# ANALYSIS OF PITTING WEAR PHENOMENA IN 30CrMoV9 STEEL SAMPLES WITH SI-DLC COATING

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**Abstract**

Pitting is a type of fatigue wear of the material subjected to cyclic loading, especially occurring in the gears or bearings. Si-DLC coatings are currently used due to their excellent properties such as low friction coefficient, high hardness, and wear resistance. Tribological studies of 30CrMoV9 steel samples with Si-DLC coating were performed using four ball testing machine T03 used for surface fatigue resistant test condition. Analysis of pitting cracks was performed using a profilometer, light microscopy, and scanning electron microscopy. The experimental results were compared with the theoretical model.

**Keywords:** Steel, Rolling contact fatigue, Pitting, Fatigue

## 1. INTRODUCTION

Pitting is a phenomenon of destroying the material under cyclic load and a lubricant environment. It spreads in a fatigue behaviour typically from the surface of the material where strong tensile stress is present [1-3]. Direction of the propagation is generally perpendicular to the surface. When a crack reaches the depth of the maximum shear stress, the direction of the propagation changes to that parallel to the surface and next the crack propagates towards the surface. Lubricant can penetrate the resulting fracture, causing its dilatation, that is the Rebinder effect [4]. In order to improve the wear resistance of materials, e.g. steel 30CrMoV9, numerous surface modification techniques can be used, such as carburizing, nitriding, applying different coatings e.g. TiN, CrN or diamond-like (DLC, Si-DLC). DLC coating has a low friction coefficient, high wear resistance, and relatively high hardness. Moreover, it is chemically inert [5-7]. The addition of Si to the DLC coatings additionally improve their wear resistance, and improve adhesiveness to the substrate [6,8-10]. Improvement of a wear resistance can be also obtained by a heat treatment of the substrate. Different kinds of tempering the material are used to obtain proper microstructure or precitipation carbide phases. Obtaining the required proportion of strengthening phases and their appropriate morphology increases the wear resistance of the material [11-20].

## 2. EXPERIMENTAL

In this research samples of 30CrMoV9 steel with Si-DLC coating were investigated in wear conditions. Tests were performed using modified friction joint of a four-ball tester T03. The modification consists of replacing the active ball by the cylinder with the truncated cone (**Fig. 1**).

**Fig. 1** Photograph of a sample used in the tribological tests

Tribological tests were performed under following conditions: friction load: 3924 N, contact pressure for balls: 8.06 GPa, the contact pressure for the cone-balls joint: 6.41 GPa, spindle speed: 1450 + 50 rpm, preload friction: 981 N, ambient temperature: 23 ± 2 °C, oil type: mineral [21]. The test was performed until nucleation of the first pitting fracture, which was confirmed by the change of the vibration amplitude. The appearance of such changes automatically ended triboligical test. Metallographic investigations were made using a Bruker Detak contact profilometer, light microscope in bright field view (LM:BF) and using differential interference contrast (LM:DIC) on a Nikon Eclipse LV150N instrument with so-called extended depth of focus, and on a FEI Versa 3D scanning electron microscope. Sites of pitting after the tribological test and after cutting perpendicular to the axis of the cross-section of the samples were analysed. Specimens were etched using 2% Nital before investigations.

## 3. RESULTS AND DISCUSSION

Tests were performed using three samples with different time to pitting nucleation: A1 in which pitting occurred after approximately 6 113 s, A2 where pitting occurred after approx. 61 958 s, and A3 sample with the longest duration of the test, pitting appeared after approx. 310 514 s. **Fig. 2a** shows the profile of a crack, and **Fig. 2b** wear on the sample A1 with marked direction of probable further cracking. This is not a typical pitting wear, because it has not fully disclosed pit wear. However, it can be clearly seen that photomicrographs of wear pit after cutting perpendicular to the axis of the sample show pitting wear (**Fig. 2c-e**) with numerous secondary fractures propagating in the bottom of the pit and fatigue cracks (**Fig. 2c**).

