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Short communication

Multi-objective optimization of green technology thermal drilling process using grey-fuzzy logic method

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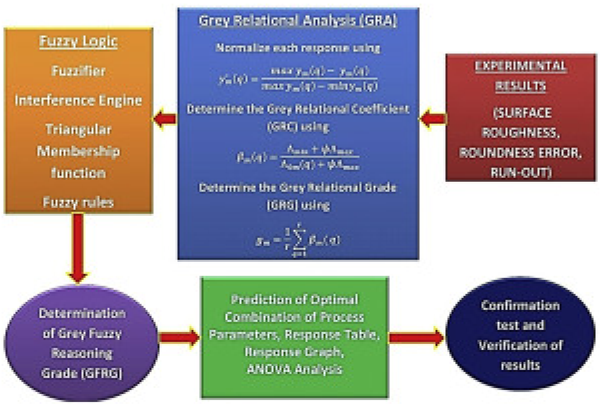
Abstract

The wastage of metal chips from conventional drilling process creates massive environmental pollution. In order to reduce emission pollution, this process should be replaced by the green technology of thermal drilling process. Thermal drilling is an energy efficient, clean and chip less drilling method that has attracted more automotive and aerospace manufacturers in recent years. The processing time, tool failure and manufacturing cost of drilling are reduced and the bushing formation is three times thicker than the workpiece, which offers a prolonged bearing area that fits a shaft firmly. However, achieving these objectives is time consuming and leads to material waste for industrial sectors. Here, we propose a robust methodology that combines experiments with modern optimization technique in order to solve the industrial challenge and further improve the drilling quality. The experiments were conducted on galvanized steel material with different thicknesses (1 mm, 1.5 mm and 2 mm). Three thermal drilling tools are developed using M2 tool steel with three different geometry angles such as 30^{o}, 37.5^{o} and 45^{o}. The recommended level (A3 B1 C2) identified in this experimental research, allows to minimize the thermal drilling parameters with intended benefits of the output parameters. It permits to identify the best solution of minimum surface roughness of 1.088 μm with the roundness error of 0.080 mm and 0.145 mm run-out. Further, the multi-objective decision technique designed offer contribution details of critical input parameters contribution of rotational speed, tool angle, and workpiece as 76.58%, 10.56%, and 1.982%, respectively.

Graphical abstract



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Introduction

It is well known that the wastes generated from the machining process are in the form of effluent waste, solid waste, atmospheric emission, and energy emission (Kovoor et al., 2012; Sepehri and Sarrafzadeh, 2018). Clean machining (less resource, better quality, shorter supplying chain route, on time process, first right and so on) is a critical step in order to meet government policies, reducing the CO_2 by 80% through 2050. The strategy needs consider robust decision makers to promote sustainable criteria that generate recovering resources by an efficient use of manufacturing conditions.

Galvanized steel has diversified usages in numerous engineering applications such as construction industry, plumping projects etc. (Hamidinejad et al., 2012; Sinha et al., 2013) which are employed to acts as a replacement of conventional steel due to the advantages of prevention of correction and rust. On account of this trend, the thermal drilling of galvanized steel sheets has become very crucial in the fabrication of structural connections. The thermal drilling process (N. R. J. Hynes & R. Kumar, 2017a; R. Hynes & R. Kumar, 2017b;

R. Kumar and Hynes, 2018a, 2018b; Rajesh, Hynes, Kumar, & A. J. Sujana, 2017) is performed before making a connection of sheet metals and the fabricated holes performance as a location of stress concentration. Therefore, augmented care is given to the failure possibilities in the drilled hole which is created by the action of creep and fatigue.

This technique (thermal drilling) produce within the local surfaces a high temperature deformation that is challenging to find by the way of experimentation, instead it can be effectively succeeded by finite element method (Kumar and Hynes, 2018c; Hynes et al. 2018). The use of thermal drilling technique was proposed as an alternative for the conventional one. It proves very successful results when is performed using bio-environmental oils (i.e. high-oleic sunflower oil) (Pereira et al., 2019). Further, the minimum quantity lubrication was proposed to obtain environmentally friendly drilling and increase the efficiency for machining of intermetallic titanium aluminide (Mathew and Vijayaraghavan, 2017). The surface texturing on the tool is a mechanical approach that allow reducing the frictional contact between the tool and workpiece and promote improvements for the energy loss (Niketh and Samuel, 2017). In the drilling of galvanized steel sheet, the increase of surface roughness, roundness error and run-out leads to increase the damage at the end of finished product practices.

