G Model
CIRPJ 443 No. of Pages 9
ARTICLE IN PRESS
CIRP Journal of Manufacturing Science and Technology xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
CIRP Journal of Manufacturing Science and Technology
journal homepage: www.elsevier.com/locate/cirpj

Experimental and Thermo-Mechanical Modeling Optimization of Thermal Friction Drilling for AISI 304 Stainless steel☆

Sara A. El-Bahloul*, Hazem E. El-Shourbagy, Ahmed M. El-Bahloul, Tawfik T. El-Midany

Production & Mechanical Design Engineering Department, Faculty of Engineering, Mansoura University, Egypt

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Thermal friction drilling
Bushing length
Axial force
Finite element modeling
Fuzzy logic
Regression analysis

ABSTRACT

The main purpose of this research is to investigate experimentally the optimal process parameters of thermal friction drilling process, based on the design of experiment method coupled with fuzzy logic and analysis of variance techniques, considering the resultant axial force and bushing length. A friction drilling machine is designed, and manufactured in Shoman Company — Egypt to perform the experimental work, and the tools are offered by Flowdrill Company — Netherlands. A temperature-dependent dynamic explicit modeling is applied, considering adaptive meshing, element deletion, and mass scaling techniques. The resultant optimal parameter levels combination is: 9.2 mm tool diameter, 30° friction angle, 50% friction contact area ratio, 60 mm/min feed rate, and 3500 rpm rotational speed. A comparison is performed between the experimental and thermo-mechanical modeling results, considering the axial force, and a similar trend is achieved. Also a regression analysis is applied to predict the expected axial force and bushing length and confirmed by confirmation test.

Introduction

Thermal friction drilling, also called friction drilling, friction stir drilling, flow drilling, or form drilling is a nontraditional method for hole-making. It uses the generated heat from friction occurred between a rotating conical tool and a workpiece, to soften and penetrate the work material, leading to bushing generation as shown in Fig. 1. Friction drilling solves the problems of joining sheet materials in a simple, economical and most efficient way, as the generated bushing can be threaded with providing high strength load bearing surface.

Miller and Shih demonstrated the modeling the workpiece temperature and material deformation, and compared the obtained results with the experimentally measured thrust force, torque, and workpiece temperature [1]. Ku et al. investigated the thermal friction drilling effects on surface roughness and bushing length, and the machining characteristics of the process were improved [2]. Krasauskas et al. investigated the influence of cutting regimes experimentally on the axial force and compared the results with the finite element simulation [3]. Ozek and Demir investigated the effect of feed rates and spindle speeds on the produced bushing length, surface roughness, and frictional heat [4]. Wu et al. studied the friction drilling process using molecular dynamics simulations, by evaluating the tool rotational velocity and substrate temperature in terms of atomic trajectories, slip vector, thrust force, stress, flow field, and hole characteristics [5].

The main objective of the present research is to investigate experimentally the optimal parameters combination of the thermal friction drilling using experimental design method coupled with Fuzzy Logic technique. The operating parameters considered are namely; tool diameter (d), friction angle (β), friction contact area ratio (FCAR), feed rate (FR), and rotational speed (RS). The optimal results are based on the measured parameters that are namely; axial force (AF) and bushing length (BL).

A three-dimensional temperature-dependent dynamic explicit modeling is performed with the help of ABAQUS/EXPLICIT finite element analysis software. A comparison is done between the experimental and thermo-mechanical modeling results, considering the resultant axial force. Also a regression analysis with the help of Statistical Package for the Social Sciences (SPSS) software is applied to predict the expected axial force and bushing length.

Abbreviations: AF, axial force; ANOVA, analysis of variance; BL, bushing length; FCAR, friction contact area ratio; FR, feed rate; H, high; L, low; M, medium; MPCI, multiple performance characteristic index; RS, rotational speed; VH, very high; VL, very low.

☆ This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

* Corresponding author.
E-mail address: sara_elbahloul@mans.edu.eg (S.A. El-Bahloul).

https://doi.org/10.1016/j.cirpj.2017.10.001
1755-5817/© 2017 CIRP.

