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# Comparison of the adhesives used in the pull-off test Mo layer of railway axle

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## Abstract

This paper deals with the influence of adhesive on the pull-off test for the molybdenum layer of the railway wheel set axle. Certain axle types are fitted with a Mo coat used to provide protection against fretting and external influences. Pressing is used for the wheel-axle assembly procedure. During the process of pressing, this surface layer is damaged, which results in a corrosive tendency in the pressed joint. That is why great emphasis must be put on the Mo layer quality and its parameters must be tested in a suitable manner. Testing means identification of the surface tensile strength. The pull-off test provides a good tool to resolve the present problem.

Key words: pull-off test, Mo-coatings, railway axles, material behaviour, fretting

## 1. Introduction

Numerous products and structures today come with a surface layer that has an aesthetic as well as protective function [1]. Damage to this surface layer may lead to exposure of the base material and, as a result, degradation processes may influence it directly and may bring subsequent impairment of the structure [2, 3]. It is for the reasons above that checks must be made not only of the actual layer but also of the layer's adherence to the base material. The pull-off test can be used advantageously to verify these properties. It provides results on the surface tensile strength that gives evidence of the actual adherence, i.e., connection of two layers.

This paper focuses experimentally on the quality check of the Mo layer coating applied to the railway wheel set axles. Certain types of railway axles come with a plasma sprayed coating of molybdenum in the area of the pressed wheel-axle joint. The structural stress of the axle and wheels results in a degradation process called fretting in the already mentioned pressed joint. The degradation process – fretting – can be defined as a special case of fatigue surface impairment, where the contact surfaces, surface strain and vibrations are very important factors [4]. Fretting is manifested by the occurrence of wear debris from surface cracks [5–7]. The debris falls out from the pressed joint and the fretting process as well as the products of fretting is very similar to the corrosion process. Because the axle-wheel joint is loaded dynamically, gradual loosening of this pressed joint occurs as a result of this degradation process.

As a countermeasure to the degradation process above, railway axles are fitted with a plasma sprayed coat of Mo. This layer is intended to improve the surface elasticity and hardness, reduce friction and possible initiation and propagation of surface cracks.

To check the above-mentioned surface layer, pull-off test method is chosen. This method is able to verify adhesion of the surface layer to the base material. Pull-off test method authentication of surface layers consists of bonding pull-off disc on the incriminated site. Next is a pull-off disc separated by uniaxial tension, either manually or automatically. Subsequently are evaluated force and the actual place.

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Table 1. Chemical composition (wt.%) of the railway axle (EA4T steel quality)

| C | Si | Mn | P | S | Cr | Cu | Mo | Ni | V |
|---|---|---|---|---|---|---|---|---|---|
| 0.22–0.29 | 0.15–0.40 | 0.50–0.80 | 0.020 | 0.015 | 0.90–1.20 | 0.30 | 0.15–0.30 | 0.30 | 0.06 |

The limitation of this method lies in surface layer and the associated using of a suitable adhesive for pull-off disc and, of course, force limits of the pull-off device. This limit suitability of used adhesive will be described below in the article.

## 2. Experimental procedure

The assessment of the performed pull-off tests used a wide assessment scale to evaluate various types of Mo coating from various manufacturers, and to determine the tension limit for non-destructive testing. Apart from the assessments mentioned above, this paper will deal with the only influence of the applied adhesive on the pull-off test result.

In the first case, a two-component adhesive, LOCTITE 9466 A&B Hysol, was used, the curing of which takes place at 100 ℃, and which achieves its mechanical properties once the bonded surfaces cool down. Because it was used for the railway axle segment, the adhesives perfect cooling and curing time was approximately 24 h. The important factor aside from the time requirement is also the problem regarding the adhesive curing when a different adhesive was tested. Then two pull-off discs were bonded next to each other and, after 24 h, one of the discs was fully cured, the other disc was not cured at all. This phenomenon occurred totally accidentally on the tested axles. It was for these reasons that an adhesive was selected that had similar mechanical properties but also a shorter curing time.

In the other case, use was made of two-component adhesive LOCTITE 3422 A&B, which was air cured at room temperature, attaining full strength within 2 h. The tensile strength and adherence of both tested adhesives were comparable.

The factor that was taken into account aside from the tests of the adhesives above was the influence of milling performed around the pull-off disc, which markedly influenced the pull-off force.

Pull-off test was performed using the COMTEST OP 3/4 instrument. The testing procedure was as follows. The axle surface was thoroughly cleaned and the pull-off disc surface stripped of the previous adhesive deposit by grinding. Depending on the applied adhesive, the axle segment was preheated to 100 ℃ ± 10 ℃. The adhesive layer was applied to the pull-off disc and the pull-off disc was placed on the tested Mo layer of the axle segment.

Once the adhesive had cured, a circle was milled off around the pull-off disc and a leveling washer installed. A pull-off device was then fixed to the pull-off disc. The average speed of the pull-off test was 0.2 kN s$^{-1}$. A schematic sketch of the pull-off test configuration can be found in Fig. 1.

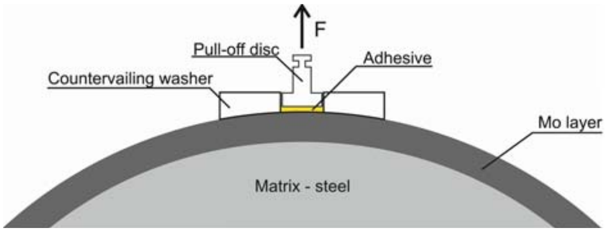

Fig. 1. Pull-off test schematic sketch.

