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Bending Behavior of Cracked Spring Steel Under Varied Material Condition

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***Abstract*: Spring is a critical and prominent piece of material in an automotive. During the service it has to function in several typical environmental conditions. Also, a wide variety of loads will come on the spring during functioning. Because of its exotic properties, the spring steel is used as the spring material. Due to continuous operation and the influence of environmental effects, wide variety of flaws in different orientations will induced in the spring. Under such circumstances the prediction of the useful life of the spring with the pre-existing flaws, is quite a challenging task. It is well known that the springs a highly susceptible to the bending loads. In the present experimental analysis, the influence of the flaw orientation on the bending behavior has been investigated. The three-point bending experimentation was carried out on computerized universal testing machine, according to the ASTM standards. Carburized with a v-notch at the one of the edge along the thickness and the specimen will be loaded in the width direction specimen is stronger. Normal condition with a v-notch at the two of the edges along the thickness and a v-notch at the one of edge along width and the specimen will be loaded in the thickness direction specimens is weaker. Coated then heat treated with a v-notch at the one of the edge along the thickness and the specimen will be loaded in the width direction specimen can take maximum load compare to coated with a v-notch at the one of the edge along the thickness and the specimen will be loaded in the width direction specimen.**

***Keywords*: Spring Steel, Corner Crack, Bending Behavior, Multi-layer Coated, Carburized, Impact Energy.**

1. Introduction

Increasing competition and innovations in automobile sector tends to modify the existing products or replacing old products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. More efforts are taken in order to increase the comfort of user [1]. Spring steel is used widely in the motor vehicle industry and many general engineering applications. Suitable for applications that require high tensile strength and toughness. Typical applications include crankshafts, steering knuckles, gears, spindles and pumps. During the last two decades, considerable efforts have been made in the development of high-performance spring steels to meet the needs for the weight and cost savings in the automotive industry [2]. The highest quality level of spring steel requires the appropriate fine grained microstructure, without segregations, large inclusions and surface defects [3].

A manufacturer of spring steels must provide a technical steel description in their production program. Namely, the durability of the springs is limited by plastic deformation, fatigue and fracturing. From this point of view, the use of spring steel with the following properties is recommended: high ductility and toughness at operating, good hardenability that provides the required mechanical properties, even at the maximum dimensions [4].

Springs are based on Hooke's law which states that "deflection is proportional to load". They are fundamental mechanical component that form the basis of many mechanical systems. A spring is defined as an elastic body, whose function is to distort when loaded and to recover to its original shape when the load is removed [5]. Suspension springs of ground vehicles are subject to high static and cyclic loads [6]. The leaf springs bend and slide on each other allowing suspension movement [7]. Parabolic springs are subjected to cyclic compression and tension load when the heavy vehicle runs on the road. In industry, only manufacturer manages to test the fatigue life of these springs using constant amplitude loading. This is because non constant amplitude proportional loading fatigue test is time consuming and adds more cost [8]. Valve springs are subjected to dynamic and impact loading during the valve opening and closing events [9].

A large variety of springs is made from one of several grades of carbon or alloy steels and is used in different components for the purpose of absorbing loads. Helical coil springs are generally manufactured from rods, which are coiled in the form of helix. Fatigue is the most common mechanism of failure in springs. Fatigue fracture generally initiates at the surface and the resolved tensile stresses cause further growth of the developed cracks and lead to premature failure of the springs. Other common causes of failures include overstressing, design deficiencies, material defects, processing errors and unusual operating conditions. In certain cases more than one cause can contribute to failure [10]. Helical compression springs are made of oil-hardened and tempered spring steel wire, stainless spring steel wire and patented-drawn spring steel wire. After drawing, the wire is coiled in a spring coiling machine. The residual stress developed in the spring wire during the cold shaping then has to be relieved by a tempering stage as the next step in manufacture [11]. The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system [12].

Cracks often develop in the corners of a structural member due to high stress concentration factor in those areas. If one can calculate the rate of crack growth, an engineer can schedule inspection accordingly and repair or replace the part before failure happens. Moreover, being able to predict the path of a crack helps a designer to incorporate adequate geometric tolerance in structural design to increase the part life. While producing durable, reliable and safe structures are the goals of every aerospace component manufacturer, there are technical challenges that are not easy to be solved [13].