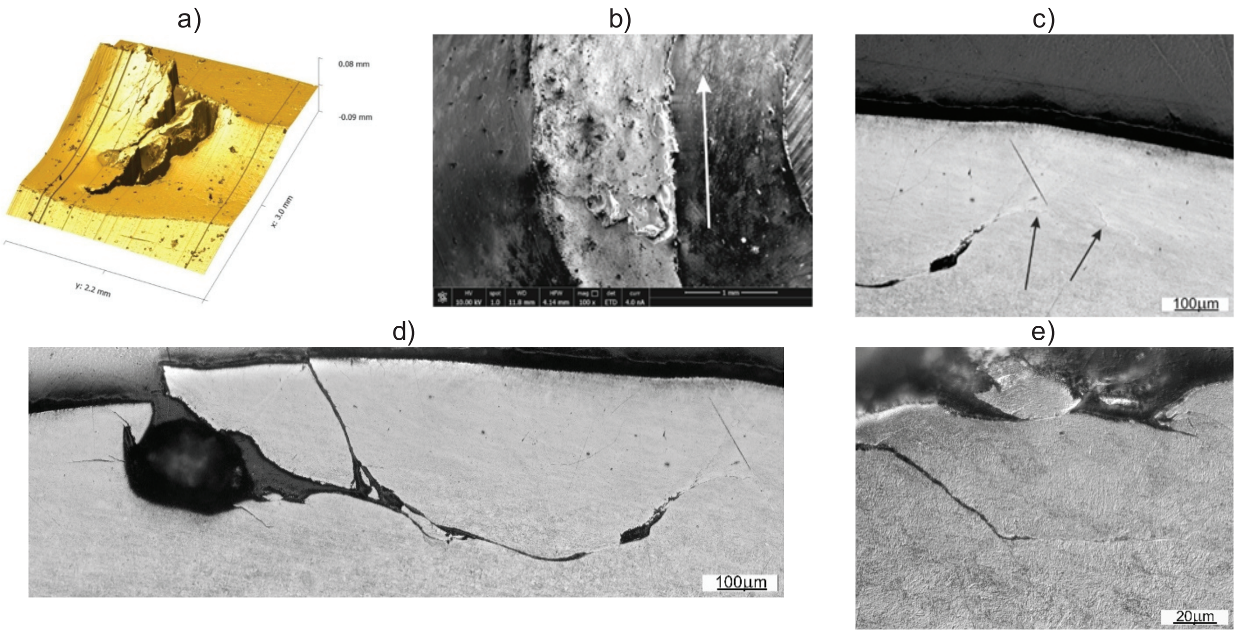


**Fig. 2** a) crack profile of A1 sample b) pitting in A1 sample (SEM-SE) - arrow shows direction of crack spreading, after etching c-d) LM:BF e) LM:DIC. Etching was in 2% Nital

In sample A2 clearly evident pitting wear exists. Profile (**Fig. 3a**) shows a section of the pit, and **Fig. 3b** worn area with marked direction of cracking. Possible direction could be concluded through observation of a specific arrangement of fatigue striations in the bottom of the pit. Also in this case a number of secondary fractures in the bottom of the pit (**Fig. 3c-e**) exist.

