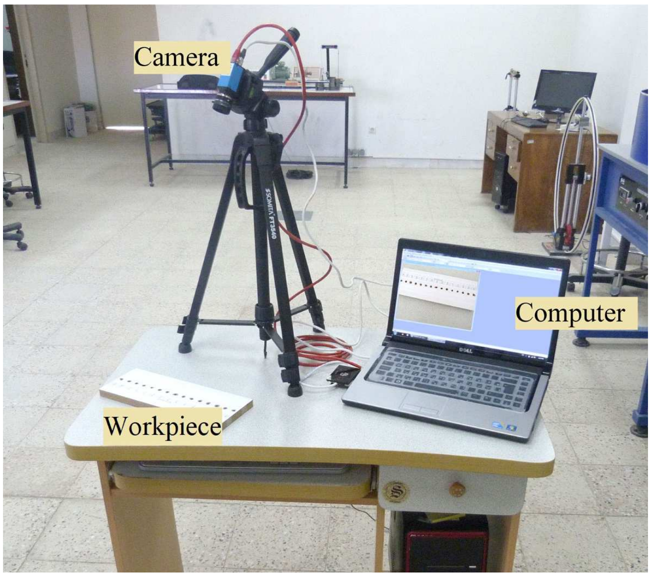


Fig. 7. Measuring the drilled holes dimensions by replacement of the calibration plane with the drilled MDF panel.

Fig. 8 shows the image taken from a drilled hole with the cutting speed of 15 m/min and the feed rate of 2.5 m/min using the brad point drill bit as an example before any further image processing.

Hereafter, the image processing stages performed here to measure the conventional/ area delamination factors for the sample drilled hole (shown in Fig. 8) is presented. The boundary of the drilled hole was detected with a circular edge detection algorithm (Fig. 9).

As shown in Fig. 9, in the circular edge detection algorithm, the boundary of the drilled hole can be detected by passing some co-center radial lines. The different gray level of the pixels in the drilled hole area A and the delamination area $A_{Delamination}$ was used to detect the boundary between these two areas. This edge detection algorithm was conducted using the IMAQ that is a commercial image processing software [15]. As depicted in Fig 9, two circles are selected; one inside the drilled hole area and the other outside the drilled hole area. Then, the values for minimum edge strength, kernel size, and projection width and gap are defined for the software to find the best edge, automatically. Consequently, the radius R and the center $C(x_c, y_c)$ of the best-fitted circle passing through 15 sample points of this boundary were calculated. For this, the basic equation of the circle was used as the fitness function F:

$$F = \sum_{i=1}^{15} ((x_i - x_c)^2 + (y_i - y_c)^2 - R^2)^2 \tag{4}$$

The least-square method was used to minimize the fitness function F. So, the best values for parameters x_c y_c and R were obtained. Consequently, the area of the drilled hole A was determined. A binary filter was applied to Fig. 8 to separate the total area $(A_{Delamination} + A)$ (Fig. 10) from the background.

According to Fig. 11, the total area $(A_{Delamination} + A)$ was measured by passing some co-center radial lines centered at $C(x_c, y_c)$ obtained for the drilled hole. Then the total area was measured from the Eq. (5):

$$A_{delamination} + A = \frac{1}{2}\int_0^{2\theta} r^2(\theta)\, d\theta \tag{5}$$

where r is the radius at the angle of θ. Regards to the complexity of the shape of the total delamination area for each 10^o a boundary point was detected, as shown in Fig. 11. The curve equation $r(\theta)$ passing through boundary points can be calculated using the Fourier method in closed form by Eq. (6) [16]:

$$r(\theta) = a_0 + \sum_{n=1}^{N} (a_n \cos n\theta + b_n \sin n\theta) \tag{6}$$

where N is the total number of boundary points that here is 36, as shown in Fig. 11. n is the harmonic number. a_n, b_n are coefficients giving the magnitude and phase for each harmonic. The radius of the dilled hole R and the maximum radius of delamination $R_{\max}$ can be determined to calculate the conventional delamination factor from Eq. 1 by setting $D = 2R$ and $D_{\max} = 2R_{\max}$.

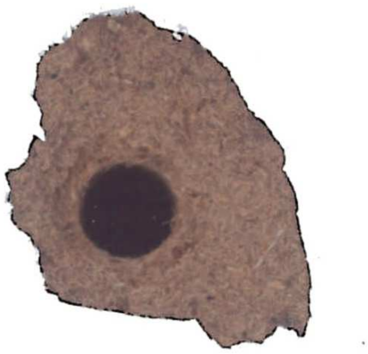


Fig. 8. The drilled hole with the cutting speed of 15 m/min and t he feed rate of 2.5 m/min using the brad point drill bit.

