Failure Analysis of Tension Spring

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***Abstract*— This paper presents the failure analysis of an automobile tension spring which failed during assembly. The fractured surfaces as well as the surface of the tension spring material close to the fractured surface were examined in a scanning electron microscope at suitable magnification. Optical microscopy was performed to evaluate the basic microstructure of the as received material. Detailed electron microscopic studies have indicated that the failure was due to presence of surface cracks near the surface of the spring material.**

Keywords—tension spring; failure; surface crack; SEM; Metallurgical Examination

I. INTRODUCTION

A spring is an elastic object and performs many functions. The basic function of a spring is to store mechanical energy, as it is elastically deformed, and then recover this energy, at a later time as the spring recoils [1]. There are various types of springs such as Leaf springs, Coil springs, etc and has different applications in different areas. Among various types of springs, helical tension springs are designed to absorb and store energy as well as create a resistance to a pulling force [2]. These are metal wire coiled around in loops. In the manufacturing process, an initial tension is incorporated to pull the coils tight against each other. It is initial tension that determines how tightly together a tension spring is coiled. This initial tension can be manipulated to achieve the load requirements of a particular application. The initial tension is equal to the minimum force required to separate adjacent coils. Small springs can be wound from pre-hardened stock, while larger ones are made from annealed steel and hardened after fabrication.

There are varieties of ends that can be put on tension springs. It may include threaded inserts, reduced and expanded eyes on the side or in the centre of the spring, extended loops, hooks or eyes at varying positions or distances from the body of the spring. These ends are very critical and generally made with standard tools in one operation. As the space occupied by the machine loop is shortened, the transition radius is reduced and an appreciable stress concentration occurs. This contributes greatly to shortened spring life and premature failure.

Often the spring is one of the last parts designed in an assembly. This means there is often limited geometry and high expectations of part life [3]. Most tension spring failures occur at the hook as the design of the end hook impacts the stress concentration. Fig.1 indicates the part of tension spring and spring design. Often stresses are higher in the spring ends than in the spring body. Hook stresses can be reduced by using forming radii, not to exceed one-half the I.D. and by reducing the end coil diameter relative to the body coils. The hook stress in torsion should not exceed 40-45 percent of tensile strength, while hook stress in bending should not exceed 75% of tensile strength.

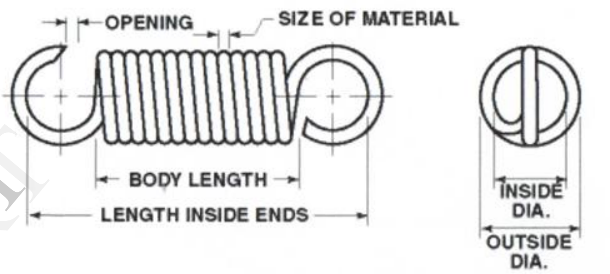

Fig. 1 Tension spring design

Earlier failure analysis reports indicated the criticality of the hook design. A typical raw material defect is the existence of a foreign material inside the steel, such as non-metallic inclusions [4]. Surface defects, tool marks and other stress concentrations were found to be the main source of the failure of springs.

In the present studies, detailed metallurgical investigations carried out on the fractured spring samples, which included visual examination, optical microscopy and scanning electron microscopy. Fracture characteristics of a tension spring are obtained by the observations and the reasons why the tension springs fracture are concluded.

II. DESCRIPTION OF THE FAILURE

The customer returned the fractured tension spring samples after premature failure during assembly. Total three (03) helical tension springs were reported failed prematurely during assembly on same day. Those were failed into two parts, preferably separated from the hook and main body of the spring. Springs are received for the further investigation. Nothing unusual occurred on the day of the failure. This particular spring hook was manufactured by simply bending the last coil outward by 45 degrees.

As per technical drawing specifications supplied by the supplier, these springs suppose to be produced by cold coil forming process from cold drawn and heat-treated patented unalloyed wires of 2.8 mm wire diameter, Gr. III as per IS 4454 Part I.

III. EXPERIMENTAL PROCEDURE

There were total three springs fractured, each into two parts. The wire diameter is measured and found to be as per the specification and also confirms to the Gr.III. Fig. 2 shows the fracture appearance of one spring with a wire diameter 2.8 mm. The upper and lower portions of the failed springs are analyzed separately.