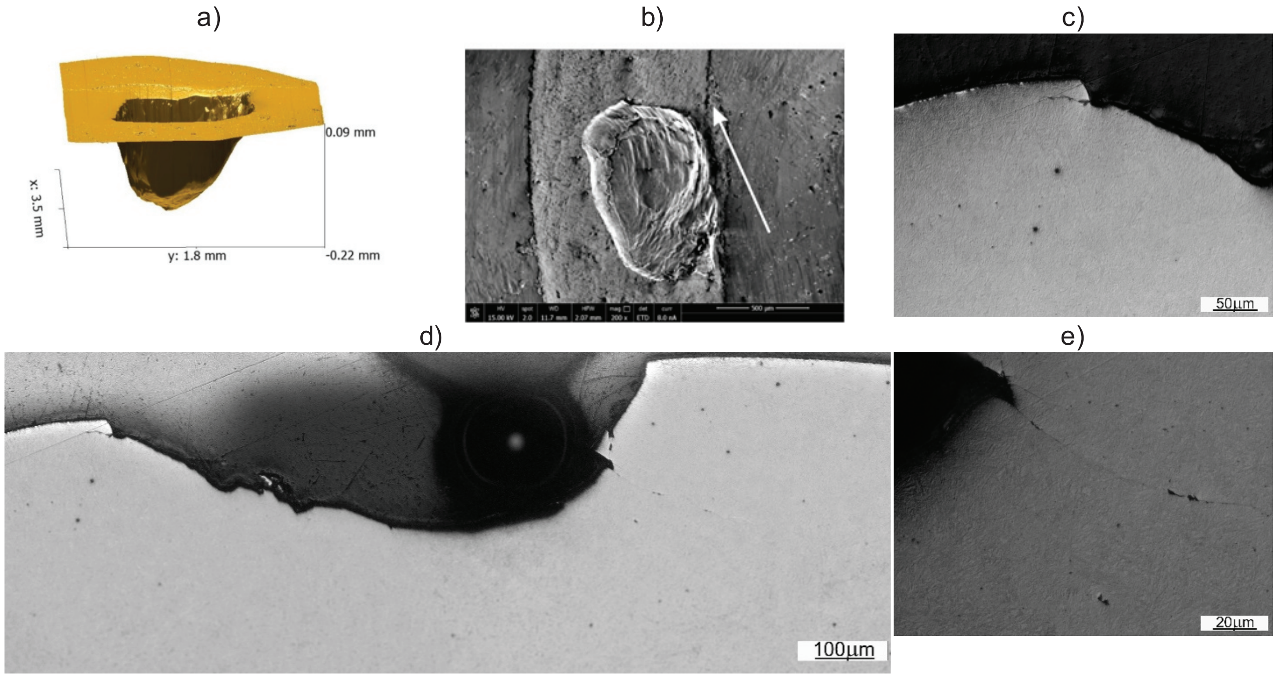


**Fig. 3** a) crack profile of A2 sample b) pitting in A2 sample (SEM-SE) - arrow shows direction of crack spreading, after etching c, e) LM:DIC d) LM:BF. Etching was in 2 % Nital

**Fig. 4a** shows the wear profile of the sample A3 (the longest time to pitting nucleation), and **Fig. 4b** wear area with marked direction of crack propagation. Also in this case there are numerous secondary fractures in the bottom of the pit (**Fig. 4c-f**).

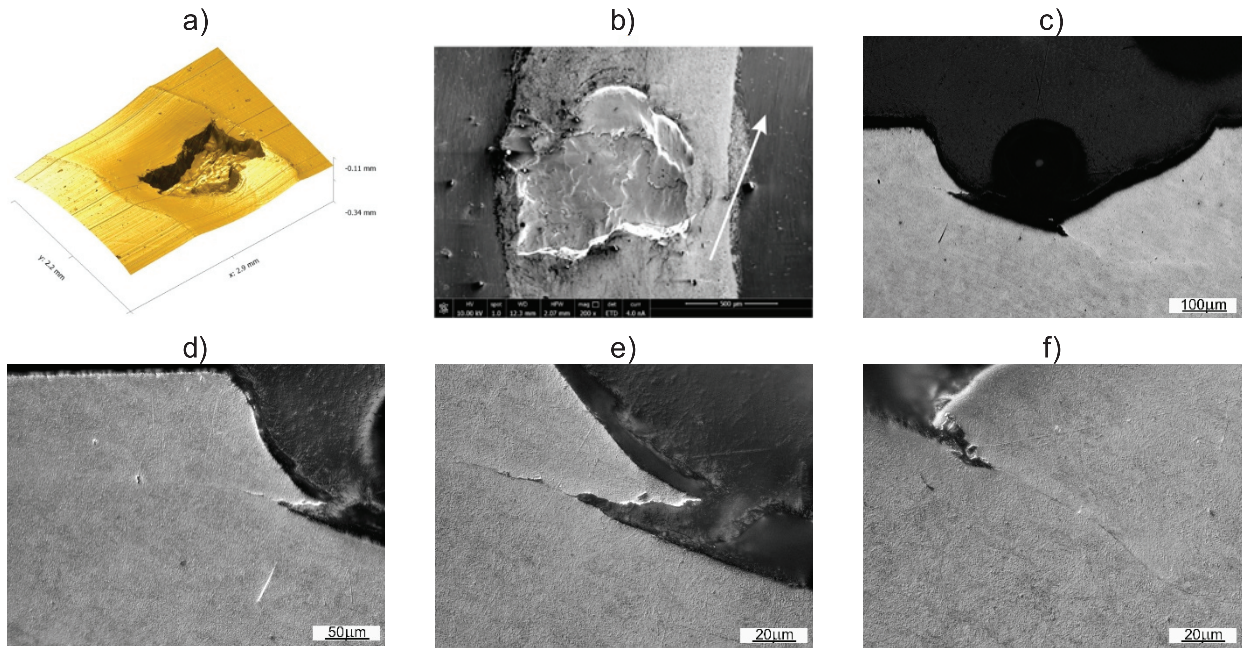


**Fig. 4** a) crack profile of A3 sample b) pitting in A3 sample (SEM-SE) - arrow shows direction of crack spreading, after etching c) LM:BF d-f) LM:DIC. Etching was in 2 % Nital