The level of performance of components in service depends on several factors such as inherent properties of materials, load or stress system, environment and maintenance. The reason for failure in engineering component can be attributed to design deficiencies, poor selection of materials, manufacturing defects, exceeding design limits and overloading, inadequate maintenance etc. Therefore, engineer should anticipate and plan for possible failure prevention in advance [14].

Oil quench and temper process offer enormous advantages to the heavy duty spring production because its treatment results can reveal optimum combination of toughness and ductility, and also improves fatigue life. The material used was a commercial grade of heavy duty spring steel. In the hardening process, selective alloy was heated up to its austenitizing temperature, 870°C, and quenched in oil. After that, tempering was done at 450°C increased by 50°C to 550°C for each tempering time (1 hr, 2 hr, and 3 hr) interval. The experimental results revealed that mechanical properties of selective alloy were significantly changed by temper treatment. By increasing the tempering time and temperature, hardness and ultimate tensile strength are gradually decreased and ductility was improved. Moreover, rather interesting condition is observed in elastic properties and endurance limit at 450°C and one-hour tempering condition, and this state is the optimum condition for spring production [15].

Coating or paint layers are often applied to the surfaces of polymeric, metallic, or composite structures. Coating layers are used for many reasons such as for protection, for decoration, for a barrier, or to provide unique surface properties. If the coating fails, it may cease to provide its function and the system has therefore failed. Failure here is not in the sense of structural failure, but rather failure of the intended purpose of the coating. For example, a cracked paint layer ceases to provide an attractive surface appearance. Coatings are not used for their loading bearing contributions. As a result, when a coated structure is subjected to loads, cracks typically develop within the coating before the substrate fails. Coating cracks usually initiate and rapidly propagate throughout the entire thickness of the coating. When the crack reaches the coating/substrate interface, it has several alternative failure modes [16]. Coatings are frequently used to increase the resistance of substrate against corrosion, wear, fatigue or to serve as protection for metallic components at high temperatures, but they are not used for their loading bearing contribution. Two extreme cases are: soft compliant coating on a stiff substrate, and hard brittle coating on a compliant structure. Principal failure modes of coatings are cracking and delamination [17].

Surface engineering may be defined as the design of engineering to improve their performance in service. This can be achieved by surface treatments, which can provide combinations of surface and bulk properties unobtainable in a single material. A ceramic on a metal, for example, can give extreme hardness at the surface, while maintaining acceptable fracture toughness throughout the section. The surface treatments may involve coating, chemical modification or physical processing. Coating processes, such as electroplating processes, produce a discrete layer of a new material with a sharp interface at the substrate. Chemical modification techniques, such as nitriding, provide a diffuse layer of a foreign element with no definitive interface. Physical processes, such as grit blasting, change the surface profile but not the chemical composition [18].

2. Material and Experimentation

The experimentation has been carried out on spring steel material EN-47. The specimen preparation and experimentation were carried out according to ASTM standards. The mechanical properties of EN-47 spring steel material has a hardness of 99 HRC, yield strength of 640Mpa, density of 7.85g/cc and modulus of elasticity 205Gpa.

A. *Material*

EN47 Spring Steel is chromium vanadium type spring steel. Spring Steel is used widely in the motor vehicle industry and many general engineering applications. Suitable for applications that require high tensile strength and toughness. Typical applications include crankshafts, steering knuckles, gears, spindles and pumps.

B. *Material Conditions*

Conditions selected in this project are,

a) Normal condition
b) Coated condition
c) Coated then heat treated condition
d) Carburized condition

C. *Specimens Preparation*

In this project, material used is EN 47 Spring Steel. Specimens are prepared according to the ASTM Standard. Three-point bending test is conducted. Three point bending test

Table 1
Chemical composition of EN 47 Spring Steel

Components	C	Mn	Cr	V	Si	P	S
Wt%	0.45 to 0.55	0.50 to 0.80	0.80 to 1.20	0.15% min	0.50% max	0.06% max	0.06% max

is conducted for specimen without v-notch and the specimen will be loaded in the thickness direction (NBT specimen), specimen with a v-notch at the one of the edge along the width and the specimen will be loaded in the thickness direction (SENWT specimen), specimen with a v-notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction (SENTT specimen), specimen with a v-notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction (DENTT specimen), specimen with a v-notch at the two of the edges along the thickness and a v-notch at the one of edge along width and the specimen will be loaded in the thickness direction (TENTWT specimen) and specimen with a v-notch at the one of the edge along the thickness and the specimen will be loaded in the width direction (SENTW specimen).