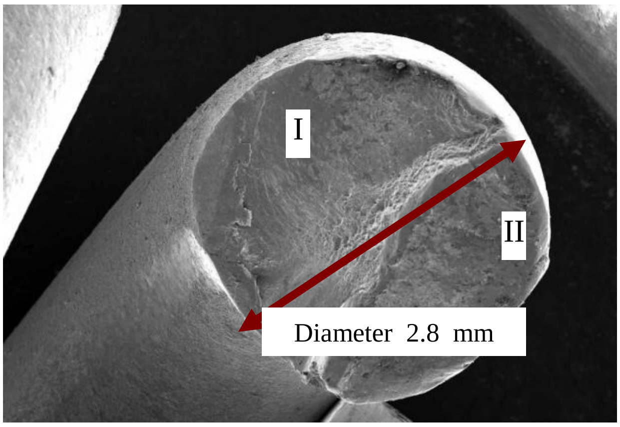

Fig. 2 Appearance of spring fracture, Region I and II and diameter of the helical tension spring

A. *Visual examination*

Visual examination of the spring samples under the stereoscopic microscope at 20X magnification revealed a brittle surface. In all the three spring samples fracture occurs at the ends. The plane of fracture is from the maximum bending location. Also, the broken portions did not show any perceptible deformation in the region of cracking. Macroscopic investigation of normal spring supplied by the supplier doesn't reveal any surface abnormality and confirms to specification.

B. *Optical microscopy*

Microscopic investigation does not reveal any abnormality in the microstructure. It shows ferrite and pearlite phase typical of a low carbon unalloyed patented spring steel.

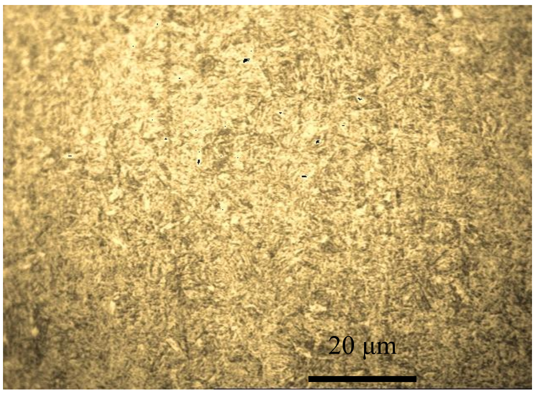

Fig. 3 Optical microstructure of low carbon unalloyed helical tension spring wire

C. *Fracture Observation*

The fractures occurring in the tension spring are basically consistent with those opened artificially along the circumferential cracks. The fracture consists of two areas. Area I is even fracture, near the spring inner surface, while Area II is quite rough and has large height difference, called slanted fracture as can be seen from the SEM images no. 4, 5, and 6. Area I of the fractures accounts for about 65% of the spring cross section.

It indicates shear marks at different locations of upper portion of failed spring [5].

