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MODELLING OF THERMAL DRILLING OF AA7075 ALUMINUM ALLOYS USING REGRESSION ANALYSIS AND ARTIFICIAL NEURAL NETWORKS TECHNIQUES

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ABSTRACT In the present research, the effects of the tool spindle speed and the conical angle on the hole diameter, bushing height and bushing thickness of the thermally drilled AA7075 aluminum alloy sheets were investigated. The AA75075 Al sheets have 3.4 mm thickness. Three different tools, made from H13 tool steel, with 25°, 30° and 35° conical angles were manufactured. The holes were drilled at different spindles speeds, typically, 3100 rpm, 3400 rpm and 3700 rpm. Both regression analysis (RA) and artificial neural (AN) modeling techniques were used for prediction the effect of the spindle speed and the conical angle on the hole diameter, bushing height and bushing thickness. The results revealed that the spindle rotational speed and conical angle affects the hole diameter, bushing height and bushing thickness. The mean absolute errors for the developed regression models were about 0.0439506, 0.204691 and 0.0595062 for models used to predict the hole diameter, bushing height and bushing thickness, respectively. The hole diameter, bushing height and thickness were successfully predicted using artificial neural network (ANN) modelling. The MLP neural network architecture 2-7-3 with Tanh transfer function exhibited the best performance with 83.62% accuracy. There is a good agreement between the measured results and simulated outputs obtained with the ANN modelling.

KEYWORDS: Friction drilling, Aluminum Alloys, Thermal drilling, Artificial Neural Network.

1 INTRODUCTION

Thermal drilling is a nontraditional hole-making method. In the thermal drilling process, a conical rotating tool is allowed to penetrate the workpiece to create a hole with a bush in a single step without generating chips [1]. The heat generated from friction between a rotating conical tool and the workpiece is used to soften the work-material and penetrate a hole [1-3].

Thermal drilling creates bushing on sheet metal, tubing, or thin walled profiles for joining devices in a simple, efficient way. The bushing created in the process is usually two to three times as thick as the original workpiece. This added thickness can be threaded, providing a more solid connection for attachment than attempting to thread the original sheet [4].

The ferrous and non-ferrous materials are commonly investigated in thermal drilling [5]. The bushing formed in the thermal drilling of ferrous materials is cleaner and more stable than bushing formed of non-ferrous materials [6]. For brittle cast metals, the bushing generated by thermal drilling exhibits cracks or petal formation.

In this research, sheets from AA7075 aluminum alloys were thermally drilled. The influence of the spindle rotational speed as well as the cone angle of the tool on the quality of the thermally drilled holes were evaluated. The diameters of the formed holes as well as the bushing height and thickness was measured. Both regression and neural network models were developed for prediction the diameter of the hole, bushing height and thickness as a function of the spindle speed and cone angle.

2 EXPERIMENTAL PROCEDURES

AA7075 wrought Al alloy sheets with thickness of 3.4 mm was used for thermal drilling. The chemical composition of the AA7075 alloy is listed in Table 1. The drill tool used was made of AISI H13 (Cr-Mo-V) hot work tool steel manufactured by Bohler-Uddeholm UDDEHOLM

ORVAR (Germany). The chemical composition of the tool's material is listed in Table 2.

Table 1: Chemical composition of AA7075 aluminum alloy (wt. -%).

Elements	Cu	Fe	Mn	Mg	Si	Zn	Cr	Ti	Pb	Al
Weight %	1.33	0.258	0.052	2.29	0.112	5.94	0.166	0.023	0.005	Bal.

Table 2: Chemical composition of H13 tool steel (wt. -%).

Elements	C	Cr	Mn	Mo	Si	V	Fe
Weight %	0.39	5.21	0.40	1.37	1.1	0.90	Bal.