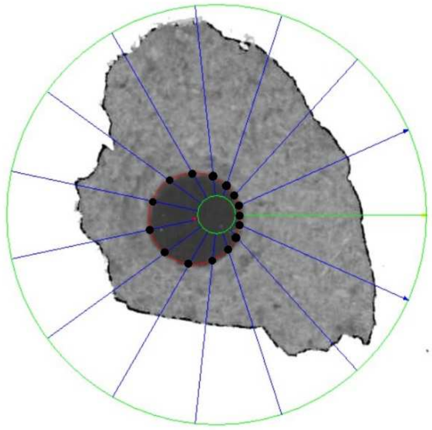


Fig. 9. The drilled hole image after image processing and edge de tection.

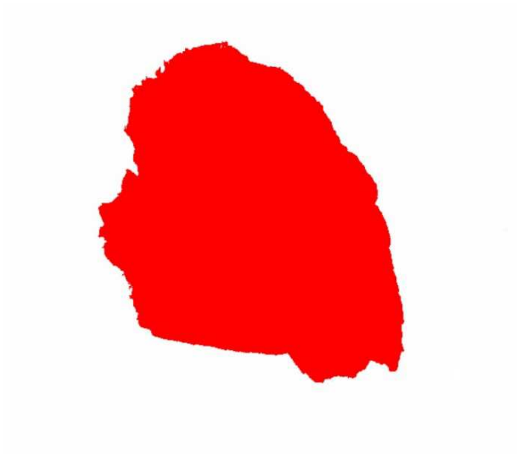


Fig. 10. Applying the binary filter to separate the total area ($A_{Delamination}$+A).

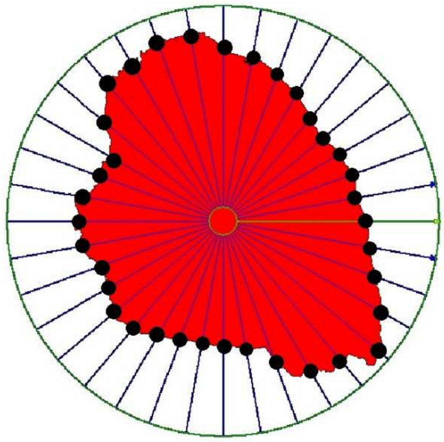


Fig. 11. The passed co-center radial lines centered at $C(x_c, y_c)$.

3.2 The effect of process parameters on the delamination at the entrance and the exit of the drill bit

Here, the effects of the cutting speed and the feed rate on the delamination at the entrance and the exit of the drill bit are investigated. The image processing methodology, explained in section 3.1, was used to determine the conventional delamination factor/ area delamination factor for the experiments listed in table 2 for both brad point drill bit and twist drill bit. The results are summarized in Figs 12(a and b) and Figs 13(a and b).

From the results shown in Figs. 12(a to d) and 13(a to d), it can be observed that, generally, the delamination value decreases with increasing cutting speed and increases with the increasing feed rate. However, there is some fluctuation in the results. For example, it can be observed that the increase of the delamination with the increase in feed rate has a higher slope at the feed rates between 1.25 to 3.75 m/min for the cutting speeds of 15 and 30 m/min at the exit of the drill bit. Also, a negative slope in the plot of the delamination against the feed rate can be seen at the start at the exit of the drill bit. This is true for both examined drill bits. Generally, the same trend of changing the delamination respect to investigated parameters can be found for the holes drilled by brad point drill bit and holes drilled by the twist drill bit.

A comparison between the results obtained using the conventional and area delamination factor to evaluate the delamination for both brad point and twist drill bits shows the same trend in the reported results. However, using the proposed area delamination factor the effect of process parameters on the delamination can be presented with higher magnitudes (compare Figs. 13(b) and 13(d) as an example). This, together with the ability of characterization of the water absorption of drilled holes indicates that area delamination factor is a more appropriate parameter to evaluate the delamination.

Also, comparing the results depicted in Figs 12 and 13 shows that the commonly used twist drill bit better performance (smaller value of delamination) than that of brad point drill bit in the drilling process of the tested MDF panel. This is because of the different geometry of these two types of drill bits. So, using the twist drill bit is recommended for the drilling process of tested MDF paned.

Also, it can be seen that the delamination value at the tool entrance (top delamination) is extremely less than its value at the tool exit (bottom delamination) (see and compare Figs. 13(c) and 13(d) as an example); so, the delamination control at the exit has a more importance. A glance view of the whole results shows that the least delamination at the exit has been obtained for the highest cutting speed of 60 m/min and the feed of 1.25 m/min.