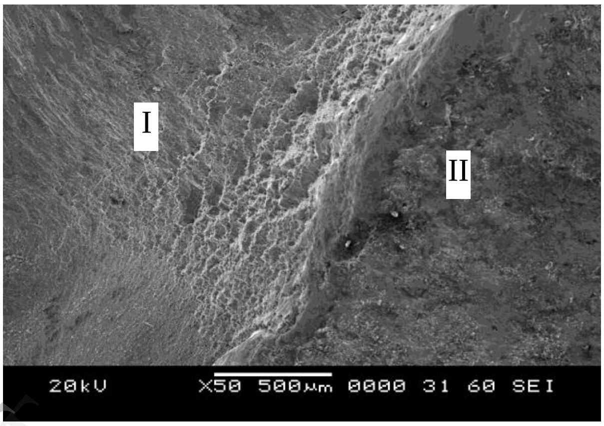

Fig. 4 Appearance of the helical tension spring fracture at X50

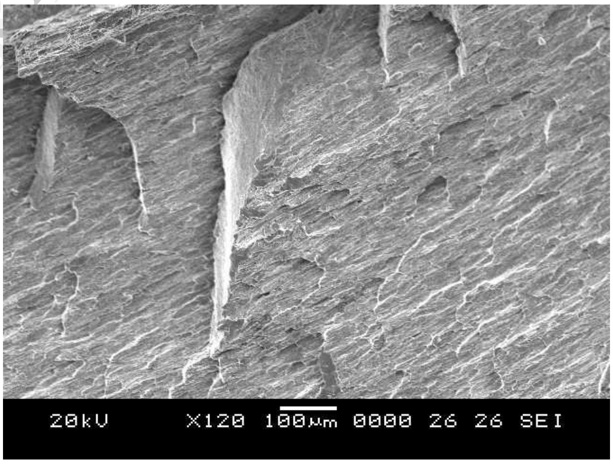

Fig. 5 Appearance of the helical tension spring fracture in area I

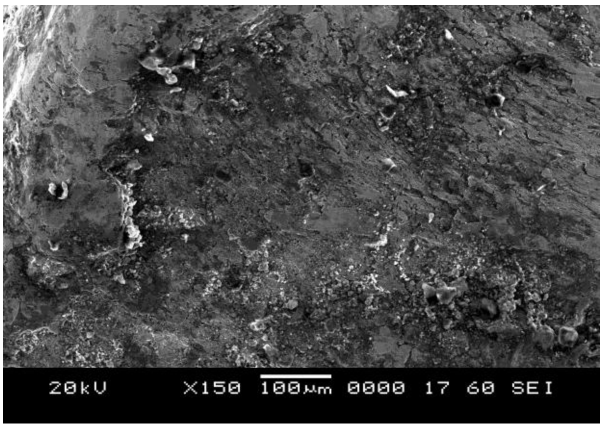

Fig. 6 Appearance of the helical tension spring fracture in area II

D. Scanning electron microscopy

Observation of the helical tension spring is conducted by scanning electron microscopy (SEM). A series of SEM images of upper and lower part of the tension spring were taken. Fig. no 7 and 8 shows the full morphology of upper and lower fractured surface of a tension spring, respectively. Very little indication of ductile behavior during failure as revealed from its SEM appearance as indicated in Fig. no. 7 and 8.

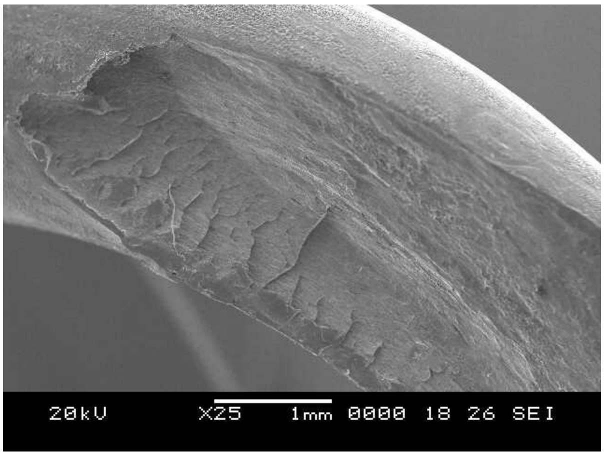

Fig. 7 Fracture zone of the helical tension spring (Upper fractured portion/Hook side)

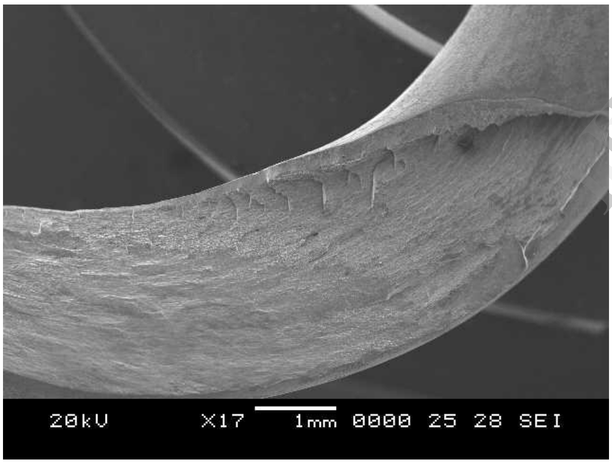

Fig. 8 Fracture zone of the helical tension spring (Lower fractured portion)

Fig. nos. 9 and 10 shows surface irregularities such as surface cracks, pits etc. at 70X magnification of upper and lower portion of the tension spring, respectively. After analyzing SEM images nos. 9 and 10, presence of outer surface crack are suggestive indications for the possible location for the start of failure.