Figure 1 shows the key dimensions of the thermal drill tool. The tool used in this investigation has D_{sh} = 30 mm, d = 15 mm, α = 70 ^{o}C, h_n = 15 mm, h_c = 4.97 mm, shoulder region = 10 mm length, shank region = 40 mm length and 15 mm diameter, and the conical angle (β) = 25^{o}, or 30^{o} or 35^{o}.

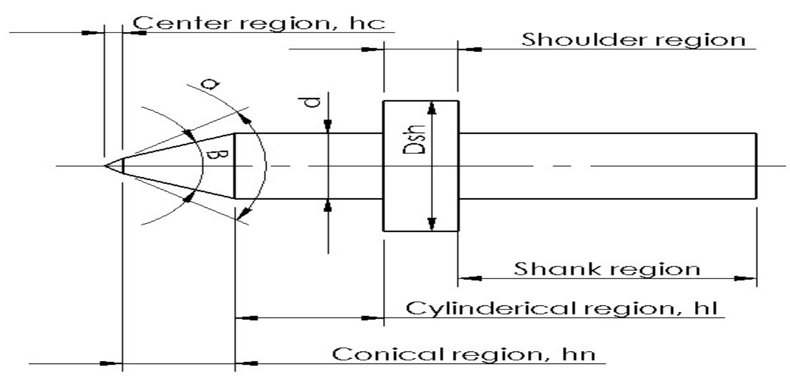


Figure 1: The key dimensions of the thermal drilling tool.

A CNC vertical machining center was used for the thermal drilling process of AA7075 Al sheets. The thermal drilling process were performed using different spindle speeds, typically, 3100 rpm, 3400 rpm and 3700 rpm. The feed rate was kept constant at 30 mm/min. Before drilling the workpiece was put on the die with a hole (30 mm diameter) and clamped rigidly.

After drilling the workpieces were cut, from the center of the hole, using wire cut machine and the hole and bushing characteristics were measured. The measured bushing dimensions are the average bushing thickness (t) and the bushing height (h). The hole diameter (d) was also measured. Figure 2 shows a schematic illustration of the measured hole and bushing characteristics. The aforementioned dimensions were measured using image analyzing techniques.

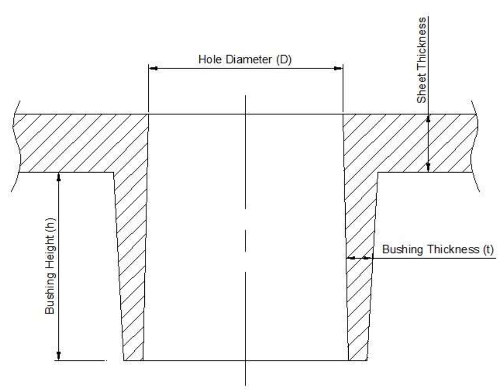


Figure 2: Bushing height, thickness and hole measurements.

The regression analysis (RA) technique was used to correlate the relation between the independent parameters (conical angle and spindle rotational speed) and the dependent parameters (hole diameter, bushing height and bushing thickness). The mean absolute error (MAE) was calculated to define the accuracy of the RA equations. The MAE is given by the following equation [7]:

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} = \frac{\sum_{i=1}^{n} |e_i|}{n} \quad \ldots(1)$$

The MAE is an average of the absolute errors $|e_i| = |y_i - x_i|$, where y_i is the prediction and x_i the true (experimental) value.

The developed ANN model is based on Multi-Layer Perceptron (MLP) neural networks. The developed ANN model can be used to predict the effects of the different thermal drilling process parameters on the dimensions of the hole and bushing. Figure 3 shows a typical architecture of MLP neural network developed in the present investigation.

