Proceedings of 30th Indian Engineering Congress, the 21st Century Engineering: The Make in India Pathway, *December 2015*, pp. 202-208

Failure of Cold Drawn Steel Wires due to Formation of Friction Martensite

Balbir Singh*, Gadadhar Sahoo and Atul Saxena

Steel Authority of India Limited, R&D Centre for Iron and Steel, Ranchi, Jharkhand, India; bsingh@sail-rdcis.com

Abstract

The C-Mn-Si steel wires with a typical composition of C-0.81, Mn-0.78, Si-0.27, S-0.006 and P-0.016 were cold drawn to various shapes and sizes for fabricating steel ropes. The steel wires thus drawn were reported to have failures/ breaks, sometimes during drawing itself and the other times during service of ropes. In order to identify the cause of failure, investigation was carried out on both the wire samples broken during wire drawing as well as during the service of rope. The diagnostics consisted of the observations under optical microscope and scanning electron microscope including EDS, measurement of micro hardness and evaluation of tensile strength. Based upon the study, it was revealed that both the wire samples, in general, contained ferrite pearlite microstructure and tensile strength ranging between 1450-2050 MPa, coupled with a total elongation between 5-9%. On careful examination of the microstructure it was revealed that a white colored layer having fine structure was present near to the wire surface/ edges at locations where failures occurred. The fine structure at higher magnification was identified as untempered martensite, which was found to have micro hardness of 754 VHN as compared to 628 VHN in the centre. This confirmed the presence of harder micro-constituent in the surface, which most probably caused failure of the wires due to its brittle nature. As far as the transformation of this type of martensite is concerned, it could be inferred that during wire drawing as well as during service of ropes, excessive wear/ friction takes place due to abusive operating conditions of improper lubrication. Thus, under the sliding wear conditions a large amount of localized heat is generated, raising the surface temperature to austenitizing levels. The heated surface subsequently cools down rapidly, resulting in transformation of harder microstructure called the friction martensite. The structure remains untempered because of the faster cooling rates, there by promoting embrittlement of the surface layer.

Keywords: Friction Martensite, Steel Ropes, White Layer, Wire Drawing

1. Introduction

The wire ropes, also known interchangeably as cables, are manufactured by twisting the cold drawn metallic wires in helical form. Application wise the cables are widely used in mining industry, power winches, cranes, oil & gas rigging operations and other engineering industries. As per the application requirement the wire ropes should have simultaneously the high strength as well as the flexibility. Both the properties in steel ropes, therefore, are possessed due to suitably designing the steel

* *Author for correspondence*

chemistry and the processing parameters. In general, high carbon steel wires cold drawn through heavy deformations are used to provide this combination of mechanical properties. It is interesting to note that in spite of precautions taken during manufacturing as well as application of cables, there have been failures of wires as well as the cables[1]. It therefore was a need to investigate the cause of such failures so that further measures could be taken to minimize their occurrence. Accordingly, the steel wires failed during cold drawing operation and also the cable failed during its operation/ application, were investigated in the present work using diagnostic tools such as optical microscope, scanning electron microscope, micro-hardness and tensile strength measurements. The results obtained were analyzed to arrive at the cause of such failures.

2. Experimental

2.1 Material

Figure 1. Cold drawn wire (R 2-12).

The investigation was carried out on two different shaped wire samples (R-12 and L-10) which failed during wire drawing operation at M/s Usha Martin Ltd (Figure 1 & 2). Additionally, tests were also conducted on similar samples which failed during service of the rope made of the cold drawn steel wires having nominal diameters of 3.88 mm (round) and 2.57 mm (two-strand). Both sets of wires were made of high carbon steel grades having low levels of sulphur and phosphorus contents. In order to assess the exact chemistry of these wires chemical composition was analyzed through optical emission spectrometer (OES).

Figure 2. Cold drawn wire (L-10).

2.2 Tensile Strength

As high strength and adequate ductility are the requirements for cold drawn wires meant for manufacturing metallic cables, tensile properties were evaluated on 200 mm long specimens cut from both the wire samples having different shape and cross sections. The specimens were tested in DAK-72103 model universal tensile testing machine for assessing their tensile strength and percent elongation.

2.3 Optical Microscopy

In order to examine the microstructure of failed wires and any variation in the morphology, specimens of about 10 mm height were cut from both shapes of wires keeping the proximity with fractured surfaces. Subsequently, the cut specimens in transverse as well as longitudinal directions were mounted using a hot mount press. The mounted specimens were polished in usual manner on grinding wheel and using alumina suspension. The specimens after final polishing were etched with 2% nital solution to reveal the microstructure. Polished surface was observed under Olympus optical microscope in both the un-etched as well as the etched conditions. Additionally, the etched specimens were photographed at low magnification for examining different microstructural zones present across the diameter and also the shape and size of pre-existing crack, if any.

