SURFACE MARTENSITE WHITE LAYER PRODUCED BY ADHESIVE SLIDING WEAR-FRICTION IN AISI 1065 STEEL

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Abstract

White layers (WLs) produced in hard steels by adhesive sliding wear without lubricants have been characterized using microindentation, optical microscopy, scanning electron microscopy (SEM) and chemical analysis through energy dispersive spectroscopy (EDS). The WL is found to have a hardness of values ranging between 825 to 916 HV and ultrafine grained structure with layer size ranged around 50 μm. These two characteristics of white layers distinguish it from martensite structure formed in steels by heat treatment. The formation of this untempered martensite with ultrafine structure is based on a large strain deformation and stress at elevated temperature states that promote conditions of severe wear by friction.

Keywords: White layer, Untempered martensite, Adhesive sliding wear, Surface failure.

Resumen

Las Capas Blancas (CBs) producidas en aceros de alta resistencia debido a roce por deslizamiento adhesivo sin lubricación han sido caracterizadas mediante el uso de indentación para medir microdureza, mediante microscopio electrónico de barrido (MEB), y por análisis químico a través de espectroscopía de energía dispersiva (EED). Las Capas Blancas tienen durezas de valores en el rango de 825 a 916 HV y las estructuras de grano ultra-fino con espesor de capa del orden de 50 μm. Estas dos características diferencian las Capas Blancas de las estructuras martensíticas formadas en los aceros por tratamiento térmico. La formación de esta martensita, de estructura ultra-fina, se basa principalmente en una deformación importante, y esfuerzos en condiciones de alta temperatura, las que promueven las condiciones de alto desgaste por abrasión.

Palabras claves: Capas blancas, Martensita no-revenida, Roce por deslizamiento adhesivo, Falla superficial.

1. INTRODUCTION

White Layers in steel is a generic term referred to as untempered martensite (UTM) layer or cover zones produced by abusive operating conditions such as high surface temperatures and stresses. A “white layer” has been found to result from operations such as drilling, grinding, milling, electron-discharge machining and abrasive cutting. Surface martensite White Layer in steels can be produced by friction [1-3], either by misuse of the steel product, creating strong wear through abrasion, or during inadequate machining, like strong grinding or hard turning [4-6]. The heat released during these friction phenomena causes localized temperature rise up to austenitizing the surface layer of the steel, which is immediately followed by very rapid cooling due to heat dissipation caused by the mass effect of the bulk. These thermal effects are sometimes large enough to cause a microstructural change where the fast cooling transforms austenite to martensite. It is possible that such a phase transformation may also cause localization of plastic flow. This new phase is present only in a very small zone and can be observed with the optical microscope as a very fine white layer with ultrafine grained or nanocrystalline structures. The fact that the martensite has not been tempered makes it difficult to etch with nital or picral, and therefore it is usually qualified as “featureless”.

This untempered martensite observed as white layers, which is hard and brittle, is the root-cause of different failure phenomena [6]. The presence of
these white layers affects product performance, namely fatigue life, stress corrosion resistance, wear characteristics, and causes failures of ropes or during forming in different mechanical working processes. The characterization of white layers, produced by grinding and turning, has been recently reported by Bartha et al. [7].

This article aims to contribute to the knowledge on white layer characteristics on steel wires caused by abrasion or adhesive sliding wear without lubricants and its failure characteristics.

2. EXPERIMENTAL PART

Failed AISI 1065 steel wires, of different origins and use conditions, were studied. One of them was part of a steel rope which failed during use in fishing boats and the other one failed during spring manufacturing. Samples were taken and analyzed by optical microscopy (OM), scanning electron microscopy (SEM), and energy dispersive spectroscopy (EDS).

For OM microstructure determination the samples were prepared with final polishing of colloidal silica. Etching was done either with nital for general viewing or by using a mixture of sodium metabisulfite and picric acid in ethyl alcohol to show better details on the martensitic and pearlite surfaces.

Vickers microhardness (HV) depth profiling was used to verify the presence of untempered martensite white layers. The applied load was 50g and the dwell time was 15 s. Indentations were spaced at least 20 μm, to avoid interference.

3. RESULTS AND DISCUSSION

3.1 Cable Wire Analysis

Visual inspection of a damaged steel rope showed that dragging the rope on an abrasive surface caused very severe wear. Figure 1 shows the failure of a severely damaged wire, where half of the transversal area wore out by friction.

Optical microscopy analysis showed the presence of a white layer, on the top of the primary pearlitic structure, which is strongly deformed, being typical for drawn pearlitic wires. The white layer, produced by abrasion, has a thickness of about 60 μm and a microhardness of 916 HV₅₀, much higher than the one of the bulk, 536 HV₅₀.