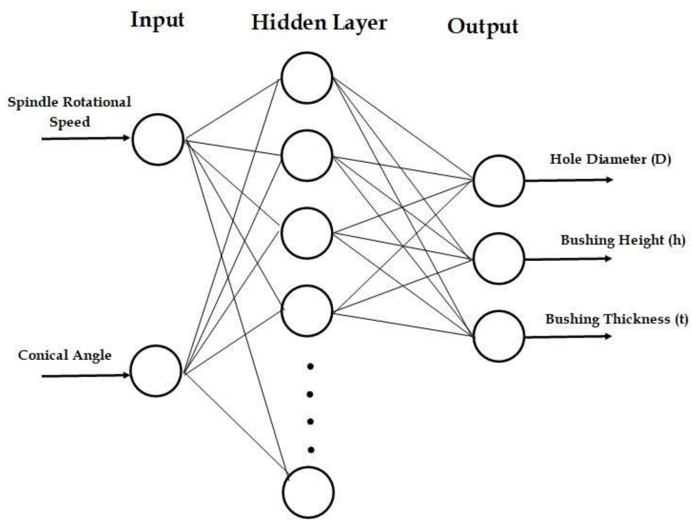
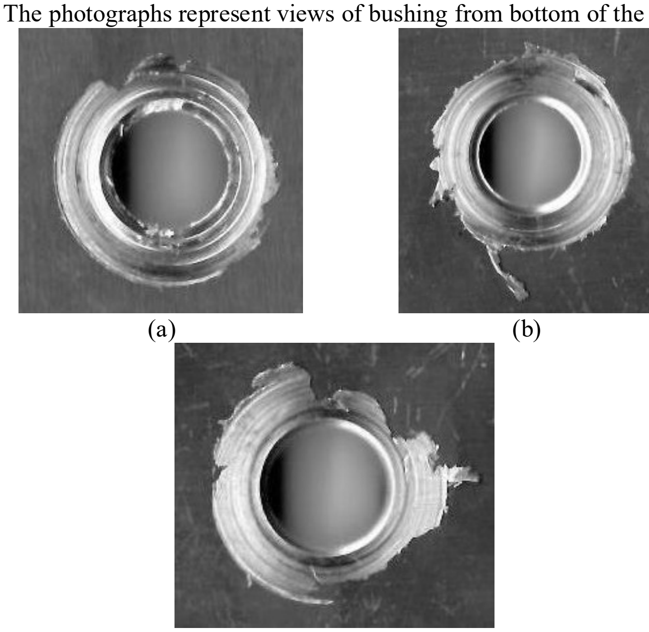


Figure 3: The architecture of MLP neural network.

3 RESULTS AND DISCUSSION

3.1. The Hole & Bushing Shapes

Figures 4 shows, typical photographs of the top views of the thermally drilled holes using constant spindle rotational speed of 3100 rpm and different conical angles. Figures 5 shows, typical photographs of bushing formed in thermal drilling of AA7075 aluminum alloy at spindle rotational speed of 3400 rpm and different conical angles. The photographs represent views of bushing from bottom of the workpiece.

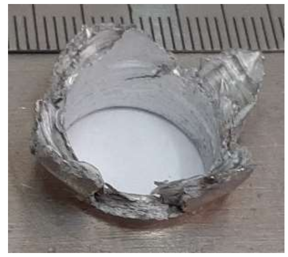


(a) (b)

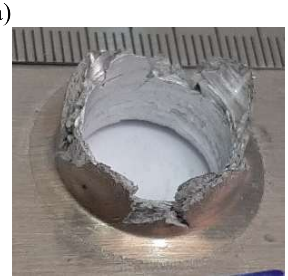
(c)

Figure 4: Top view of holes drilled with a constant spindle speed of 3100 rpm and different angles of (a) 25°, (b) 30° and (c)35°.

(a)



(b)



(c)

Figure 5: Bushing formed in thermal drilling of AA7075 Al alloy at constant spindle speed of 3400 rpm and different angles of (a) 25°, (b) 30° and (c)35°.

Petal formation was observed in the photographs. It has been reported that petal formation is an undesirable characteristic in thermal drilling [6]. The petals were observed to peel from the workpiece in the radial direction. The petals have bright and curved surfaces. This shows that the petal is a part of the bushing during the early stage of thermal hole drilling. As the strain in the bushing reaches a critical value, the bushing fractures along the axial direction and bursts into four to six petals.