2.4 Microhardness

Microhardness was measured under Litz-MM6 microhardness tester on the polished surfaces in different zones of the cross section using 400 gm weight. This would help to study the characteristics of different microstructural features across the diameter of wires.

2.5 Scanning Electron Microscopy

In order to identify the mode of fracture whether ductile or brittle, the fractured surfaces of wire samples were examined under EVO MA-10, Carl Zeiss make scanning electron microscope. The surfaces were observed at lower as well as higher magnifications to reveal desirable features of the fractured surface.

3. Results and Discussion

3.1 Chemical Composition

The chemical composition of the 3.88 mm diameter round wire sample (R-12) as determined through OES is given in Table 1. It is observed from the table that the wire belongs to high carbon category which is a requirement of wires used for high strength applications. Manganese content is also to the higher side for promoting grain refinement and thereby providing strength to the material. The S level is low which is desirable for avoiding formation of MnS inclusions well known for deteriorating mechanical properties.

Table 1. Chemical composition of cold drawn wire sample R-12

C	Mn	Si	S	P
0.81	0.78	0.27	0.006	0.016

3.2 Tensile Strength

The tensile strength and total elongation as measured using DAK-72103 model universal tensile testing machine on 200 mm gauge length samples of R-12 and L-10 wires are given in Table 2. It is observed from the table that sample R-12 possesses very high tensile strength of 2056 MPa coupled with 9.23% total elongation. This range of tensile strength and the ductility qualifies the material suitable for fabricating high tensile cables for industrial applications. The properties could be obtained in the wires due to its higher carbon and Mn contents and also lower values of S content. In addition, higher amounts of cold reductions imparted during wire drawing also contributed in attaining such levels of tensile properties. In case of L-10 wire the properties obtained are lower than the R-12 grade because of the reason that it belongs to different category steel and used for manufacturing lower grades of cables.

Table 2. Tensile properties of cold drawn wires

Sample No.	Nominal Diameter (mm)	Tensile Strength (MPa)	Total Elongation (%)
R-12	3.88	2056	9.23
L-10	2.57	1446	5.36

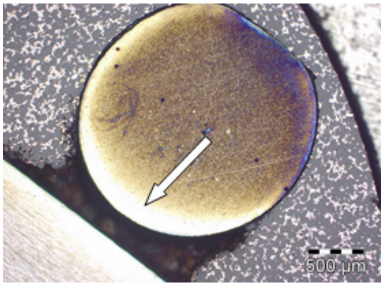

Figure 3(a). Cross section of R-12 wire sample at low magnification.

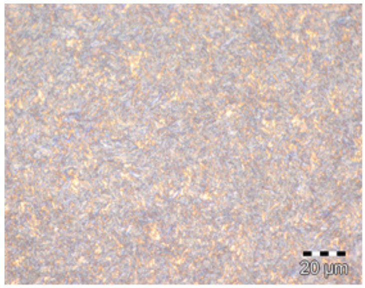

Figure 3(b). Fine pearlite & ferrite in transverse direction at 1000x.

Figure 3(c). Fine pearlite & ferrite in longitudinal direction at 1000x

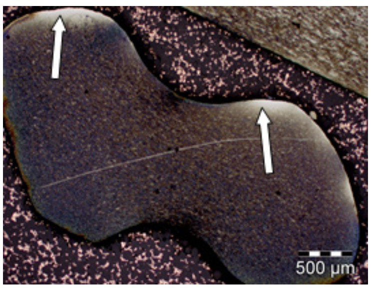

Figure 4(a). Cross section of R-10 wire sample at low magnification.

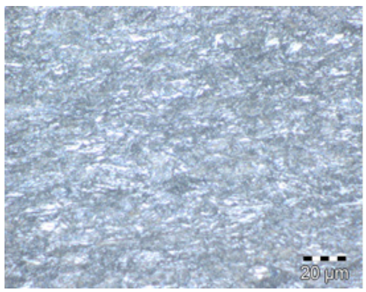

Figure 4(b). Fine pearlite & ferrite in transverse direction at 1000x.

