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Review

A review of the degradation mechanisms of the hot forging tools

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ABSTRACT

The mechanisms of the degradation of hot forging tools and several mathematical models for the theoretical evaluation of them are described. Examples of abrasive wear, oxidization, thermomechanical fatigue and plastic deformation and the interdependences between them, based on the authors' research, are provided. According to the presented research the commonly accepted view that abrasive wear is the dominant mechanism in the degradation of the dies in hot forging is highly dubious. The effect of each of the above phenomena on the life of forging dies is generally considered separately and there is no holistic description of the physical wear process, which would cover all the phenomena simultaneously. In reality, the degradation phenomena occur simultaneously and interact with each other.

1. Introduction

Die forging is currently the most advanced forging technique used in the mass production of critical parts. It has several obvious benefits, but is not devoid of drawbacks, the most serious of which is the low durability of the forming tools [1,5–8]. It is estimated that the costs of the tools may amount to as much as 8–15% of the total production costs. Actually, if the time needed to replace the worn out tooling and the cases when the tools unexpectedly fail are taken into account, the costs may increase by as much as 30–50%. Moreover, tool wear significantly contributes to deterioration in the quality of the produced forgings. The most common forging defects caused by tool wear are die cavity filling errors, i.e. under-filling, laps, burrs, distortions, scratches, delamination and micro- and macrocracks. The defects affect the functionality of the end product made out of the forging. Because of the high market competition, manufacturers of die forged products continually reduce their costs and improve the quality of the forgings, whereby they are very much interested in the low tool durability problem [3,8].

Tool durability (life) is defined in several ways. In production terms, the durability of a tool is usually expressed by the number of forgings which can be performed with this tool to obtain products of desired quality. According to this definition the average tools durability can change in very wide range from 2000 to 20,000 pieces.

In tool terms, durability is associated with degradation and so it is defined as the ability to withstand degradation phenomena [9]. In the paper mainly second definition is considered.

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The great number and variety of degrading factors having a bearing on the life of forging tools, and their mutual interactions make an analysis of the problem very difficult [8,10,11,15].

In the literature on the subject one can find much information on degradation phenomena, which are variously classified. According to the statistics provided by many authors, forging dies are taken out of service because of: the loss of their dimensions due to abrasive wear – 70% [1,7,16,19–21] and plastic deformation – 25% of the forging dies, fatigue cracks and for other reasons (structural and material defects or faulty heat and thermochemical treatment) – only 5%. Many of the phenomena often occur simultaneously and the correlations between them depend mainly on the design of the tools, the conditions in which they are forged and made, the heat treatment of the tool material, the shape of the preform and the slug, etc. [1,8,10].

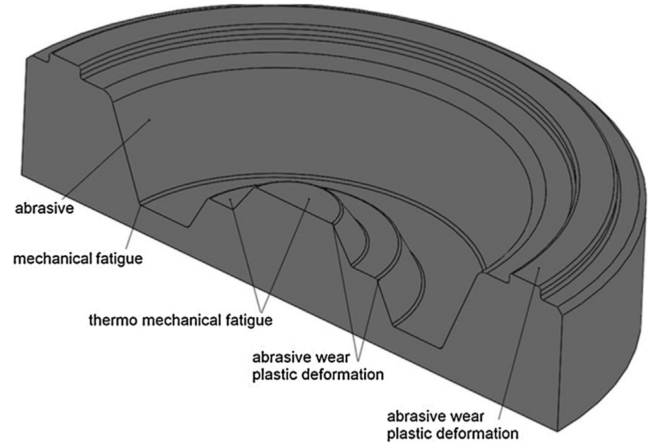

Fig. 3.1 – Schematic showing places where dominant types of wear occur in forging die cross section.

2. Forging die operating conditions

During hot die forging the tools are subjected to the action of the three main degrading factors: intensive thermal shocks, cyclically variable mechanical loads and very high pressures at high temperature [15,22].

In order to reduce yield stress during the hot forging of steel products the formed material is heated up to a temperature of 1000–1200 °C. At the instant when the material is being deformed the temperature of the tools in their surface layer may reach 800 °C, which is followed by intensive cooling, whereby the tools are exposed to large temperature gradients. In the die cross-sectional plane the difference between the temperature on the surface and the temperature in the near-surface region may amount to a few hundred degrees.

Warm die forging is conducted at lower temperatures than hot forging, e.g. the temperature of the steel being formed amounts to about 900 °C. This means that the tool heat loads resulting from the cyclic heating and cooling of the tool surface are not so large as in the case of hot forging. Despite this, the tools used in semi-hot forging processes have a rather short life due to the combination of cyclically variable tool temperatures and large mechanical loads resulting from the deformation of the cooler, and more hard, material [2,4].

3. Degradation mechanisms in forging tools

The service life of forging tools depends mainly on their design, and make, the heat treatment of the tool material, the conditions in which they are forged, the shape of the preform and the slug, etc. [8]. In the literature on the subject one can find much information on the degradation phenomena involved. These mechanisms are variously classified [8,23]. Research has shown that the following wear mechanisms occur in the surface layer of forging tools: abrasive wear, thermomechanical fatigue, plastic deformation, fatigue cracking, adhesive wear and oxidation [24].

The shape of the tool working impression, determining the contact time, the pressures, the friction path and the changes in temperature, has a bearing on the rate of occurrence of the particular degradation mechanisms. Fig. 3.1 shows the places in the cross section in which the particular mechanisms dominate.

In the flat areas where the duration of contact between the tool and the hot material being shaped is the longest and where the greatest pressures occur, thermomechanical fatigue is the dominant degradation mechanism.

The inner radii of the roundings are the places where cyclic tensile stresses produced by the external loads arising as the forging is being formed tend to concentrate. As a result, fatigue microcracks, developing into large cracks in the course of tool service, appear in these places.

The outer radii in the die impression and the areas where the die impression passes into the flash bridge are the places where due to material weakening under high temperatures the yield point of the material is lowered, which results in plastic deformation. The intensive flow of the formed material in these areas causes abrasive wear, which is further intensified by the hard oxides (acting as an abrasive material) formed during the high-temperature oxidation of the surfaces of the tool and the forging [12,13].

3.1. *Abrasive wear*

Abrasive wear is the result of material loss, mainly through material separation from the surface. This occurs when there are loose or fixed abrasive particles or protruding irregularities (formed of harder material) on the surfaces of the interacting parts (Fig. 3.2a) [1,17,18,23,27]. In the case of forging tools, which are much harder than the material being formed, such a mechanism occurs when abrasive particles are present in the areas of contact between the tool and the material being formed (Fig. 3.2b).

Abrasive wear can be intensified by the hard oxides formed during the high-temperature oxidation of the surfaces of the forging and the die and small particles torn from the surface of the die (Fig. 3.3a).

As a result of this mechanism, grooves form along the direction in which the material being formed shifts. Their depth and shape depend mainly on the forging conditions. The protrusions (groove ridges) (Fig. 3.3) are particularly susceptible