Finally, it should be mentioned that the results are generally consistent with the other previously published works [1-3].

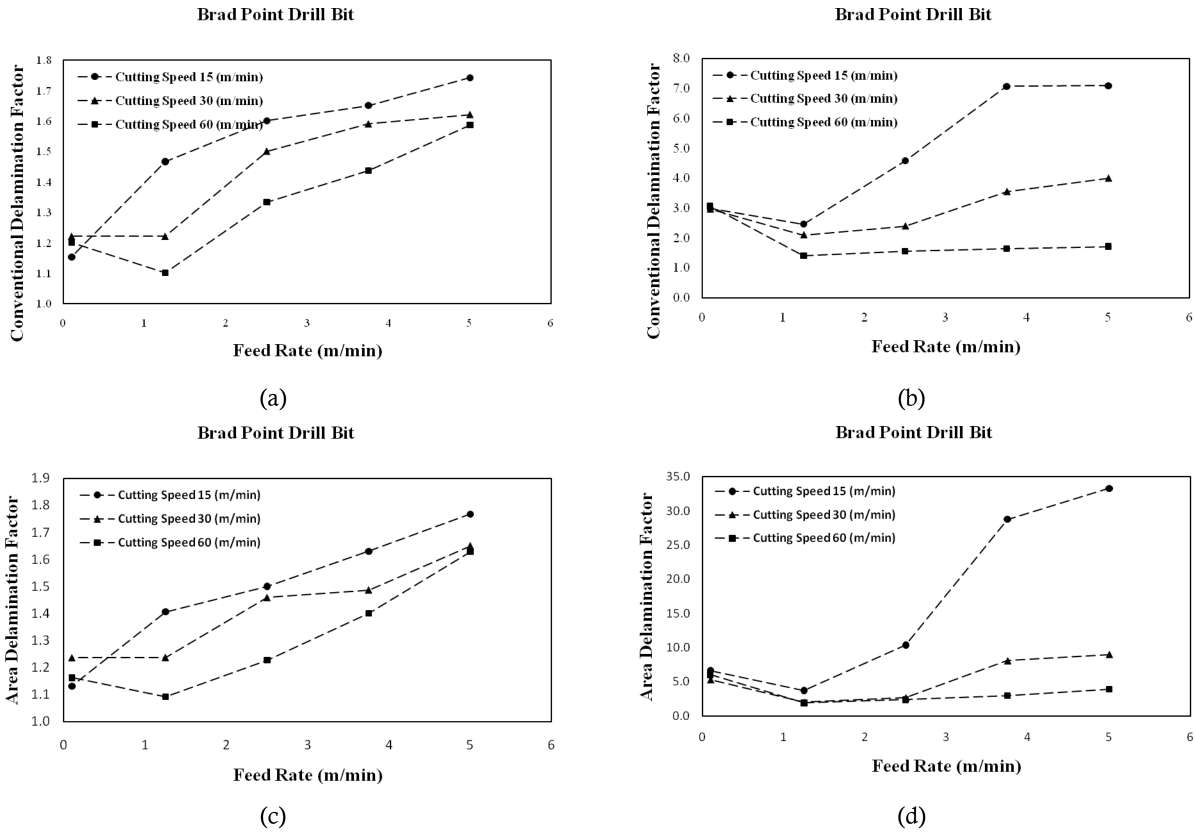


Fig. 12. The effects of cutting speed and feed rate on the delamination for brad point drill bit a) conventional delamination factor at entrance b) conventional delamination factor at exit c) area delamination factor at entrance d) area delamination factor at the exit.