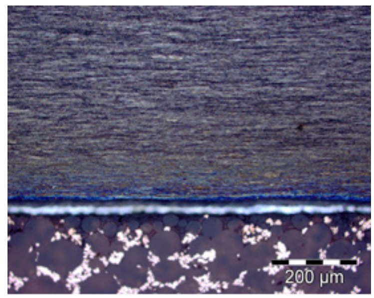

Figure 4(c). Fine pearlite & ferrite in longitudinal direction at 200x.

3.3 Microstructure

The microstructure of both the wires was observed under optical microscope after etching the polished specimens with 2% nital solution. Microphotographs were taken at low magnification as well as at 1000x for revealing the structures/ features present across the diameter which are shown in Figs. 3 & 4. On examining the microstructures it was revealed that the wires, in general, contained ferrite-pearlite microconstituents across the cross section (Figure 3b-c & Figure 4b-c). However, near to the surface/ edges a white layer (arrow marked) of fine microstructure was found to exist (Figure 3a & 4a). Taking a closer view of these layers it was revealed that the morphology resembles with that of a low carbon martensitic microstructure, which most probably might have been transformed during wire drawing operation. Similarly, during service the industrial cables come across the un-lubricated pulleys and/or other parts of assembly, which causes friction and get heated upto austenitizing temperatures resulting in transformation of friction martensite.

3.4 Microhardness

In order to support the occurrence of friction martensitic layers near to the surface of the drawn as well as the serviced wires, microhardness was measured using 400 grams weight at three different locations – white layer, intermediate layer and centre. The locations of indentation are marked in Figure 5 and 6 respectively for R-12 and L-10 wire samples. The hardness measured at these locations is given in Table 3. It may be seen from the Table that in R-12 wire sample white region has an average hardness of 754 VHN, while towards centre the value reduced to about 628 VHN. Similarly in case of L-10 wire sample, white layer was found to have 552 VHN microhardness and 484 VHN in the centre. Thus, attaining higher hardness values in white layers of both the wire samples helped in inferring that these layers are the harder microconstituents transformed during cold drawing operation and also during service of cable in the industrial environment.

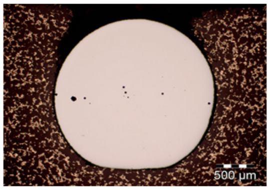

Figure 5(a). Location of micro-hardness indentations in R-12 wire sample.

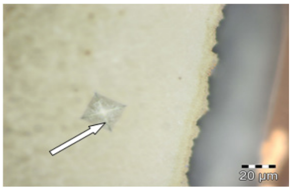

Figure 5(b). Location of indentation in the white layer.

Table 3. Micro-hardness of cold drawn wires at different locations

Sample No.	Micro-Hardness at 400 gm weight (VHN)		
	In white region near surface	In between	In the Centre
R-12	754	710	628
L-10	552	-	484

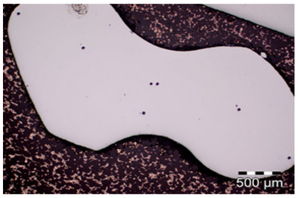

Figure 6(a). Location of micro-hardness indentations in L-10 wire sample.

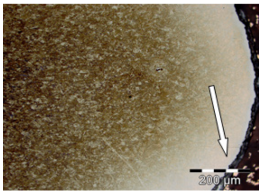

Figure 6(b). Location of indentation near white edge.

3.5 Scanning Electron Microscopy

Scanning electron microscopy was conducted on the fractured surfaces of both the wire samples to identify the mode of fracture in the central parts as well as in the white layered regions. Photographs depicting the fractured surfaces of R-12 and L-10 samples are shown in Figure 7 and 8 respectively. It may be observed from these figures that the central parts of wires have experienced dimpled ductile fracture (Figure 7c & 8c), while the white layered regions have undergone shining brittle fractures (Figure 7b & 8b). This, in fact confirms the presence of harder phase (martensite) in the white layers as identified through optical microscopy as well as the micro-hardness measurements.

The results obtained through optical microscopy, scanning electron microscopy, micro-hardness measurements and tensile testing of both the sample helped in inferring that the wires failed due to initiation of crack in the harder phase known as the friction martensite. There is evidence in the literature[2] that during wire drawing operation excessive wear/ friction takes place due to high speeds and abusive operating conditions of improper lubrication. As a result, under the sliding wear conditions a large

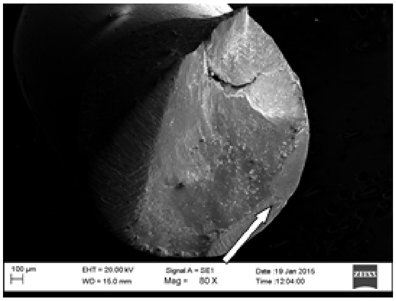

Figure 7(a). Broken surface of R-12 sample at low magnification.