Notations

DF_e	Degree of freedom for error
DF_k	Degree of freedom for each process parameter k
d	Tool diameter
k	Process parameter
Lf	Quantization levels of the output
$(M)_p$	Measured values trails mean for each experiment p
$M(\min)$	Minimum values of M for all experiments
$M(\max)$	Maximum values of M for all experiments
MSe	Mean squares of error
MS_k	Mean squares for each process parameter
p	Experiment number
SS_k	Sum of the squared deviations due to each process parameter k
SS_T	Total sum of the squared deviations
t	Workpiece thickness
z_i	Quantization value
β	Friction angle
$\mu_B(y_i)$	Degree of membership of z_i to the fuzzy set B
ηm	Total mean of the MPCI
$(N\eta)p$	Normalized M for every experiment number p

Experimental setup

Thermal friction drilling machine

A thermal friction drilling machine is designed, manufactured, and assembled with the assistance of Shoman Company — Egypt. Fig. 2 shows the designed and manufactured friction drilling machine (A), machine control unit (B), multi-component dynamometer (Kistler-type 9257B) (C), dynamometer data acquisition and amplifier (D), and laptop (E) to resolve the experimental results. Fig. 3 illustrate the elevation and plane sectional views of the machine.

The machine consists of six main assemblies: driving motor assembly, feed motor assembly, column assembly, balance weight assembly, base assembly, and fixture assembly. The driving motor assembly consists mainly of is an induction motor of 2.2 kW achieving rotational speed range of 0–4200 rpm. The tool chuck is coupled to the motor to provide the required tool rotational speed. The feed motor assembly consists mainly of an induction motor of 2.2 kW achieving rotational speed range of 0–2400 rpm. The feed rates, with a range of 0–218.182 mm/min, can be obtained by the power screw and nut that is coupled to the feed motor. The power screw and nut are guided within the column assembly by means of two dovetail guide ways. Both the required rotational speeds and feed rates are controlled by the control unit. To avoid unnecessary loading conditions on the tool during drilling, two balancing weights are used, to equate the moving parts weight of the driving motor assembly. Finally, the driving motor, feed motor, column, balance weight, and workpiece fixture assemblies are fixed on the rigid base assembly.

Fig. 2. The manufactured friction drilling machine (A), machine control unit (B), multi-component dynamometer (C), dynamometer data acquisition and amplifier (D), and laptop (E).

AISI 304 stainless steel workpiece material with 1 mm sheet metal thickness (t) is used in this research, since this material is hard to process and results in a serious tool wear and a rough surface in machining process. Tungsten carbide tool material is used during the experimental work.

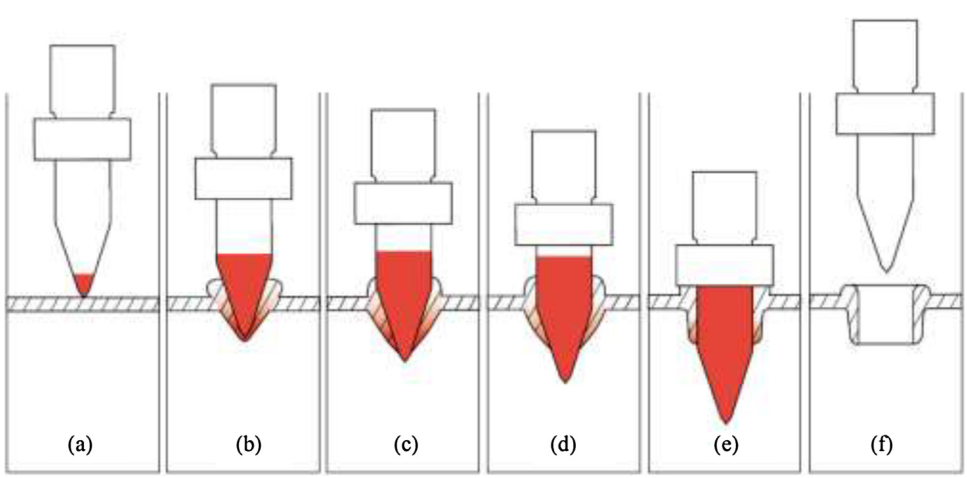

Fig. 1. Friction drilling steps: (a) initial contact; (b) tool-tip penetration to the material; (c) material flow; (d) tool-cylindrical region penetration; (e) bushing forming; (f) tool withdrawal.