Conditions selected in this project are normal condition, coated, coated then heat treated and carburized. In coated condition, specimens are multi-layer Coated (two layers) by electrolytic coating process. One layer is Nickel of 10µm and is followed by another layer is Chromium 5µm. In coated then heat treated condition, coated specimens are heat treated to temperature 125^0C for 45 minutes. Carburizing is a heat treatment process of adding carbon to the surface. Carburizing is done by exposing the normal condition specimens to a carbon rich atmosphere at 900^0C temperature and allows diffusion to transfer the carbon atoms into specimen up to the depth of 1mm.


Fig. 1. NBT specimen.


Fig. 2. SENWT specimen.


Fig. 3. SENTT specimen.


Fig. 4. DENTT specimen.


Fig. 5. TENTWT specimen.


Fig. 6. SENTW specimen.

D. Experimentation

The experimentations are carried out in order to investigate of bending behavior. Three-point bending test Procedure is as follows.

Prepare the specimen according to ASTM Standard. Place the specimen on the two rollers, which is on the bottom table. Start the UTM and apply the load gradually (By closing LCV, open RCV slowly). Dead weight of the piston should be nullified. Then press start button and apply the load gradually. Note down the load and the displacement readings on digital display at specific increment of load. The test is continued until the specimen get fractured, note down the maximum load. Plot the graph of load vs. displacement. UTM is connected with computer, so we can also get the load vs. displacement data and graph by using the FIE Software.


Fig. 7. Placement of the NBT specimen on the rollers.


Fig. 8. Placement of the SENWT specimen on the rollers.


Fig. 9. Placement of the SENTT specimen on the rollers.

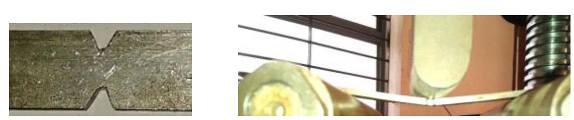
Fig. 10. Placement of the DENTT specimen on the rollers.

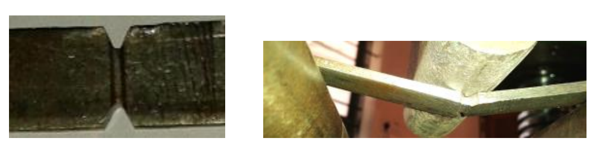
Fig. 11. Placement of the TENTWT specimen on the rollers.

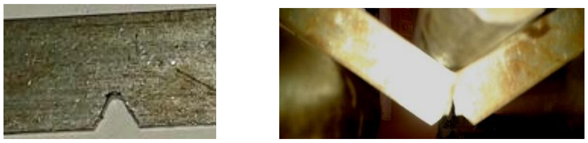

Fig. 12. Placement of the SENTW specimen on the rollers

3. Results and Discussions

The results of the experimentation have been summarized and discussed as follows.

A. Effect of notch orientation on Bending Strength

Maximum load that can take from the normal condition specimen without notch and the specimen will be loaded in the thickness direction (NBT specimen) is 0.7 KN and displacement of the specimen at maximum load is 10.78 mm. Coated NBT specimen can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 15.72 mm. Maximum load that can take from the coated then heat treated NBT specimen is 0.5 KN and displacement of the specimen at maximum load is 12.86 mm. Carburized NBT specimen can take maximum load of 1.0 KN and displacement of the specimen at maximum load is 12.52 mm as shown in Fig. 13.

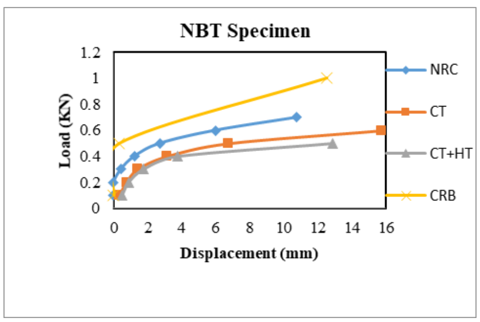

Fig. 13. Load vs. Displacement graph of NBT specimen.