Figure 6 show, typical photograph of the cross-sections of bushing formed in thermal drilling of the AA7075 aluminum alloy sheets at 3100 and 25°. The cross-sectioned photographs were used to measure the bushing height (h) and busing thickness (t). The measurements were performed using image analysis technique.

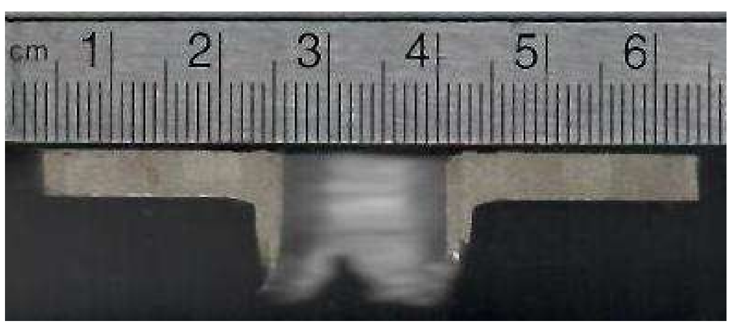


Figure 6: Bushing cross-sections formed at constant spindle speed of 3100 rpm and 25°.

3.2. Regression Modeling

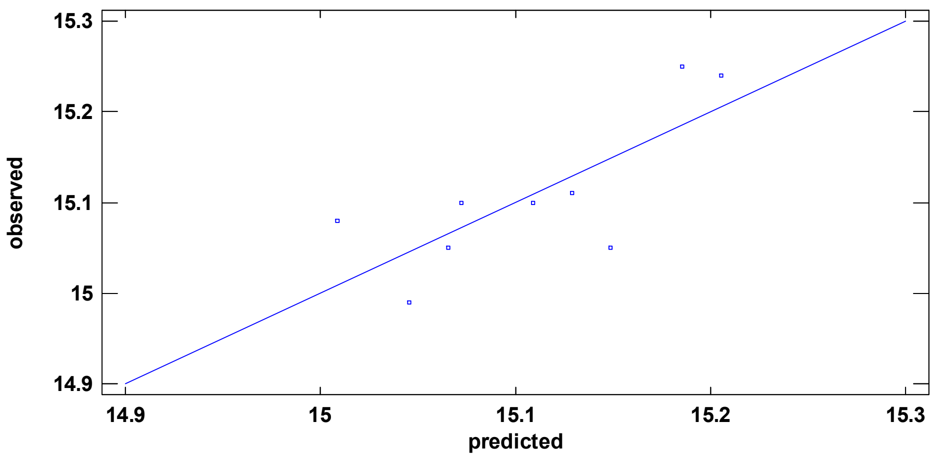
The following equations show the developed fitted models for hole diameter (D), the bushing height (h) and bushing thickness (t), respectively:

$$D = 15.1078 + 0.00555556 \times I1(1) - 0.0311111 \times I1(2) + 0.0722222 \times I2(1) - 0.0677778 * I2(2) \quad \ldots(1)$$

