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IMPROVING DURABILITY OF HOT FORGING TOOLS BY APPLYING HYBRID LAYERS

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This paper deals with problems relating to the durability of the dies used for the hot forging of spur gears. The results of industrial tests carried out on dies with a hybrid layer (a nitrided layer (PN) + physical vapor deposition (PVD) coating) applied to improve their durability are presented. Two types of hybrid layers, differing in their PVD coating, were evaluated with regard to their durability improvement effectiveness. The tests have shown that by applying hybrid layers of the nitrided layer/PVD coating type one can effectively increase the durability of hot forging tools.

Key words: forging, tool, die, durability, hybrid layer

INTRODUCTION

Because of the high intensity of wear of the tools used in die forging processes die durability is receiving increasingly more attention. Despite the considerable technological progress and scientific advances in this field, forging tools are still characterized by unstable and relatively low durability, which significantly increases the production costs and adversely affects the quality of the forgings [1-4]. A large number of factors, among them the forging process conditions (the temperature, the geometry of the tools and the preform, the speed of the process, the kind and amount of the lubricating medium ensuring optimum tribological conditions, etc.), have a bearing on the durability of forging tools. Also the tool material, the proper design and workmanship of the tools, the proper heat treatment and the modification of the surface layer affect the durability of the dies [5-8].

Research on complex surface treatment methods, conducted in many research centres, has resulted in the development of hybrid technologies consisting in the use of two or more surface engineering techniques. The best results are achieved in the case of hybrid methods which combine heat treatment and the PVD technique. The most popular are PN+PVD hybrid coatings [9-13].

APPLIED HYBRID LAYERS

A hybrid layer of the nitrided layer/PVD coating type was applied to tools made of steel WCLV, used for the hot forging of a spur gear. A photo of the tools is shown in Figure 1. Two versions of the coating: CrN

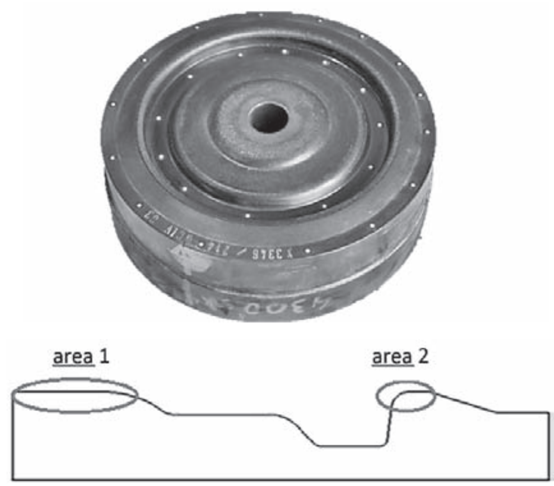

Figure 1 Photo of tested dies and areas of microstructure research

(chromium nitride) and TiCrAlN were adopted. The hybrid layers were designed and produced in the Surface Engineering Department of the Institute for Sustainable Technologies in Radom. Tables 1 - 3 present the properties of the nitrided layer and the CrN coating.

Table 1 **Parameters of nitrided layer**

Phase structure	diffusion zone
Surface hardness	1 000 HV 0.5
Effective width of zone with hardness 800 HV	g_{800} = 0,13 mm
Nitriding parameters	T = 520 °C Atmosphere: 90 % H_2 + 10 % N_2 p = 4,3 mbar

DESCRAPTION OF TEST

In-service tests of the tools were conducted in industrial conditions in the Jawor Forge PLC. This paper presents the test results for the bottom tools (their durabil-

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Table 2 **Parameters of hybrid layer of nitrided layer/ CrN coating type**

Thickness	g $\approx$ 5,28 mm
Hardness	H = 24 ± 1,6 GPa
Young's modulus	E = 279 ± 16 GPa

Table 3 **Parameters of hybrid layer of nitrided layer/ TiCrAlN coating type**

Thickness	g $\approx$ 6,7 mm
Hardness	H = 30 ± 2,1 GPa
Young's modulus	E = 337 ± 12 GPa

ity in the analyzed process was the lowest) in the second operation. After forging 3 000 units all the dies were subjected to preliminary macroscopic examination and to wear measurement by means of an optical scanner. Then the dies returned to production where they forged the next 4 000 units. Detailed studies of the wear mechanisms in the dies were carried out after the total of 7 000 units had been forged. Macroscopic and microscopic analyses of the tools were carried out to compare the effectiveness of the two coatings. In addition, the determined wear of the dies with the hybrid coatings was compared with that of the only nitrided dies. The wear results for the dies are described in more detail in [8].