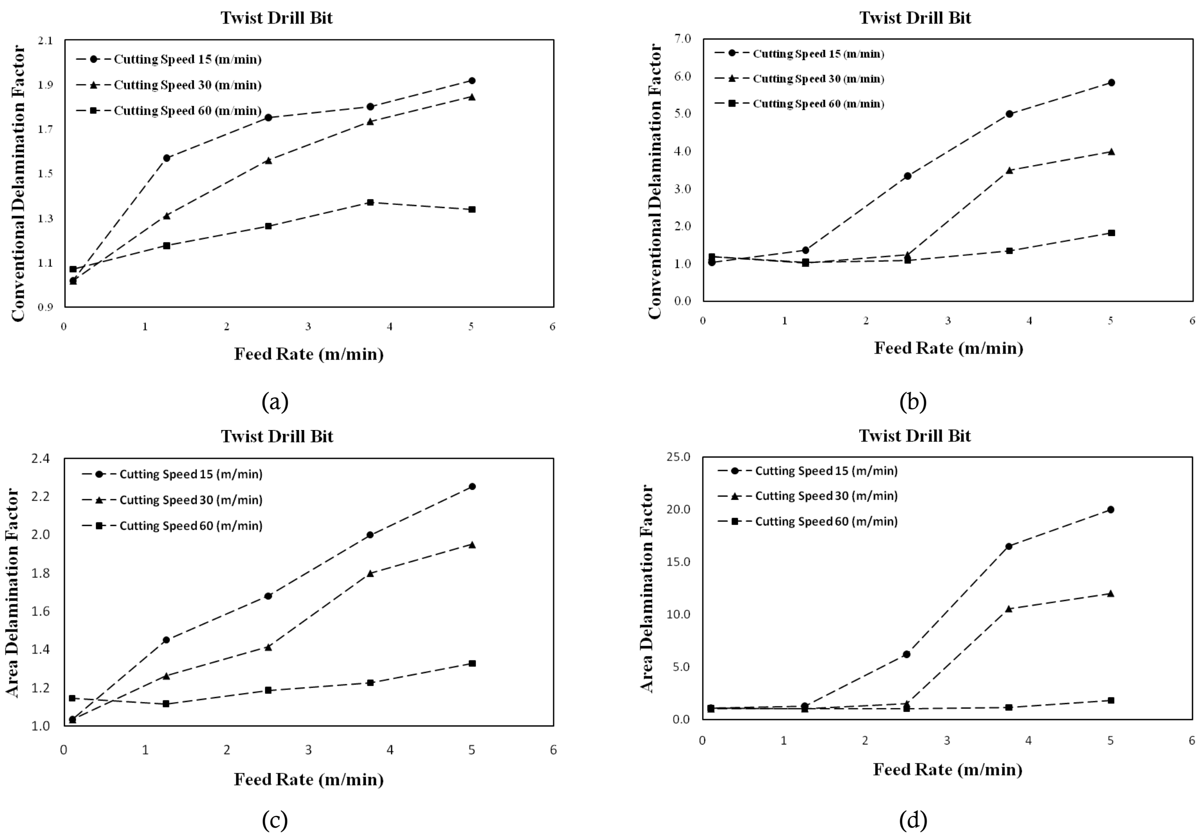


Fig. 13. The effects of cutting speed and feed rate on the delamination for twist drill bit a) conventional delamination factor at entrance b) conventional delamination factor at exit c) area delamination factor at entrance d) area delamination factor at the exit.

4. Conclusions

In this work, the effect of the processing parameters on the delamination in the drilling process of melamine coated MDF panel was investigated. The drilling process was conducted using two different drill bits; one a brad point drill bit and the other a twist drill bit. Conventional delamination factor and a new proposed area delamination factor were used for assessment. It was found that the delamination value decreases with increasing cutting speed and increases with increasing feed rate. Though, there was some fluctuation in the results. The increase of the delamination with the increase in feed rate had a higher slope at the feed rates between 1.25 to 3.75 m/min for the cutting speeds of 15 and 30 m/min at the exit of the drill bit. Also, in the plot of the delamination against the feed rate, there was a negative slope at the start at the exit of the drill bit. Generally, the same trend of changing the delamination respect to the investigated parameters was found for the holes drilled by brad point drill bit and holes drilled by the twist drill bit. The proposed area delamination factor showed the same results as the results obtained by the usage of conventional delamination factor. However, using the proposed area delamination factor the effect of process parameters on the delamination can be presented with higher magnitudes. This, together with the ability of characterization of the water absorption of drilled holes indicates that area delamination factor is a more appropriate parameter to evaluate the delamination. Under the present experimental conditions, in comparison to using the brad point drill bit, a smaller value of delamination was obtained using the commonly used twist drill bit. It was observed that the delamination value at the tool entrance is extremely less than its value at the tool exit. The least delamination at the exit was obtained for the cutting speed of 60 m/min (the highest cutting speed) and the feed rate of 1.25 m/min. It should be mentioned that in this work the used drill bits were sharp. Analysis of the correlation among the delamination, tool wear, and drill thrust force can be conducted in the future.

Author Contributions

M. Rakhshkhorshid and M. Lakhi planned the scheme, initiated the project and suggested the experiments; M. Rakhshkhorshid, M. Lakhi and S. Ghahremani conducted the experiments and analyzed the empirical results. The new area delamination factor was proposed by M. Rakhshkhorshid. S.M. Emam developed the image processing technique as a measuring tool for this research. The manuscript was written through the contribution of all authors. All authors discussed the results, reviewed and approved the final version of the manuscript.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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Data Availability Statements

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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