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The failure mechanisms of hot forging dies

Zbigniew Gronostajski *, Marcin Kaszuba, Sławomir Polak, Maciej Zwierzchowski, Adam Niechajowicz, Marek Hawryluk

Wrocław University of Technology, Poland

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ABSTRACT

This paper describes the phenomena taking place on the surface of the dies used for hot forging. Because of this paper's limited space only changes in the tool surface layer during the forging of a gear wheel, as most representative, are presented. Similar changes were observed in the case of the other two investigated closed die forging processes, i.e. the forging of a cover and a yoke, respectively. The research was aided by FEM, which supplied a lot of information about the forging conditions. The most intensive wear of the tools occurs in the place of their longest contact with the material being forged, regardless of the number of produced forgings. The research has shown that the one of the most adversely factor affecting the investigated forging process is thermomechanical fatigue which results in fine cracks quickly developing into a network of cracks extending over the entire tool/forged material contact surface. Also the abrasive wear of the investigated die is high due to the intensive flow of the material in the presence of abrasive oxide particles and tools bits created by thermomechanical fatigue. An attempt to model the abrasive wear using the Archard model is presented.

1. Introduction

Hot forging tools have a rather short life which, depends on the forging process conditions, the tool design, the heat treatment (proper for the tool material), the shape of the preform, the workmanship and so on. In order to improve the durability of the tools used in hot and warm forging processes one needs to accurately identify the changes, caused by various failure mechanisms, taking place in the surface layer of the tools in the course of their service [1]. About 15 years ago there was much research in this field, but its results were difficult to interpret because of the inadequate technical capabilities. However, the degradation mechanisms are variously interpreted and the problem is compounded by the fact that many of the phenomena occur simultaneously [2]. There exists a general observation that tool fatigue cracking is critical in cold forming while excessive abrasive wear, the plastic flow of the material and thermal fatigue are critical in hot plastic forming [3]. The most difficult situation is in worm forming since each of the phenomena can be equally critical. In such conditions the tools must bear very high pressures (as in cold forming) and at the same time they must be resistant to high temperature (as in hot forming). According to Lange [4] tool life at high forming process temperatures depends on the abrasive wear in 70% of the cases. However, this opinion is a gross simplification since the principal failure mechanism depends mainly on the die operating conditions and may change in the course of the process. Moreover, other mechanisms may predominate in the particular areas of the die. It seems that despite the considerable increase in research capabilities, the problems relating to the description of tool failure phenomena have been neglected in recent years [5,6]. The intensity of the physical phenomena taking place on the surfaces of hot and warm forging dies depends on the forging process conditions, the design, manufacture and heat treatment of the tools, the shape of the blank and the preform, etc. The large number and variety of factors having a bearing on the forging process, and their mutual interactions make this process difficult to analyse [7]. Research so far has indicated that as regards the die's surface layer, the wear mechanisms listed below are decisive.

Abrasive wear results from material loss, mainly through the separation of material particles from the surface. This process arises when there are loose or fixed abrasive particles or harder material protrusions (acting as local microblades) in the friction areas of the interacting elements [8].

Adhesive wear occurs on the surface where local bonds form between the friction faces and are then destroyed as metal particles break away or as metal is smeared on the friction faces. Adhesive wear occurs in the case of low-velocity sliding friction under high unit pressures in areas of actual contact if the particles of the two friction faces are brought close enough together so that they come within the reach of molecular forces [9].

* Corresponding author.
E-mail address: zbigniew.gronostajski@pwr.wroc.pl (Z. Gronostajski).

