EVALUATION OF THE MECHANISM OF DAMAGE TO THE FORGING DIE USED IN THE DIE FORMING HAMMER

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Abstract

The paper describes the mechanism of destruction of forging die used for plastic working processes by die forging on hammers. The test material was a matrix after exploitation for plastic processing using the hot forging method, made of WNLV grade material. Cyclical changes in temperature and stress in the matrix led to degradation of the structure to the extent that it ruptures during operation. The criterion determining in industrial conditions the degree of remaining operational usefulness is the assessment of material hardness performed by non-destructive methods of hardness measurement (Leeb method). Obtaining extended material characteristics after exploitation will allow to predict the time of safe work of the die, as well as to determine the moment in which the matrix can be repaired, e.g. by making a pad in the working layer or by machining the cavity. The research focused on the assessment of the structure and properties of the damaged matrix. The scope of the work included the assessment of the structure carried out by means of light microscopy, scanning electron microscopy and determination of mechanical properties in the impact test and static tensile test. The obtained results were referenced to the WNLV steel parameters given in the standard.

Keywords: Degradation, tool steel, properties, die forging

1. INTRODUCTION

Forging is one of the oldest metal forming processes. The forging dies are made of tool steel for hot work. The forging dies are used in hot forging processes, are exposed to many destructive mechanisms. They are affected by high values of mechanical and mal loads [1]. The shaped material transfers heat, resulting in the tool being heated locally to a temperature of 500 - 600°C [2,3]. The mechanisms of wear and destruction occur with varying intensity, depending on the design of the pattern and process conditions. The basic processes of wear and destruction of forging dies include abrasive wear, thermal fatigue, mechanical fatigue and plastic deformation [4-6]. Abrasive wear is one of the major causes making forming tools lose their initial opera-ting capability. It is the result of a material loss, mainly due to the separation of material particles from the surface. Abrasive particles that cause wear and destruction of the material are hard oxides formed as a result of oxidation of high temperature matrix surface as well as forging [7,8]. The next mechanism is thermal fatigue. Cyclical changes in temperature cause the material to be alternately stretched and compressed. In addition to thermal stresses, dynamic loads have a significant effect on wear and destruction of the die, which additionally increase the stresses in the material and lead to cracks on the die surface [9,10]. During forging, when the temperature of the surface layer exceeds the tempering temperature of the dies, the material reduces hardness and undergoes plastic deformation. In connection with the above, it is important for reasons of safety and operational and economic point of view to determine the degree of degradation of the matrix material during the use of the matrix. Determining the advancement of material consumption processes makes it possible to classify a matrix for repair or scrapping. The aim of the studies was to determine the wear resistance of selected dies after forging processes.

2. RESEARCH MATERIAL AND METHODOLOGY

The test material was a die for hot forging after operation. The die, which was the subject of this work, was made of tool steel for hot work of the 55NiCrMoV7 grade. High strength at elevated temperatures and a low tendency to deform during hardening determine the desirability of using 55NiCrMoV7 steel for uniform medium and small forging matrices. The chemical composition and properties of 55NiCrMoV7 steel compliant with the PN-EN ISO 4957: 2004 standard are presented in **Table 1**. The processed matrices were visually inspected, then the microstructural investigations were performed using the Olympus GX51 light microscope and the Hitachi S-4200 scanning electron microscope with X-ray microanalysis chemical composition of EDS. The next step was to determine the mechanical properties of the matrix using a static tensile test. In addition, the state of the surface and the resulting fractures of the matrix were analyzed using scanning electron microscopy.

Table 1 Chemical composition of 55NiCrMoV7 steel in initial state - value according to the standard and in actual brackets (% by mass)

C	**Cr**	**Ni**	**Mo**	**V**	**W**
0.5 - 0.6 (0.56)	0.8 - 1.2 (1.05)	1.5 - 1.8 (1.64)	0.35 - 0.55 (0.37)	0.05 - 0.15 (0.09)	max. 0.3 (-)
Co	**Mn**	**Si**	**P**	**S**	**Cu**
max. 0.3 (-)	0.6 - 0.9 (0.78)	0.1 - 0.4 (0.19)	max. 0.03 (0.006)	max. 0.03 (0.002)	-

3. EXPERIMENTAL RESULTS

The matrices after exploitation were subjected to macroscopic observations, the results of which are shown in **Figure 1**. It has been found that there are different mechanisms for destroying tools in matrices, and in some cases these mechanisms occur together. The basic ones include abrasive wear, plastic deformation, thermal and mechanical fatigue. From the matrix which broke (**Figure 1c**), the material for the microstructure investigation was collected, the results of which are shown in **Figure 2**. The analysis of the structure of the matrix after exploitation made it possible to determine the presence of a martensitic structure with bright areas of the so-called white spots. This effect may be a consequence of segregation of the chemical composition or incorrectly conducted heat treatment (hardening).