MEASURMENT OF WEAR

A GOM ATOS II optical scanner was used to determine wear in the particular places of the analyzed tools. The data acquired from the surfaces scanned after work were compared with the original shape of the tools before work. The results in the form of colour maps showing deviations from the nominal dimension (the scan of the dies before work) are presented in Figures 2 - 4.

Tool wear after the forging of 3 000 units is the highest for the nitrided dies, whereas for the other dies it is negligibly small: only slight wear can be observed in the central part of the die and on the flash bridge. Because of the way of lubricating the tool its central area is most exposed to thermal material fatigue, which means that the coating should be characterized by a low heat exchange coefficient. In comparison with the CrN coating, the wear of the TiCrAlN coating in this area (Figure 4) after forging 3 000 and 7 000 units is considerably greater. The wear of the die with the TiCrAlN coating after forging 3 000 units is heavier in the flash bridge area. But as the number of forgings increases (to 7 000 units) the wear in this area decreases in comparison with the tool with the CrN coating. Due to the network of thermomechanical cracks forming on the surface the initially better abrasive wear resistance on the bridge radius (CrN) worsened with the number of forged units. The tests presented in the next section show that the CrN coating undergoes brittle cracking and its loose particles act as an abrasive, contributing to the wear of the tool. The worse brittle cracking resistance of the CrN coating contributed to the greater wear of the whole die.

MICROSCOPIC EXAMINATION

Changes in the surface layer of the tools in the areas shown in Figure 1 were examined by means of a TESCAN VEGA 3 scanning electron microscope.

Area 1

Grooves characteristic of abrasive wear are visible on the surface of the whole area 1 of the die with the nitrided layer after forging 7 000 units. Because of the

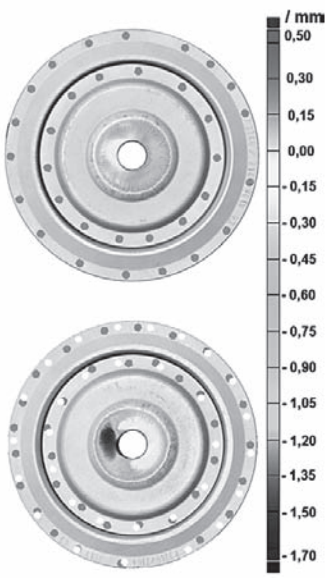

Figure 2 View of wear of only nitrided dies, obtained from optical scanner for bottom tool in second operation after forging: up – 3 000 units and down – 7 000 units

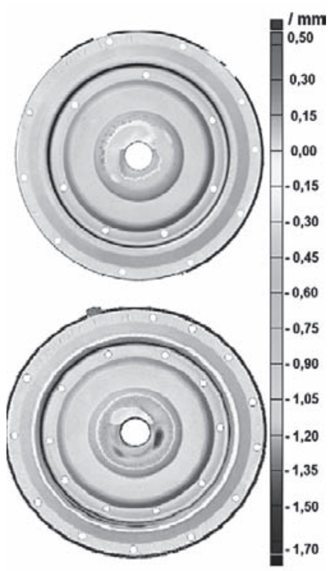

Figure 3 View of die with hybrid layer (CrN coating), obtained from optical scanner for bottom tool in second operation after forging: up – 3 000 units and down – 7 000 units

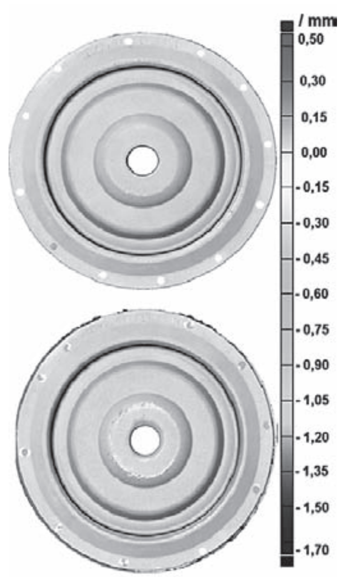

Figure 4 View of die with hybrid layer (TiCrAlN coating), obtained from optical scanner for bottom tool in second operation after forging: up – 3 000 units and down - 7 000 units

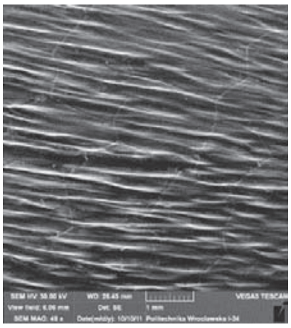

Figure 5 Work surface in area 1 of analyzed nitrided die after forging 7 000 units