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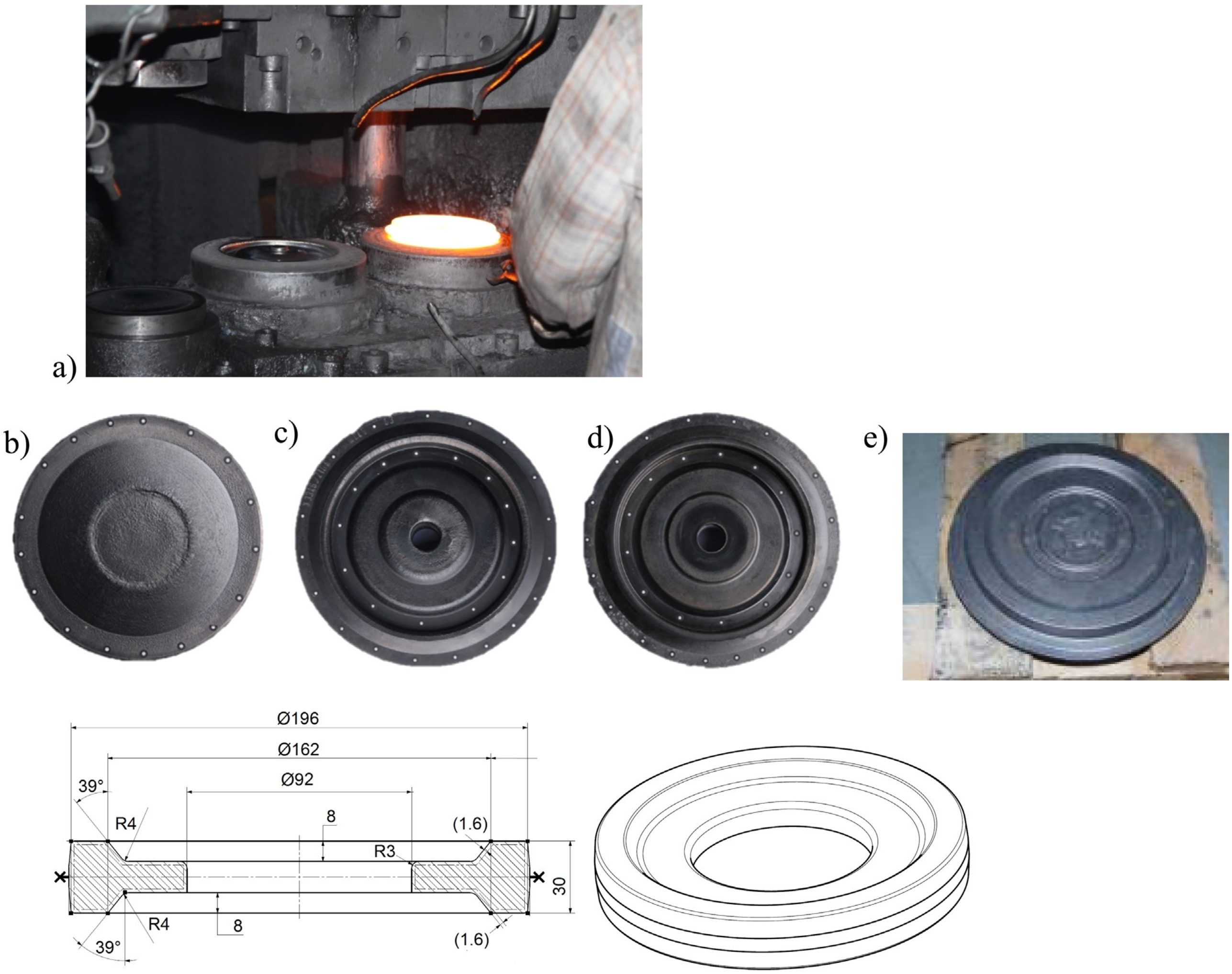

Fig. 1. Forging of gear wheel: (a) investigated process; worn out bottom tools after operation: (b) 1- upsetting, (c) 2-blocking forging, (d) 3-finishing forging; (e) forged wheel and (f) sketch of wheel.

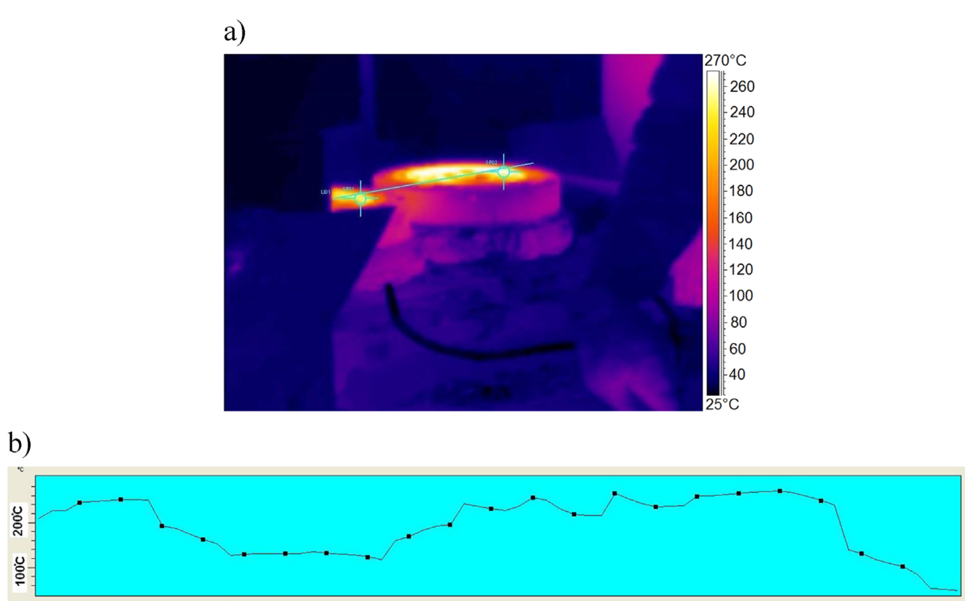

Fig. 2. Temperature of tools in operation 2: (a) photo taken by thermovision camera and (b) temperature distribution measured by thermovision camera along line shown in Fig. 2a.