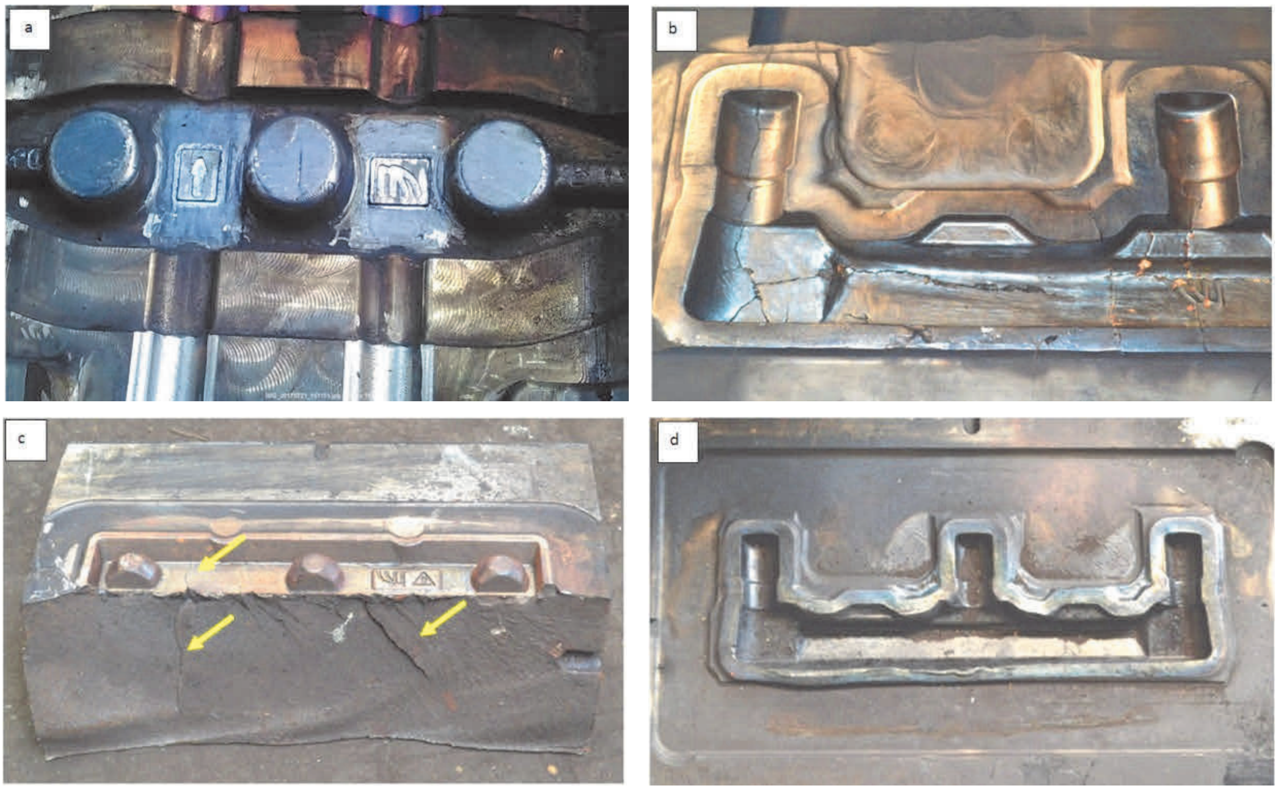

Figure 1 Examples of wear for hot forging dies: a - abrasive wear, b - thermal fatigue, c - mechanical damage, d - plastic deformation

The results of mechanical properties are presented in **Table 2** and **Figure 3**. It was found that the material meets the requirements specified by the standard in terms of tensile strength and yield strength.

Table 2 List of mechanical properties of the matrix after a static tensile test

Samples	$R_{p0.2}$ (MPa)	R_m (MPa)	A (%)	Z (%)
1	1712	1961	3.8	1.7
2	1655	1954	3.3	4.6
3	1700	1971	2.3	5.9
average	1689	1962	3.8	12.7
standard deviation	30.0	8.5	1.5	15.6