Therefore, an investigation is needed to get desired quality characteristics along with minimization of surface roughness, roundness error, and run-out. This process is a multi-input and multi-response method because the response factors being closely combined with each other, spending of cost and time are consumed by the way of execution of trial and error approach to achieve optimal drilling processing sets through the various combination of drilling parameters to manufacture reliable drilling quality. Through using the Adaptive Neuro Fuzzy Inference System (ANFIS) and genetic algorithm (GA) (Saw et al., 2018; Kumar and Hynes, 2019) detected the best drilling parameters during drilling of cylindrical mild steel.

Taguchi based Design of Experiments (DOE) (Kim et al., 2008) was performed to find the optimal manufacturing conditions (Pal, 2015). (Ku et al., 2011) based on develop Taguchi strategy designed a novel type of thermal drill with sintered tungsten carbide material. However, this method has been utilized to optimize a single response of the manufacturing problem. Therefore, handling of additional significant multi-response characteristics has enhanced the interest of research. For computing the multi-response complex problem, a grey-based system theory is employed. The Grey Relational Analysis (GRA) was developed by the author (Deng, 1989) who utilizes a specific model of information. Grey Relational Grade (GRG) is calculated by average values of Grey Relational Coefficients (GRC) leads to create an interrelationship between the responses of the given problem. But, this analysis has the specific degree of indecisiveness. This limitation is overcome by fuzzy logic theory and it was developed by the author (Zadeh, 1965) to deal the complex problems with vague and uncertainty information. Fuzzy logic (FL) is a methodology which is developed from artificial intelligence approach and it is an efficient software tool for handling non-linear complex problems (Hynes et al., 2018). This methodology is performed based on the mathematical expression which integrates the probability theory with multivalued logic and artificial intelligence approaches in order to tackle complex systems. In real world, the fuzzy multi-objective strategy were designed to solve the choice challenge of suppliers and transportation decisions (Govindan et al., 2017).

The above approaches promotes creating solution for advances systems used in industrial sector in order to generate resources for Cleaner Production (CP). Further, they are alternative tools for identifying option which lead to clean technology. Intelligent manufacturing based on big data linked to computer numerical control (CNC) machine are of great importance to save resources (Chen et al., 2015). Fuzzy Analytic Hierarchical Network Process were implemented to reduce the vagueness and complexity presented in the green technology selection process (Promentilla et al., 2018). Hierarchical optimization drive a combination of a systematic modelling together with an efficient optimization model on the machine tools that facilitate solving two main goals: reducing the processing time and power consumption (Wójcicki et al., 2018). To reduce the generation of waste and the consumption of resources was established a bi-level fuzzy algorithm for a particular case of nuclear power freshwater and the wastewater treatment (Aviso et al., 2010; Tan et al., 2011). Further, it is compulsory implementing the manufacturing scalability of laboratory-derived clean energy technologies (Huang et al., 2018). For a sustainable development Cheng (2016) proposed the spatial correlation and interaction between manufacturing agglomeration and environmental pollution.

This survey efforts permits improving the manufacturing through quality when is used thermal drilling of galvanized steel sheets. This is achieved by the integration of GRA and FL, the multi-response features of a given manufacturing problem that can be changed into a single Grey Fuzzy Reasoning Grade (GFRG). With the GFRG values, the optimization of a process can be easily done by Taguchi method. The present work used a Taguchi based grey-fuzzy logic method to optimize the thermal drilling process parameters. Rotational speed, tool angle, and workpiece were chosen as the input controllable factors. Surface roughness, roundness error, and run-out were considered as the output quality characteristics. The GRC of three input parameters is converted into a GFRG which acts as a multi-performance characteristic index. Then, Taguchi method is executed along with the outputs of grey-fuzzy logic analysis to optimize the thermal drilling process leads to achieve a minimization of surface roughness, roundness error, and run-out.