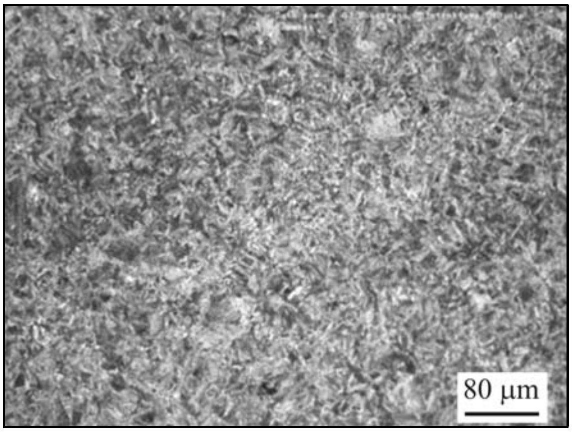

Fig. 2. Material structure under the failure point specimen 3B – martensite-bainite.

Table 2. Basic characteristics of Mo layer

| | |
|---|---|
| Average layer thickness | 285.5 µm |
| Layer porosity | 5.82 % |

For clarification, it is necessary to give information on the base material and tested Mo layer. The base material is the EA4T steel with the chemical composition stated in Table 1.

In terms of metallography, bainite and martensite were found under the pull-off point where the analysis was made (Fig. 2), where the structure from the optical microscope is given.

In addition to the structure, a basic analysis was

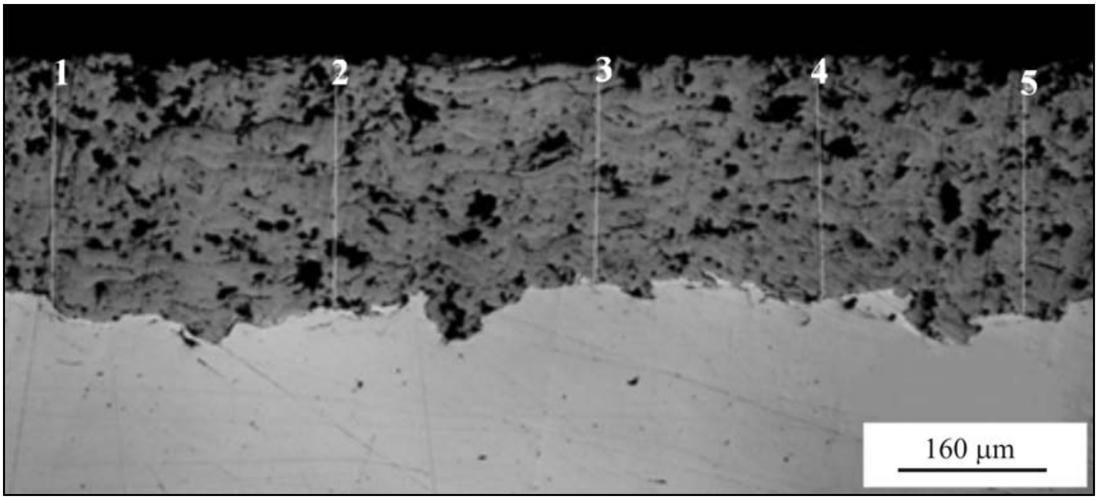

Fig. 3. Cross-section through the Mo layer – base material interface.

Table 3. Pull-off results: (a) with milling, (b) without milling

| | | | | | | |
|---|---|---|---|---|---|---|
| Loctite 3422 adhesive pull-off tension (MPa) | | | | | | |
| (a) | 7.62 | 16.39 | 11.1 | 9.51 | 7.07 | 9.58 |
| (b) | 10.24 | 12.94 | 11.42 | 5.29 | 11.27 | 11.10 |
| Loctite 3430 adhesive pull-off tension (MPa) | | | | | | |
| (a) | 13.94 | 12.19 | 10.79 | 13.40 | 5.72 | 4.19 |
| (b) | 10.91 | 15.52 | 13.77 | 7.29 | 6.76 | 5.65 |
| Loctite 9466 adhesive pull-off tension (MPa) | | | | | | |
| (a) | 10.28 | 26.29 | 21.06 | 25.97 | 11.71 | 20.18 |
| (b) | 15.02 | 16.77 | 13.99 | 16.73 | 20.15 | 17.28 |

made of the plasma sprayed surface molybdenum layer. This analysis pertains to the assessment of the layer thickness and its porosity. Table 2 gives these measured values.

Figure 3 depicts a polished scratch pattern of the cross section through the base material and surface layer with indicated sections of the measured thickness.

## 3. Discussion

The following results were obtained upon the performed tests. Table 3 depicts the pull-off forces attained in the tests of both adhesives with and without milling of the circle.

Each pull-off test was documented. Table 4 gives only a few significant pull-offs for each applied adhesive type. These figures show significant differences between the applied adhesives.

## 4. Conclusions

The compared results show that the best choice is the application of LOCTITE 9466 with the pull-off surrounding area milled off. The other adhesive type that was only air cured at room temperature was very far behind such results.

As you can see in the figures in the Table 4, when LOCTITE 34xx type adhesive was used the molybdenum layer was not pulled off, only the actual adhesive was impaired.

Pull-off test values without milling were slightly lower (Table 3). This paper focused predominantly on the pull-off test result assessment using various adhesives with similar properties. The pull-off test is greatly influenced by the surface roughness. The crucial factor is the adherence between the adhesive and molybdenum layer. Exploration of the influence of roughness and quality of the Mo layer on the pull-off test exceeds the scope of this publication. This influence is under continuous exploration.

Table 4. Documentation of the pulled-off surfaces

| Pull-off with LOCTITE 9466 adhesive | Pull-off with LOCTITE 3430 & 3422 adhesive |
|---|---|
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|  |  |

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