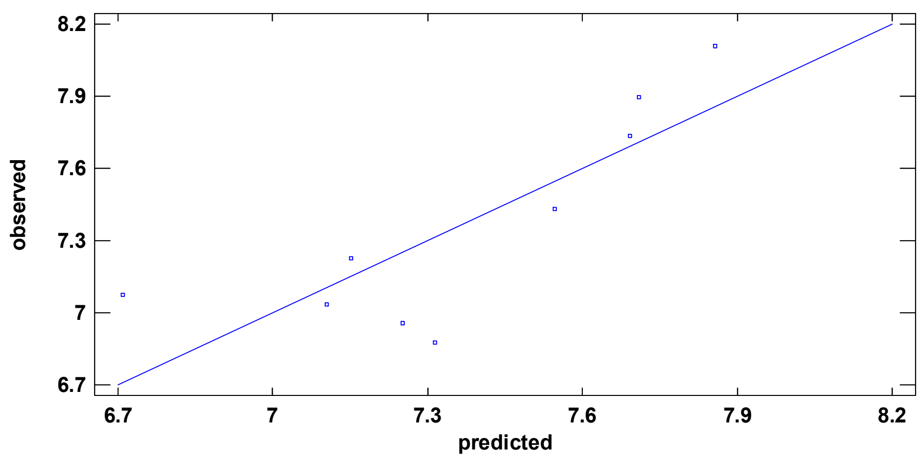
$$h = 7.37056 + 0.0827778 * I1(1) - 0.312222 * I1(2) + 0.0927778 * I2(1) + 0.256111 * I2(2) \quad \ldots(2)$$

$$t = 1.82722 + 0.0527778*I1(1) + 0.0527778*I1(2) + 0.116111*I2(1) - 0.0522222*I2(2) \quad \ldots(3)$$

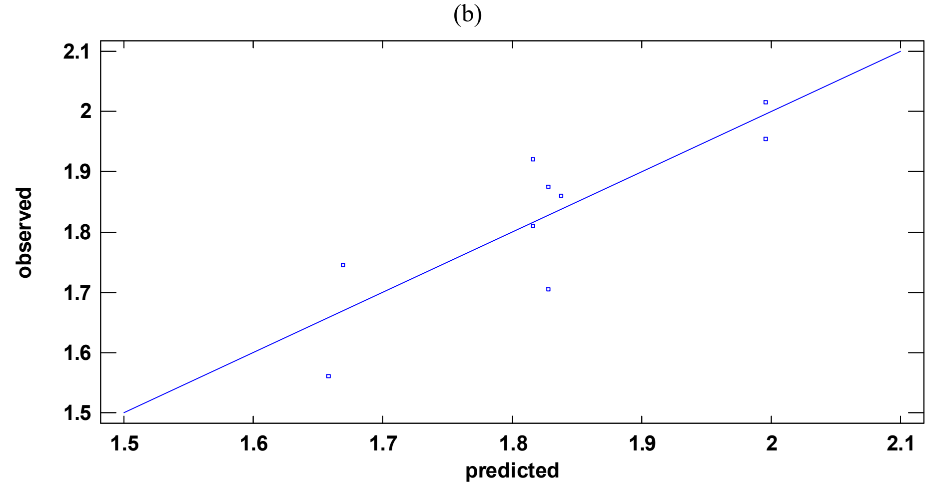
Where: D is the hole diameter in mm, I1(1) = 1 if S=3100, -1 if S=3700, 0 otherwise, I1(2) = 1 if S=3400, -1 if S=3700, 0 otherwise, I2(1) = 1 if A=25, -1 if A=35, 0 otherwise I2(2) = 1 if A=30, -1 if A=35, 0 otherwise. The MAE for Equation 1, 2, and 3 are equal to 0.0439506, 0.204691 and 0.0595062, respectively. A comparison between the observed (measured) and the predicted (modelling) hole and bushing dimensions are shown in Figure 7. The measured and predicted values developed are highly scatter around this line.



(a)



(b)

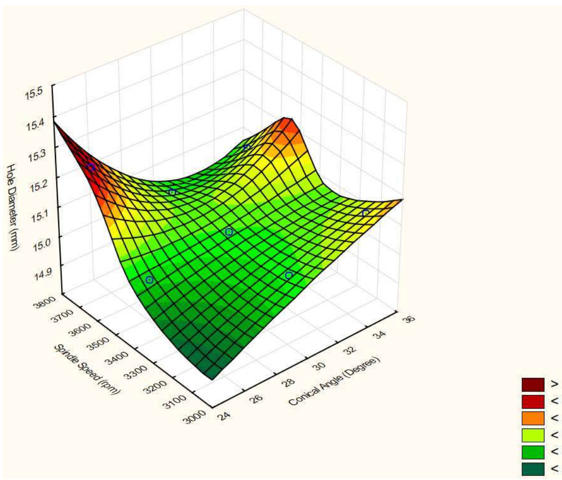


(c)