The suggestive indications are confirmed after analyzing SEM images nos. 11, 12, and 13 of the upper fractured surface of spring. A portion marked on the SEM image no. 11 is magnified and analyzed at higher magnification X140 and X350 gives a clear indication of the presence of surface crack of about 100-150 micron in depth from outer surface which is responsible for decreasing the effective cross sectional area of the steel wire.

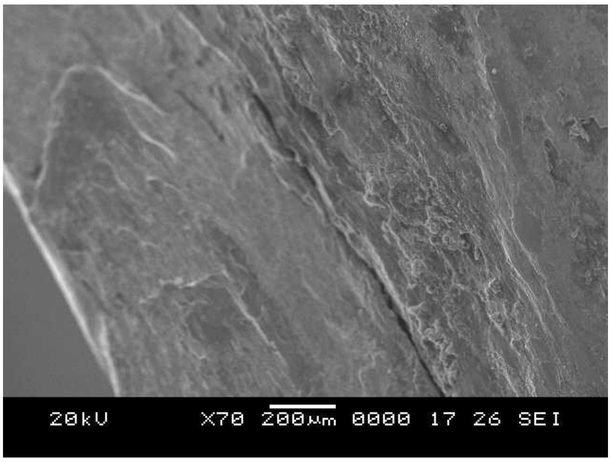

Fig. 9 Surface irregularities on the outer surface of the helical tension spring (Upper fractured portion/Hook side)

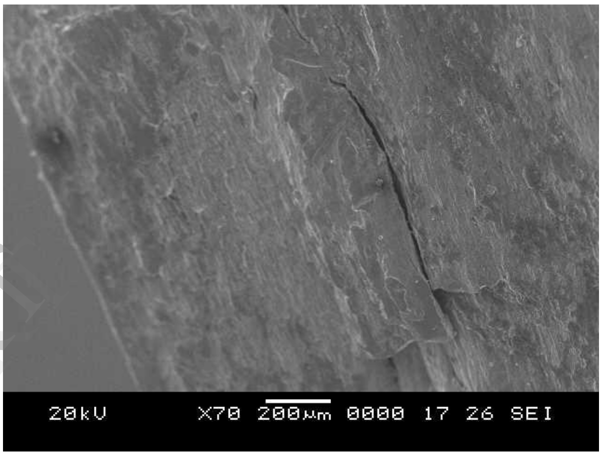

Fig. 10 Surface cracks on the outer surface of the helical tension spring near the fractured end (Lower fractured portion)

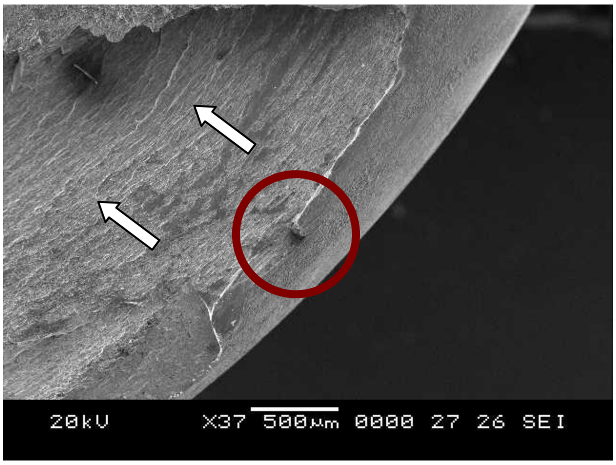

Fig. 11 Fracture zone of the helical tension spring and direction of crack propagation The red marked area is further magnified in SEM images 12 and 13 (Upper fractured portion/Hook side)

