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ORIGINAL ARTICLE

Investigating the surface quality of the burnished brass C3605—fuzzy rule-based approach

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Abstract In this work, prediction of burnished surface roughness (R_a) is achieved by using a fuzzy rule-based system. The process state variables used were burnishing speed, feed, and depth. The fuzzy rule-based system has achieved an accuracy of 95.4 % to predict the burnished surface roughness and proved to be convenient in terms of least computational complexity and dealing with nonlinear data such as that obtained in this work.

Keywords Fuzzy logic system · Surface roughness · Burnishing process · Brass C3605

1 Introduction

Burnishing is a plastic deformation process in which the force is applied to a workpiece surface by a hard smooth ball or roller. The mechanism of a burnishing operation is that asperities peaks of the workpiece are compressed to fill in the valleys and thus characteristics of the surface under consideration are changed [1–4]. The characteristics of a burnished surface depend upon controlling burnishing parameters such as applied burnishing force (burnishing depth), burnishing speed, burnishing feed rate, and number of passes, geometry and material of burnishing tool, as well as the material of burnished surface. In the current work, the author's intention is to implement a new approach to predict the burnishing process state variable (R_a). In this respect, there are different approaches which can be adopted. The first approach is based on developing analytical model from fundamental concepts [5–7] which requires a procedure to represent the response (output) as a function of the process parameters (inputs) [8]. In this approach, although some parameters can be included and fairly good prediction of the response is achieved, still a lot of other parameters cannot be included which usually contribute significantly to the state variables. In the case of the burnishing process, condition of burnishing tool, deflection of workpiece, friction, and heat generation between burnishing tool and workpiece are expected to contribute to the accuracy of the analysis.

The second approach depends on experiments by studying the effect of one factor at a time and analyzing the results [9–11]. Experiments are usually carried out to investigate the effect of most important factors and the analysis of the results requires a high level of understanding of the phenomenon under investigation. This approach is followed by many researchers [12–15]. It is commonly implemented where the analytical formulation of the cause and effect relationship between various factors is complex and difficult to achieve. Nevertheless, the strategy of experiment, observation, analysis, and conclusion is the most conventional approach which represents the corner stone of most scientific research activities. However, the drawback of this approach is that the conclusions are usually confined to the range of the test conditions and cannot be generalized, i.e., conclusions have limited applications and this should be expected because of various types of test equipments and techniques, different environment conditions and other missing factors.

The third approach is to use design of experiment (DOE) together with analysis of variance (ANOVA) to develop an empirical model (regression model) based on some collected

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experimental data (inputs and outputs). This approach is also implemented by several researchers [16–19]. This is a systematic approach which involves planning of experiments, collection and analysis of data with the aid of response surface methodology (RSM) and occasionally used for optimization [20, 21]. It is basically a model formulation procedure to investigate how important factors affect the response of the experiment. It aims to a development of first- or second-order polynomial model that includes the parameters under consideration and their statistical significance.

The fourth approach uses unconventional methods, namely, soft computing techniques. Soft computing techniques are useful when exact mathematical information is not available and these differ from conventional computing in that it is tolerant of imprecision, uncertainty, partial truth, approximation, and met heuristics. Fuzzy logic is one of the soft computing techniques that play a significant role in input–output matrix relationship modeling. Fuzzy logic starts with and builds on a set of user-supplied human language rules. The fuzzy systems convert these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world. Additional benefits of fuzzy logic include its simplicity and its flexibility [22]. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity. “If you don't have a good plant model, or if the system is changing, then fuzzy will produce a better solution than conventional control techniques [23]”.

It is used when subjective knowledge and suggestion by the expert are significant in defining objective function and decision variables. Fuzzy logic is preferred to predict the burnished surface roughness based on the input variables due to nonlinear condition in the burnishing process [24, 25]. Fuzzy logic is a simple rule based on: if X and Y then Z fuzzy mathematics is a metaset of Boolean logic and denotes relative correctness [26, 27]. The fuzzy theory is still a prominent theory although sometimes it describes uncertain and indefinite phenomena having the following structure:

1. Fuzzification: making something fuzzy.
2. Fuzzy rule base: in the rule base, the if-then rules are fuzzy rules.
3. Fuzzy inference engine: produces a map of the fuzzy set in the space entering the fuzzy set and in the space leaving the fuzzy set, according to the rules if-then.
4. Defuzzification: making something nonfuzzy.

2 Scheme of investigation

This work is planned in two main stages. In the first stage, experimental preparation, measurements, and collection of results are conducted. In the second stage, fuzzy logic basis function is implemented. Figure 1 shows the procedure of data collection during experimentation, the training of fuzzy logic algorithms and testing of fuzzy logic, respectively.

3 Experimental setup

3.1 Work piece material

In the present work, the workpiece material was selected from commercially available brass (C3605: 56–60 % Cu, 3–5–4.5 % Pb, 0.50 % Sn, 0.7 % Fe, and Rem Zn). The strength and relatively good mechanical properties of the brass C3605 make this material suitable in many industrial applications such as bushes and valves, etc. Some mechanical properties of the C3605 brass material are given in Table 1. The C3605 brass rod were turned and burnished by using CNC turning machine.

3.2 Burnishing operation

The burnishing setup is shown schematically in Fig. 2a and a typical arrangement is shown in Fig. 2b. Initially, C3605 material was received in the form of cylindrical rods (125 mm length × 37 mm diameter). The cutting and burnishing tools were clamped simultaneously onto the turret of the CNC turning machine and thus turning and burnishing operations were completed one after another without separations process. The preparation of burnishing specimens starts by turning the rods into circular bars of 24 mm diameter. This turning process is followed by setting the desired burnishing conditions (burnishing parameters) and applying burnishing

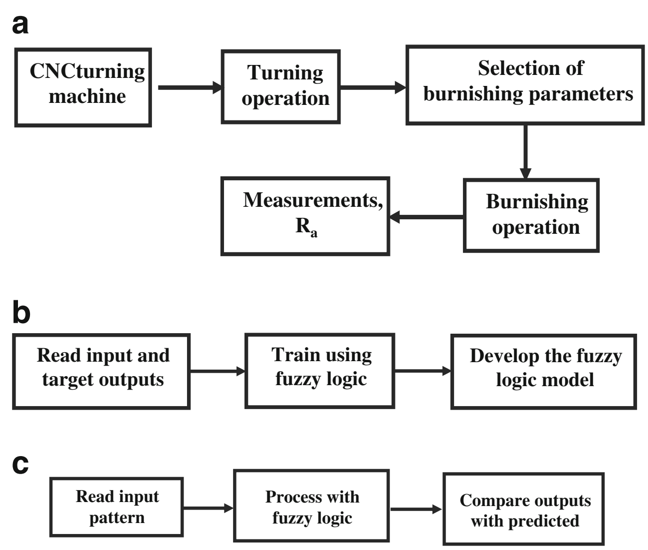

Fig. 1 Stages of experimental work and data analysis. **a** Schematic flow of experimental work. **b** Training fuzzy. **c** Testing fuzzy