ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 18 (2018) 1079–1091

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Durability analysis of forging tools after different variants of surface treatment using a decision-support system based on artificial neural networks

Barbara Mrzygłód [a], *Marek Hawryluk* [b,*], *Zbigniew Gronostajski* [b], *Andrzej Opaliński* [a], *Marcin Kaszuba* [b], *Sławomir Polak* [b], *Paweł Widomski* [b], *Jacek Ziemba* [b], *Maciej Zwierzchowski* [b]

[a] *AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland*
[b] *Wroclaw University of Science and Technology, Department of Metal Forming and Metrology, Lukasiewicza Street 5, 50-370 Wrocław, Poland*

ARTICLE INFO

Article history:
Received 27 September 2017
Accepted 14 February 2018
Available online

Keywords:
Artificial neural network
Decision support system
Durability of forging tools
Destructive mechanisms

ABSTRACT

This article concerns a decision-support system based on artificial neural networks (ANN) enabling analysis and forecasting of the durability of forging tools used in the hot forging process of a cover forging – a sealing element of the driveshaft in road freight vehicles. The process of knowledge acquisition, adopted neural network architecture and parameters of the developed network are presented. In addition, 3 variants of a hybrid layer (gas nitrided layer GN + PVD coating) were applied to the selected tools (punches applied in the 2nd top forging operation): GN/AlCrTiN, GN/AlCrTiSiN, and GN/CrN, in order to improve durability, and the resultant tools were also compared to standard tools (with only gas nitriding) and regenerated tools (after repair welding regeneration). The indispensable knowledge about the durability of selected forging tools (after various surface engineering variants), required for the process of learning, testing and validation for various neural network architectures was obtained from comprehensive, multi-year studies. These studies covered, among other things: operational observation of the forging process, macroscopic analysis combined with scanning of tools' working surfaces, microhardness measurements, microstructural analysis and numerical modeling of the forging process. The developed machine-learning dataset was a collection of approx. 900 knowledge records. The input (independent) variables were: number of forgings manufactures, pressing forces, temperature on selected tool surfaces, friction path and type of protective layer applied to tool. Meanwhile, output (dependent) variables were: geometrical loss of tool material and percentage share of the four main destructive mechanisms. Obtained results indicate the validity of employing ANN-based IT tools to build decision-support systems for the purpose of analyzing and forecasting the durability of forging tools.

* *Corresponding author.*
E-mail addresses: mrzyglod@agh.edu.pl (B. Mrzygłód), marek.hawryluk@pwr.edu.pl (M. Hawryluk), zbigniew.gronostajski@pwr.edu.pl (Z. Gronostajki), andrzej.opalinski@agh.edu.pl (A. Opaliński), marcin.kaszuba@pwr.edu.pl (M. Kaszuba), slawomir.polak@pwr.edu.pl (S. Polak), pawel.widomski@pwr.edu.pl (P. Widomski), jacek.ziemba@pwr.edu.pl (J. Ziemba), maciej.zwierzchowski@pwr.edu.pl (M. Zwierzchowski).
https://doi.org/10.1016/j.acme.2018.02.010
1644-9665/

1. Introduction

The hot die forging processes are in the group of the most difficult production processes in the aspect of their implementation. Additionally, the wear of forging tools causes a change in the geometry of the manufactured product, which makes all the surface defects (cracks, losses) being reflected on it, thus affecting its end quality [6]. Forging tools and instrumentations used in hot forging processes work under very hard, if not extreme, conditions periodical mechanical reaching even up to 1000 MPa and thermal from 60 to 800 °C at the surface loads [8,37]. That is why they are exposed to the operation of many destructive factors, which cause their wear. The areas especially exposed are the working surface and the surface layer of the tool, and so, most of the mentioned destructive mechanisms refer to these tool areas [9,23]. Premature wear and low durability of tools continue to be difficult, unsolved problems, in both scientific and economic terms. Tool wear and destruction during hot forging make up a significant share of production costs [10,11,22]. It is currently estimated that tool costs may reach up to 8–15% of total production costs, and in extreme cases, in small production series, even 30%. In reality, considering the time required for replacement of worn out instrumentation or in the case of unexpected tool destruction, these costs may reach up to as much as 40% [17]. The most common occurring destructive mechanisms are: plastic deformation and abrasive wear in warm forging [4] and hot forging [20] thermal fatigue cracking [1,19,31], thermo-mechanical fatigue [3]. The main factors having an effect on the process of forging and a durability of forgring tools are: tool and preform temperature, slug geometry, press settings, process speed, lubrication and cooling, and tool shape and quality. The low durability of the tools lowers the quality of the forgings. This in turn affects the functionality of the final product obtained from forgings and the increase in manufacturing costs.