Section snippets

Methodology

In this research work, the procedure were built on the Taguchi based grey-fuzzy logic method and were used to optimize the processing conditions of process for getting good quality features such as surface roughness, roundness error, and run-out. The different phases of this approach are demonstrated in Fig. 1 (Das et al., 2016; Liu et al., 2009).

The six steps (details in Annex 1) were used to design the Taguchi based grey-fuzzy logic method in order to optimize the process parameters of

Analysis of means (ANOM)

ANOM of the GFRG is applied to conclude the optimal combination process parameters of the thermal drilling (Table 8). As per DOE in this research work is L_{27} orthogonal array, thus it is probable to find out the influence of each parameter of thermal drilling at various levels. Basically, the higher mean value of GFRG is the better multi-response. The response graph is plotted based on the mean GFRG value which is shown in Fig. 14. From Table 8, the recommended levels of thermal drilling

Confirmation test

Once the optimum level for the processing of thermal drilling was detected, it was proceeded with the confirmation test that is conducted in order to forecast and prove the improvement of multi-response characteristics (El-Bahloul et al., 2018). The output of the confirmation test is conveyed by the assessed GFRG value. The determination of predicted GFRG is accomplished by the following expression, $g_{Predicted} = g_{tm} + \sum_{i=1}^{m} (g_i - g_{tm})$ where g_{tm} and g_i are the total mean of GFRG and mean of GFRG at the

Conclusions

The present study focused on determining the optimal processing conditions to achieve the minimization of the multi-performance features such as surface roughness, roundness error and run-out in the thermal drilling of galvanized steel using the grey fuzzy logic technique. The implemented method combine the GRA with the FL technique which allows to determine the GFRG based on the GRC of each response.

The recommended level (A3 B1 C2) detected from the thermal drilling parameters allows to

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References (50)

K.B. Aviso *et al.*
Bi-level fuzzy optimization approach for water exchange in eco-industrial parks
Process Saf. Environ. Prot. (2010)

J. Chen *et al.*
CPS modeling of CNC machine tool work processes using an instruction-domain based approach
Engineering (2015)

Z. Cheng
The spatial correlation and interaction between manufacturing agglomeration and environmental pollution
Ecol. Indicat. (2016)

K.-T. Chiang
The optimal process conditions of an injection-molded thermoplastic part with a thin shell feature using grey-fuzzy logic: a case study on machining the PC/ABS cell phone shell
Mater. Des. (2007)

B. Das *et al.*
Application of grey fuzzy logic for the optimization of CNC milling parameters for Al–4.5%Cu–TiC MMCs with multi-performance characteristics

Eng. Sci. Technol. Int. J. (2016)

S.A. El-Bahloul *et al.*
Experimental and thermo-mechanical modeling optimization of thermal friction drilling for AISI 304 stainless steel
CIRP J. Manufact. Sci. Technol. (2018)

K. Govindan *et al.*
Fuzzy multi-objective approach for optimal selection of suppliers and transportation decisions in an eco-efficient closed loop supply chain network
J. *Clean. Prod.* (2017)

B.M.U. Gowda *et al.*
Optimization of process parameters in drilling of epoxy Si3N4 composite material
Mater. Today: Proceedings (2015)

S.M. Hamidinejad *et al.*
The modeling and process analysis of resistance spot welding on galvanized steel sheets used in car body manufacturing
Mater. Des. (2012)

K.J. Huang *et al.*
Designing for manufacturing scalability in clean energy research
Joule (2018)

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…As shown in Fig. 16, EQmESC owns the best MPPT performance. As no mathematical system model is required in fuzzy logic control (FLC), the uncertain factors like unmodelled physical quantities, nonlinearities, and unpredictable varies in operating points can be well deal with (Kumar et al., 2019; Alajmi et al., 2011). A typical block diagram of FLC is depicted in Fig. 17.…

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A bibliometric study of sustainable technology research ↗

2020, Cogent Business and Management

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