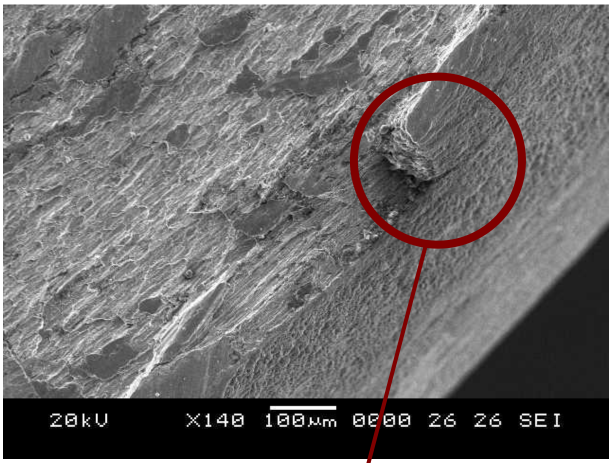

Fig. 12 Fracture zone of the helical tension spring (Upper fractured portion/Hook side)

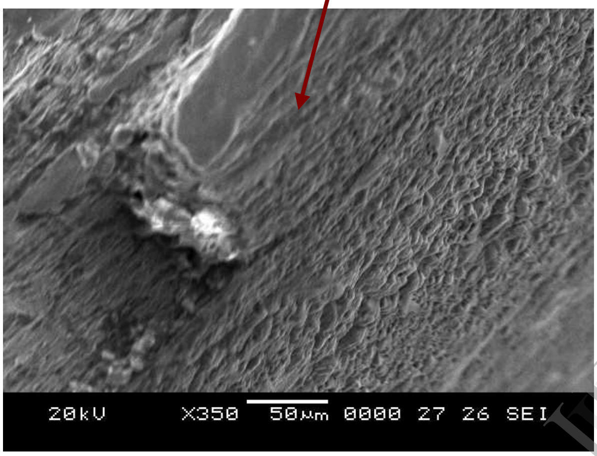

Fig. 13 Crack Morphology in the helical tension spring at X350 (Upper fractured portion/Hook side)

IV. DISCUSSIONS

It can be seen from the visual observations that the tension spring fail from the hook portion. The plane of fracture is from the maximum bending location. Surface irregularities such as pits and surface cracks are present on the surfaces which are responsible for increasing the stress concentration sites. It can be seen in SEM images 11 to 13 that crack originated from the surface and travels inside. The depth of the crack is about 100-150 micron which reduces the effective cross sectional area of the spring, fig.14.

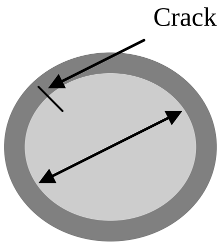

Fig. 14 Effect of presence of surface crack on cross section of the helical tension spring

The appearance of the fracture surface also changes from the surface to the core of the spring. The Material fails from a bending location where maximum tensile stresses are expected to occur which subsequently exceeds the fractured strength of material during assembly.

V. CONCLUSIONS AND RECOMMENDATIONS

(1) From the above observations we can conclude that the presence of surface irregularities and presence of inclusions are the potential sites for the crack initiation and subsequent failure.

(2) It is a shear type of failure originated in the bending region where tensile stress generated exceeds the fractured strength of material.

(3) Spring fails from a location of maximum bending stress which may have subsequently exceeded the fractured strength of material during assembly.

Following precautions can minimize the chances of premature failure- 1. Stress reliving operations will minimize the failure. 2. Increasing stress reliving time will help in reducing the stress level and subsequent failure. 3. The elimination of above crack pone sites leads decrease in the failure in future. 4. Reducing surface irregularities will decrease the chances of failures.

[1] K.V. Sudhakar, “Failure analysis of an automobile valve spring”, *Engineering Failure Analysis*, 8,2001, pp.513–520.

[2] T.S. Eyre, “Design of Helical Coil Compression Spring”, *International Journal of Engineering Research and Applications*, 2,6,Nov-Dec2012 pp. 513–522.

[3] Doug Hornbach,“Optimization of spring performance through understanding and application of residual stress”, Spring Industry Technical Symoposium, 1999 pp. 111–119.

[4] Y.Prawoto, M.Ikeda, S.K.Manville, A.Nishikawa, “Design and failure modes of automotive suspension springs”, Engineering Failure Analysis, 15 (8) 2008;pp.1155–1174.

[5] HOU Weiguo, ZHANG Weigang, LIU Xiao, “Failure Analysis of Aviation Torsional Springs”, Engineering Failure Analysis, 15 (8) 2008;pp.1155–1174.