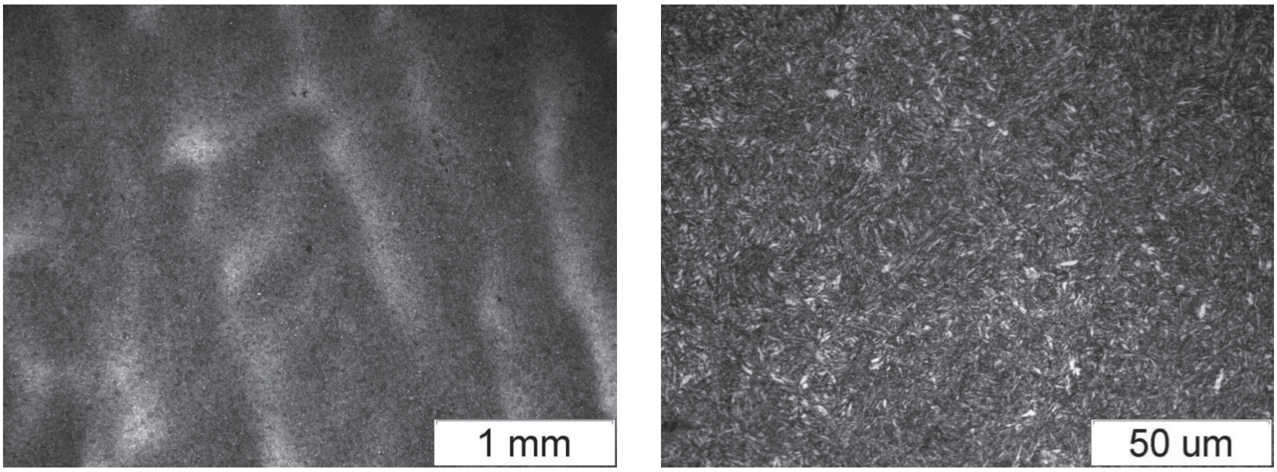

Figure 2 The microstructure of the die for hot forging after operation. The structure of low-martensite, martensite and the presence of white patches

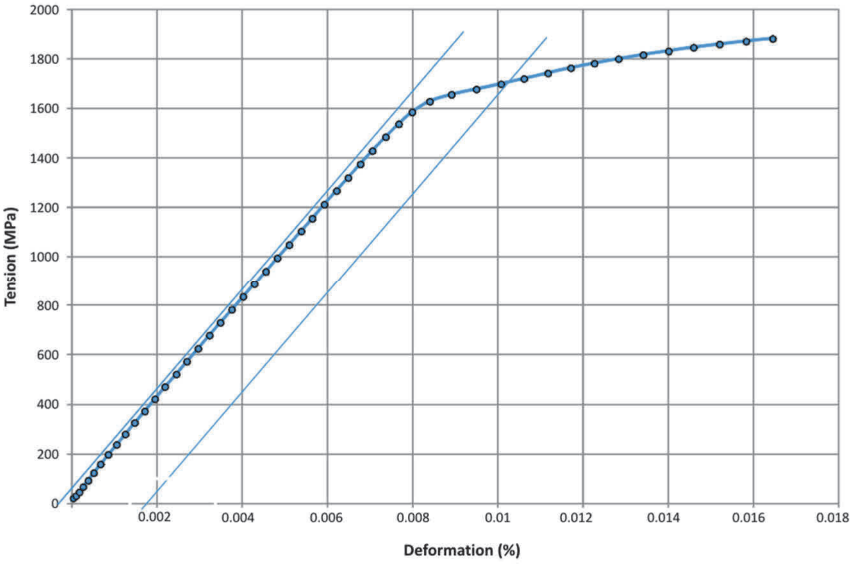

Figure 3 Diagram of mechanical properties after a static tensile test for sample 1

The obtained breakthroughs after a static tensile test were subjected to observations by means of a scanning electron microscope. The results are shown in **Figure 4**. it was found that the surface of the matrix fracture is mixed (ductile and brittle). Toughness of the matrix was determined using the Charpy test. Subsequently, observations of the surface of obtained breakthroughs were performed using the Hitachi S-4200 scanning electron microscope. The results of breakthrough observations are presented in **Figure 5**. The impact strength results are summarized in **Table 3**. It has been found that the material has an impact resistance at a low level. The drop in impact strength may result from the presence of microcracks in the material, which are a consequence of the matrix operation.