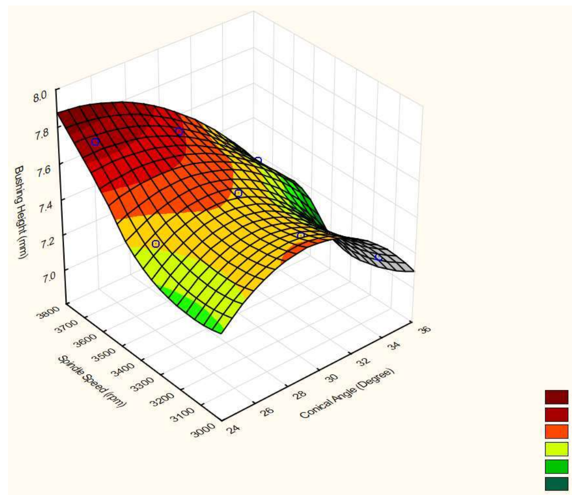
Figure 7: Observed vs. predicted (a) hole diameters, **(**b**)** bushing height and (c) bushing thickness.

3.3. ANN Modeling

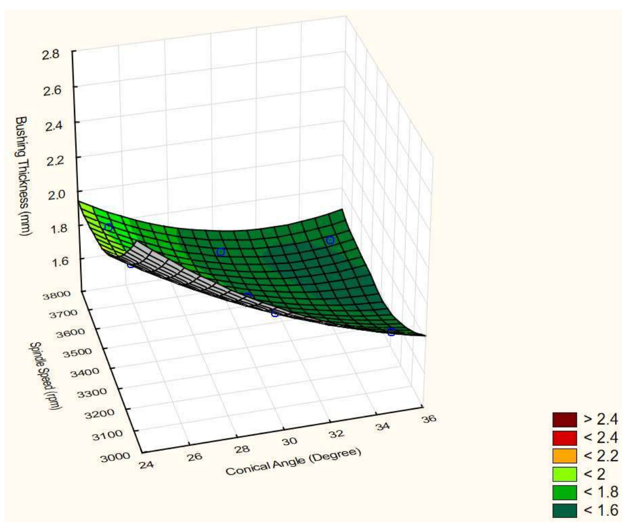
The MLP neural network architecture 2-7-3 with Tanh transfer function exhibited the better performance with 83.62% accuracy. The graphical representations of the ANN prediction results for the hole diameter, bushing height and bushing thickness are shown in Figure 8. The results indicate that both hole diameter, bushing height and thickness can be predicted using the MLP 2-7-3 ANN model with an acceptable accuracy.



(a)



(b)



(c)

Figure 8: Variation of the (a) hole diameter, (b) bushing height and (c) bushing thickness with the spindle speed and conical angle resulted from ANN modelling.

4 CONCLUSIONS

The conclusions of significance are drawn as follows :-

7. The spindle rotational speed and conical angle affects the hole diameter, bushing height and

bushing thickness of thermally drilled AA7075 aluminum alloy sheets with 3.4 mm thickness.

8. Regression modelling was used to develop equation for prediction the hole diameter, bushing height and bushing thickness. The mean absolute errors were about 0.0439506, 0.204691 and 0.0595062 for models used to predict the hole diameter, bushing height and bushing thickness, respectively.
9. The hole diameter, bushing height and thickness were successfully predicted using artificial neural network modelling. The MLP neural network architecture 2-7-3 with Tanh transfer function exhibited the best performance with 83.62% accuracy. There is a good agreement between the measured results and simulated outputs obtained with the ANN modelling.

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