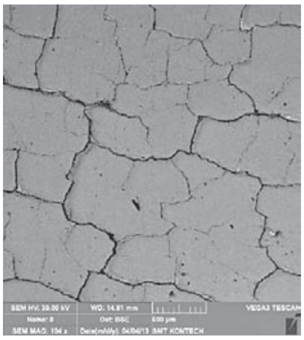

Figure 6 Work surface in area 1 of analyzed die with hybrid layer (CrN coating) after forging 7000 units

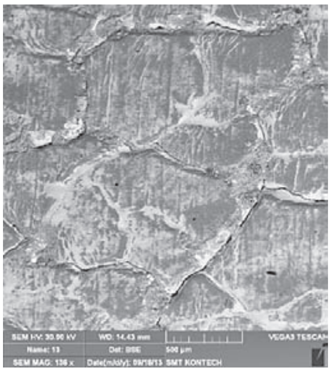

Figure 7 Work surface in area 1 of analyzed die with hybrid layer (TiCrAlN coating) after forging 7 000 units

heavy wear in this area, the initial network of thermo-mechanical cracks is poorly visible (it has been rubbed out) (Figure 5).

A network of thermomechanical cracks is also visible on the surface of the die with the CrN (chromium nitride) layer, but there are no grooves in this area (Figure 6); grooves form only after the coating is removed and its hard particles intensify the abrasive wear of the die.

In the case of the die with the multilayer TiCrAlN coating, for which the least wear was observed, only a network of thermomechanical cracks is clearly visible, but this network does not tend to crumble as in the case of the CrN coatings (Figure 7).

Area 2

Area 2 covers the die bridge. The wear in this area is uniform along the whole circumference of the analyzed

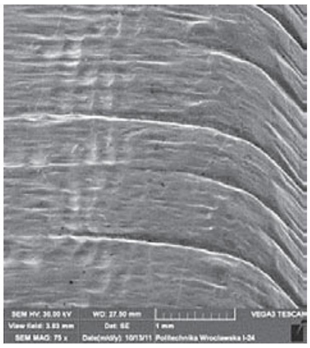

Figure 8 Work surface in area 3 of analyzed nitrided die after forging 7 000 units

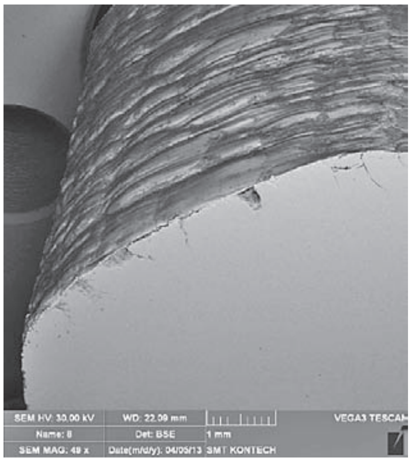

Figure 9 Work surface in area 3 of analyzed die with hybrid layer (CrN coating) after forging 7 000 units

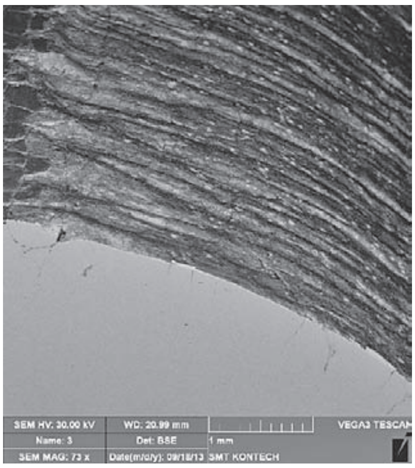

Figure 10 Work surface in area 3 of analyzed die with hybrid layer (TiCrAlN coating) after forging 7 000 units

dies. The wear is the heaviest for the nitrided dies. The radius in this area becomes truncated and the bridge width decreases. Besides normal wear, deep grooves (originating from large spalls) form in the radial direction on the bridge (Figure 8). In the case of the dies with the hybrid layers, wear in this place is more uniform. In the case of the dies with the CrN coating, the formation of grooves is intensified by the crumbling hard PVD coating (Figures 9 and 10).

CONCLUSION

The behaviour of the layers in the in-service conditions was described on the basis of metallographic, macro- and microscopic examinations. The macroscopic examinations have shown that the key factor responsible for the resistance of the tool hybrid layer is the character of the cracking of the applied coating. The influence of brittle cracking on the wear of the die with the CrN coating was confirmed by measurements performed using the optical scanner. It has been found that the hybrid layer with the TiCrA1N coating shows better in-service parameters. The wear of the tools with such coatings is twice smaller than that of the nitrided tools. The presented results prove that durability can be considerably increased through the conscious choice of hybrid layers.

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Note: The responsible translator for English language is lecturer from Wrocław University of Technology, Leonard Garczyński, Poland