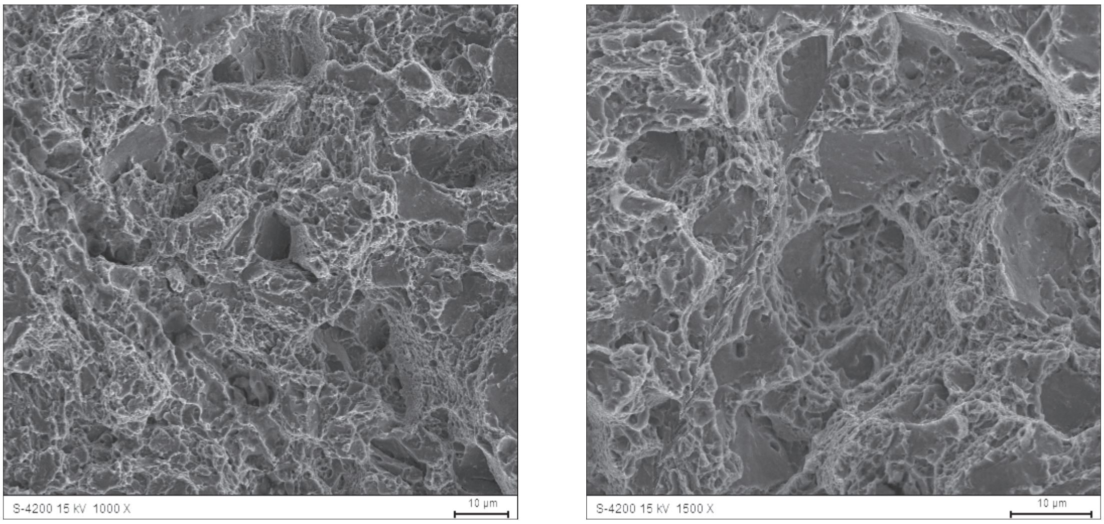

Figure 4 Surface of the fracture of the sample after a static tensile test,mixed breakthrough

Table 3 Toughness impact assessment after Charpy test

Samples	**J/cm^2**
1	11
2	8.6
3	8.6
average	9.4
standard deviation	1.4

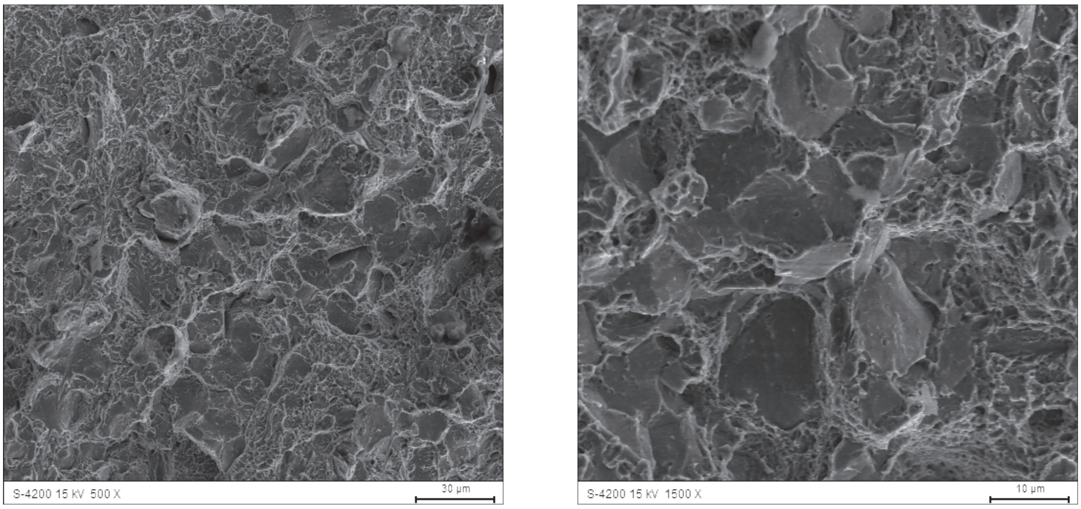

Figure 5 Surface of the fracture of the sample after a impact tests. Mixed breakthrough.

4. CONCLUSION

On the basis of the conducted research and analysis of their results, the following final conclusions were drawn:

1) The material has a different martensitic structure, from correct (locally) to degraded to a degree that makes it impossible to continue using the matrix.
2) The material hardness of the die indicates improper heat treatment, consisting of tempering the die after hardening in too low a temperature or in too short a time (low-martensite).
3) The microstructure is differentiated by the presence of soft spots, the occurrence of which is the result of unheated or insufficiently intensive cooling, or due to the heterogeneity of the initial structure, e.g. ferrite clusters.
4) The correct structure enables the matrix to be repaired based on the use of the machining process or the repair by the method of welding. The change in the structure that prevents further use of the matrix results mainly from the fact that the structure, which has been degraded to a large extent, causes a drop in impact strength, and consequently an increase in susceptibility to cracking during the forging process.
5) There was no loss of plasticity, as evidenced by the results of static tensile test and ductile fracture on the material after the impact test (observations by scanning electron microscopy).

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