Chemical etching with 3% nital solution reveals very few microstructural features, but does show numerous cracks initiating at the pearlite-martensite interface. The propagation of these cracks in the martensitic phase deviates until being parallel to the drawing direction, as shown in Figure 2. The final failure shows propagation in the pearlitic zone also changing towards a parallel direction to the drawing direction.

By SEM, the martensitic layer and the pearlitic bulk were easily distinguished by roughness differences that were produced by etching the polished surface of metallography samples. The interface between the martensitic and the pearlitic phases is very thin, and does not reveal special characteristics. As
Figure 3. Failed spring wire. (a) Photograph. (b) Optical micrograph of a cross section, showing the cracked white layer and deformed pearlite. Sodium metabisulfite and picric acid etch. (c) SEM micrograph of the same sample.

Figure 4. Micrograph of cross-sectioned wire sample. White martensitic layer generated during drawing, showing crack initiation and growth. Micro-Vickers indentations in white layer and bulk pearlite. Sodium metabisulfite and picric acid etch.

expected, no difference between chemical compositions of the white layer and bulk was found by EDS, since structural modifications were, exclusively, metastable phase transformation, i.e. pearlite transformation into austenite by friction induced heating the surface, which quenches rapidly due to the high heat conductivity of the large bulk, and forms martensite. It is worth to note that the fast martensite transformation does not allow segregation, therefore no local chemical variations, detectable by EDS, occur.

3.2 Spring Wire Analysis

The visual appearance of a SAE 1065 steel wire, which failed during spring manufacturing, is shown in Figure 3a. Numerous cracks may be seen in a narrow zone of the convex surface of the bent wire. OM and SEM observations on a longitudinal cut shows short white layers present between cracks, which propagated in pairs towards each other, as shown in Figure 3b-c and Figure 4. The thickness of such white layers grow gradually up to 40 microns and finishes abruptly in a deep crack. After a short pearlitic length a new white layer is shown, growing slowly in thickness until being arrested by the development of a new crack due to the hardness of the martensitic phase.

The microstructure in both zones, white layer and pearlite, was determined suggesting the presence of bainite and a small amount of residual austenite in untempered martensite. It was observed that the
A martensitic layer was formed with a very fine grain microstructure. The original coarser grain zone adjacent to the white layer shows a very deformed microstructure of pearlite and ferrite.

A more detailed study of both areas was performed with SEM-EDS investigations.

The white layer hardness was measured, showing values of 825 HV$_{50}$ for the white layer, as compared to 480 HV$_{50}$ on the bulk phase.

Observation of the wire on scanning electron microscope without etching, as shown in Figure 5, reveals a scratched surface in the drawing direction on the healthy zones, while the affected zone shows only superficial shadows and lines in different directions, reflecting the higher hardness. Also definitively the contrast is lighter.

Semi-quantitative analysis realized with EDS spectrum on both areas revealed once again and in a similar way as in the cable wire, the same elements between white layer and bulk, as shown in Figure 6. Carbon and manganese profiles shown in the same Figure 6, obtained through around 110 to 120 microns length over these zones, confirm that the martensitic transformation took place as a thermal effect with rapid quenching of local austenite produced by friction, without variation and segregations of elements.

These observations suggest that the white layer was generated by overheating during drawing, probably due to localized lack of lubrication. In these operation conditions, a severe adhesive wear developed in the sliding contact between the steel wire and die, made of WC based cemented carbide. EDS spectrum on the wire surface, shown in Figure 5a, revealed the presence of W in a concentration of about 6 weight %. As this element it is not contained in the bulk, as shown in Figure 5b, its presence on the surface is an evidence of material transfer between the mating bodies, i.e., an intense adhesive sliding wear. After forming, the brittle white layer cracks and partially delaminates under the high contact pressure.

The manganese profile shown in Figure 6, obtained through around 110 to 120 microns length over these zones, confirm that the martensitic transformation took place as a thermal effect with rapid quenching of local austenite produced by friction, without variation and segregations of this element. While carbon analysis is less precise, it suggests similar conclusions.

**Figure 5.** (a) SEM micrograph of fractured spring wire. (b) EDS of the apparently sound surface, and (c) EDS in a zone where the white layer is partially delaminated.
4. CONCLUSIONS

Abused materials, as it is often the case of high carbon steel ropes, originally adequate for their intended use, may not only be subject during use to very strong wear due to abrasion, but may also form martensite on the surface as the thermal phenomena generated during friction causes surface temperature rise followed by very rapid cooling due the mass effect of the bulk. This untempered martensite, which forms a long white layer, is brittle. Induced cracks initiate at the pearlite-martensite interface and propagate first perpendicularly to the interface and then parallel to the drawing direction, leading to failure and to the need to discard an originally sound cable.

On the other hand white layers generated during wire drawing, due to localized lack of lubrication during the process, are non-continuous and generate cracks initiating at the surface when the martensite thickness grows to a critical value. This definitively impairs its use for further product manufacture as it causes material failure during the subsequent plastic deformation.

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6. REFERENCES