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Review

Review of selected methods of increasing the life of forging tools in hot die forging processes

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ABSTRACT

The work concerns the possibilities of applying various methods with the purpose to increase the life of forging tools, which, based on the experience and research of the author, realized in cooperation with the forging industry, exhibit the highest effectiveness in improving the life of forging tools. Durability of forging device is determined by the presence of destructive mechanisms under the extreme work conditions of forging tools - a high cyclic mechanical loads (up to 1000 MPa) and thermal (from 800 °C to 800 °C on the surface). The tool life is also an element which affects the quality of the forgings, as too high and intensive wear/damage of the dies and stamps causes a change in the geometry of the manufactured product, and any surface faults (cracks, defects) are represented on the forged product. The presented investigation results refer to: selection of the tool material for a particular process, its adequate thermal and thermo-chemical treatment, use of surface engineering techniques: hybrid with the use of coatings applied physically from the gaseous phase, use preventive pad welding, as well as optimization of the die shape and construction of the instrumentation set. The work also presents the use of control and measurement systems, allowing for full monitoring of the forging process, and the application of innovative solutions (use of acoustic emission signal) allowing for an effective improvement of the life of the forging tools and instrumentation. At present, by way of applying a range of methods, which the most popular shows in this article, as well as many other computer-aided tools, it is possible to solve many problems related to a short tool life.

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1. Introduction

The increasing global interest in the manufacture of products of a precise shape, or one which is close to the shape of ready components, has led to a significant development of the hot and cold die forging technology [60]. This is mainly connected

with the high competitiveness in the industry, which, for many years now, has been searching for new energy-saving and environment-friendly production technologies. Die forging, due to its advantages, is currently the most advanced production technique used in the mass production of responsible components. Despite its many undoubted merits, die forging has, however, several drawbacks, of which the

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most important one is the not sufficiently long life of the shaping tools – mainly dies, stamps, pushers and other instrumentation elements [12,18,33,35,40,43,58].

Forging tools, especially those used in hot die forging processes, characterize in an unstable and relatively short life, which, in turn, significantly affects the quality and cost of the manufactured forgings. The short life of forging tools, caused by the extreme operation conditions of the industrial hot forging processes, resulting from a simultaneous occurrence of many complex phenomena and degradation mechanisms, constitutes a difficult and still unresolved issue, both in the scientific and financial context.

The wear and damage of the tools during hot forging constitutes a significant contribution to the production costs. At present, it is estimated that the costs of the tools may constitute even 8–15% of the total production costs, and in extreme cases, with small production series, even 30%. In fact, considering the time necessary to replace the worn instrumentation or in the case of unexpected tool damage, these costs can rise even to 40%. What is more, tool wear significantly decreases the quality of the produced forgings. The most common faults caused by tool wear are lapses in the filling of the die impression, i.e. incomplete forging, overlaps, flashes, scratches, delamination, micro- and macro-cracks, etc. This, in turn, affects the functionality of the final product made from the forging.

The literature says that, statistically, 70% of forging dies are removed from production due to the loss of dimensions, as a result of abrasive wear and plastic deformation, 25% – as a result of fatigue cracks and only 5% – for other reasons (disregarding the technology guidelines, construction defects, material defects or thermal and thermo-chemical treatment defects) [37]. What is more, the constant competitiveness on the market forces the forging producers to constantly reduce the costs and to manufacture forgings of high quality, which creates a high interest in the problem of short tool life [32,38,42]. That is why, more and more often, both forging instrumentation producers and scientific and research and development centers use a series of IT tools and advanced research, as well as develop modern technologies, allowing for both the analysis and increase of the “lifetime” of the forging tools. The investigation of the destructive mechanisms and other accompanying phenomena and predicting the tool life in the forging processes is a very difficult and complex issue, and the commonly used degradation models are insufficiently discussed in the analytic manner [1,15,17,18,22,30,32,33,42,43,58].

One of the easier ways of determining the parameters affecting the tool life is a numerical analysis of the technological forging process, e.g. with the use of numerical modeling, verified by experimental tests. However, the “standard” descriptions of degradation models used in the newest calculation packages, in many cases, are insufficient and do not allow for an appropriate and full description of the occurring phenomena. That is why it is necessary to validate them or to propose new mathematical descriptions of degradation (abrasive wear mechanical cracking, thermo-chemical fatigue, plastic deformations, etc.), and next perform experimental tests allowing for their verification and implementation in MES [1,18,35,43,58], which will make it possible to significantly improve the calculation packages and thus to

perform a more thorough analysis of the tool life. At present, there are no clear criteria for the evaluation itself or the selection of methods to improve the tool life [6,12–14,16,28,42,47,54,55,60]. We are only familiar with some general directions, and each forging process should be analyzed separately, as the process parameters resulting from the technology, or the tribological conditions, as well as many other factors, are closely related to the particular industrial process. The most well-known methods of evaluation and analysis of quality include: statistical analysis of wear, thermovision tests, macroscopic observations and tests, often combined with scanning of the tool impression surface, microhardness measurements, advanced microscopic metallographic tests, numerical modeling and the use of specialized laboratory stations dedicated to the analysis of the particular degradation mechanisms, or modern measurement and analysis systems [38,52]. In turn, the most popular methods of tool life improvement are: appropriate selection of the tool material for the given process or operation [14,63], its adequate thermal and thermo-chemical treatment [62], the use of techniques of surface engineering [8,12,39,47,50,54,57,58,61], as well as optimization of the shape and construction of instrumentation [18,27,28]. They also include: appropriate selection of the technological conditions (e.g. those related with the determination of the optimal temperatures, with the cooling and lubricating agent and the manner of its application), and construction and technological solutions as well as control and measurement systems [5,19,21,31,33,38,53], which can constitute specific systems of tool supervision. The application of the presented methods, both in the evaluation and improvement of tool life should allow for a more thorough analysis of the problem of short tool life, as well as significantly increase the life of the forging instrumentation.

That is why, it is highly justified to assume a complex approach to the problem of short tool life, which applies a whole spectrum of modern methods and techniques as well as devices, allowing for the achievement of the general goal, which is a better understanding of this complex issue and improvement of the life of forging instrumentation.

2. Applied methods of tool life improvement

At present, there are no clear criteria for the selection of methods of tool life improvement. We are only familiar with the general directions. That is why, each forging process should be approached to separately, as its parameters directly resulting from the technology, or the tribological conditions between the shaped forging material and the tool, as well as many other factors, are closely connected with the process. It is so, as it may happen that, for the process itself, a minimal change in the shape or construction of the tool, or in the process temperature, a change in the lubrication manner (the cooling and lubricating agent) or even the atmospheric conditions outside the forge will decide about the life of such forging instrumentation [16,42].

Usually, the factors related with the forging and operation for the already elaborated industrial forging process are predetermined and remain constant. Possible changes can only refer to the factors related with the tool – its surface layer. Fig. 1

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