From the one side, nowadays, the most commonly used, and one of the cheapest, methods of improving forging tool durability is nitriting. Despite the fact that this method is well-known and well-mastered, it does not always provide a clear effect of durability improvement. That is why other methods are being searched for to improve tool durability in forging processes, which are more effective, yet more expensive as well [29]. The most recent methods include undoubtedly hybrid technologies, consisting in the use of two or more surface engineering techniques [12,25,28,33,40]. Hybrid techniques can combine, e.g. thermo-mechanical treatment methods and one of the PVD techniques. This technology makes it possible to provide the surface with the appropriate performance properties and to create a barrier which will effectively limit the influence of the destructive factors [27]. Another technology which can significantly improve forging tool durability is pad welding [39]. The latter consists in coating the forging tools with a metal layer by means of the welding technique with a simultaneous melting of the substrate. The basic task of the pad welding technology is ensuring the possibly best performance properties of the coating, with the possibly lowest costs, that is, prolonging the total operation time by prevention (enrichment) or repair (regeneration of the used components).

Unformatelly, at present there are no clear criteria applicable in the evaluation or selection of methods to improve the life of tools [22–24]. Therefore, various methods are being developed that are designed to analyze the wear of forging tools and predicted their durability, which is justified by considerations of both financial and scientific character. Predicting the life of a forging tool used in a die forging process and pointing to the dominant wear mechanisms and their effect on the 'life time' of the tool are very important [5,7,8,11,13]. Currently, numerous and different IT methods and tools are available to allow for partial replacement of costly and time-consuming physical experiments with virtual experiments. Also, new formalisms of representing knowledge in computer systems are being developed, such as: the graph theory, fuzzy logic, artificial neural networks, or genetic algorithms, thus providing the opportunity to construct expert systems supporting various areas [21,30]. Expert systems are widely applied mainly as advisory systems for the tasks of identification, classification, control, simulation and diagnostics. Efforts are also made to use decision support systems in optimization of the tools used in forging operations [2,5,7,18,24,26,32,38]. These systems have different aims and take advantage of various formal methods of the system knowledge representation. Katayama et al. developed an expert system to design a cold forging process. Fuzzy logic was used to formulate the principles of the database of this system [18]. Fuzzy logic was also used to develop an expert system for predicting the analysis results with the finite element method when solving the problem of rubber cylinder compression [34]. Gangopadhyay et al. elaborated an expert system for predicting loads and axial stresses during forging [5]. Artificial neural networks have been applied to solve many problems [36]. The application of the finite element method and intelligent system techniques to predict the applied force during the radial forging process was studied in [2]. An artificial neural network was also applied to acquire the relationships between the mechanical properties and the deformation technological parameters of the TC11 titanium alloy, with the use of the data from the isothermal compression test and the conventional tensile test of the forged TC11 titanium alloy at room temperature [24,35]. The authors' original works also testify to the great potential and capabilities of ANN, as confirmed and verified by research results. For example, article [7] presents an expert system for durability analysis, while article [16] presents the application of ANFIS for wear analysis of forging tools. Article [14] demonstrates that ANN are suitable as decision-support systems for global analysis of forging tools' operation under different operating conditions. For this reason, it is justified to use ANN in further applications, including in an attempt to develop a decision-support system for analysis and forecasting of the durability of forging tools coated with protective coatings (nitrided layer + PVD coating) as well as tools that have been nitrided and repair-welded.

The goal of this work is to develop a decision-support system to support analysis and forecasting of the durability of forging tools based on ANN, for which the database constituted results of multi-year, comprehensive tests of forging tools applied in the second cover forging operation, after different surface treatment variants applied for the purpose of improving durability.