The samples were etched in 2% Nital, however, etching could not conclusively prove that pitting cracks propagate intergranularly or transgranularly. However, it is not disclosed metallurgical defects that could initiate crack. Additionally, hardness depth profiles of the substrate (**Fig. 5**) do not show a direct correlation between the hardness of the substrate and the time of pitting nucleation.

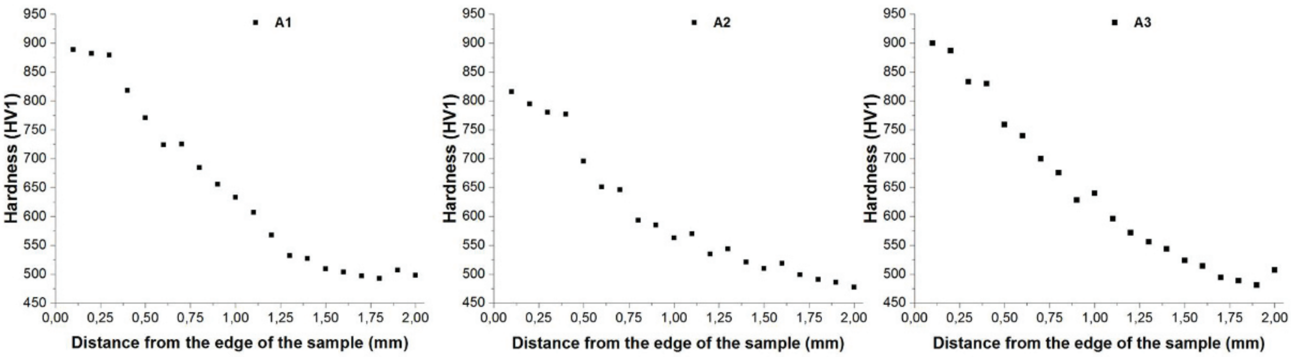


**Fig. 5** Hardness depth profiles of investigated samples

The relationship between theoretical model [22] and experimental results of the depth of the greatest shear stress based on the profilometry measurement of sample A2 was also examined. Calculated (228 μm) and experimental depth (220 μm) values are in good agreement (**Fig. 6**).

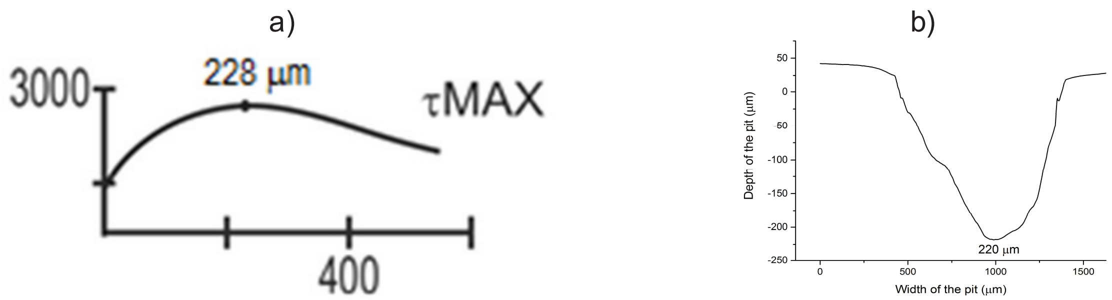


**Fig. 6** Dependence of the depth of the greatest shear stress a) theoretical model b) experimental results

## 4. CONCLUSION

In examined samples of 30CrMoV9 steel with Si-DLC coating, pitting nucleation occurred from surface the sample. The depth of cracks is in good agreement with the theoretical model of the greatest shear stress, which allows predict of deep cracks pitting. The hardness of the substrate seems to has no essential influence on the time of pitting nucleation, and the way of crack propagation cannot be clearly defined (intergranularly or transgranularly). It should be noted that pitting crack is heavily dependent on environmental changes of friction contact. Shorter time for experiment termination for sample A1 in comparison to sample A2 and A3 may be caused by changes in the amplitude of the wobble system long enough to terminate the experiment before the full unveiling of the pit.

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