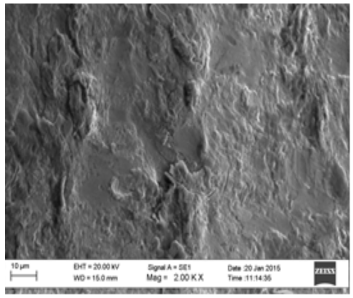

Figure 7(b). Shining brittle fractured surface at the edge (2000x).

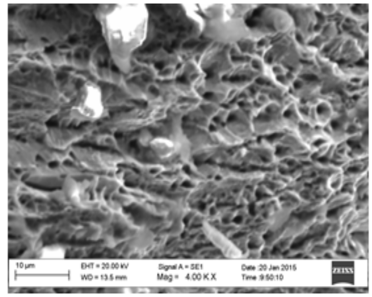

Figure 7(c). Dimpled ductile fracture surface in centre (4000x).

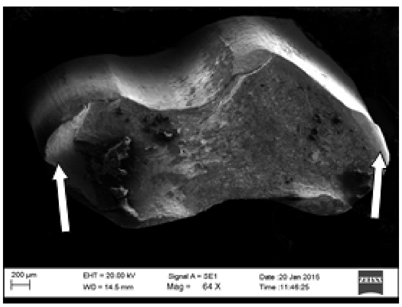

Figure 8(a). Broken surface of L-10 sample at low magnification.

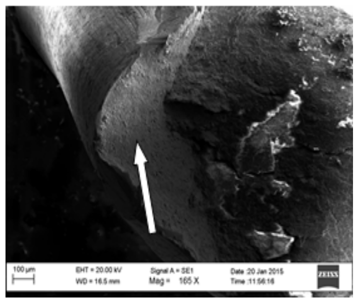

Figure 8(b). Shining brittle fractured surface at the edge.

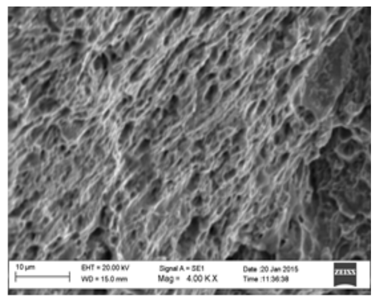

Figure 8(c). Dimpled ductile fracture surface in centre (4000x).

amount of localized heat is generated, raising the surface temperature of wire to austenitizing levels[2]. The heated surface subsequently cools down rapidly, resulting in transformation of harder microstructure called the friction martensite. The structure remains untempered because of the faster cooling rates, thereby promoting embrittlement of the surface layer[3]. In order to avoid formation of friction martensite in the surfaces, therefore it is important to have proper lubrication between the wire surface and the drawing dies during wire drawing operation. Similarly, cables in industrial applications should be used carefully so that friction between the surfaces is avoided.

4. Conclusion

Based upon the investigation conducted on the wires failed during cold drawing operation as well as during service of steel cable following inferences may be drawn.

- Chemical composition (C-0.81, Mn-0.78, Si-0.27, S-0.006, P-0.016) of the wire failed during cold drawing operation was found suitable for manufacturing high tensile wire ropes.
- Tensile strength (1450-2050 MPa) and % elongation (5-9%) adequately conformed to the requirement of high tensile applications of ropes fabricated using the experimental wires.

- Microstructural observations and the micro-hardness measurements confirmed the presence of white layered harder phase (the friction martensite) on the surfaces of the cold drawn wire as well as the service cable strand.
- The wires failed under loading conditions, most probably, due to initiation of crack in the friction martensilte which formed because of excessive wear between the surfaces.

5. Acknowledgement

The authors would like to acknowledge the support of M/s Usha Martin Ltd Ranchi for providing the cold drawn samples for this study. They are also thankful to the management of R&D Centre for Iron and Steel, SAIL for kind permission to present the paper in the 30th Indian Engineering Congress 2015.

6. References

1. Sipos K, et al. Revista Latinoamericana de Metalurgia y Materiale. 2008; 28(1):46–50.
2. Bartha BB, Zawadzki J, Chandrasekar S, Farris TN. Metall Mater Trans A. 2005; 36(6): 1417–25.
3. Arkan S, Shah S, Moylan SP, Chhabra PN, Chandrasekar S, Yang HTY. Metall Mater Trans A. 2002; 33(4):1245–54.