Normal condition NBT specimen has less displacement at maximum load that can take from the specimen compared to other condition specimens. Hence it is stiffer compared to other condition specimens. Carburized NBT specimen can take maximum load compare to other conditions. Hence it is stronger compared to other condition specimens. Coated NBT specimen is flexible compared to other condition specimens because it has more displacement at maximum load that can take from the specimen compared to other condition specimens. Coated then heat treated NBT specimen will take less load compare to other condition specimens. Hence it is weaker compared to other condition specimens as shown in Fig. 13. Coated layer peel off is more in coated then heat treated NBT specimen compared to coated NBT specimen. Bending in coated NBT specimen is more compared to other condition NBT specimens.

Normal condition specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction (SENWT specimen) can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 9.26 mm. Coated SENWT specimen can take maximum load of 0.5 KN and displacement of the specimen at maximum load is 16.53 mm. Maximum load that can take from the coated then heat treated SENWT specimen is 0.6 KN and displacement of the specimen at maximum load is 10.73 mm. Carburized SENWT specimen can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 5.62 mm as shown in Fig. 14.

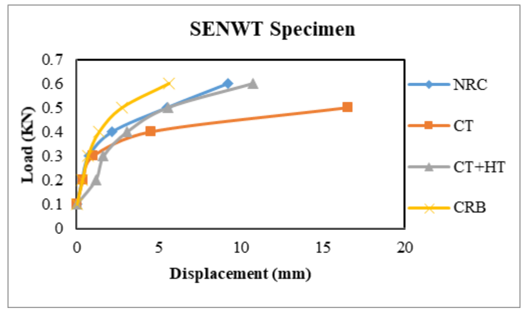

Fig. 14. Load vs. Displacement graph of SENWT specimen.

Carburized SENWT specimen has less displacement at maximum load that can take from the specimen compared to other condition specimens. Hence it is stiffer compared to other condition specimens.

Carburized SENWT specimen can take maximum load with minimum displacement compare to other condition specimens. Hence it is stronger compared to other condition specimens. Coated SENWT specimen is more flexible compared to other condition specimens because it has more displacement at maximum load that can take from the specimen compared to other condition specimens. Also coated SENWT specimen will take less load compare to other condition specimens. Hence it is weaker compared to other condition specimens as shown in Fig. 14. Coated layer peel off is more near the notch in coated then heat treated SENWT specimen compared to coated SENWT specimen. Bending at the notch in coated SENWT specimen is more compared to other condition SENWT specimens. Notch enlargement during bending is more in coated SENWT specimen compared to other condition SENWT specimens.

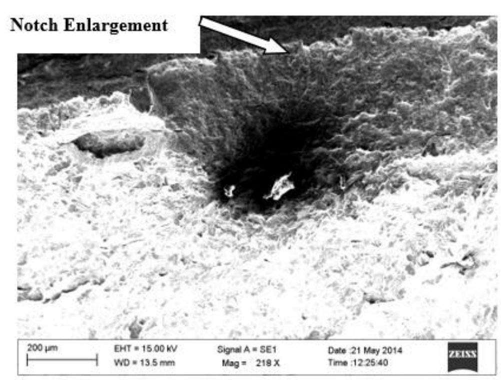

Fig. 15. SEM image of notch enlargement in carburized SENWT specimen.

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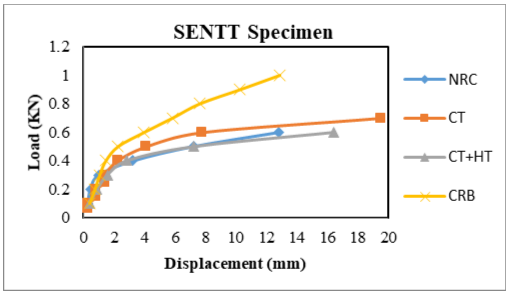

Fig. 16. Load vs. Displacement graph of SENTT specimen.

Maximum load that can take from the normal condition specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction (SENTT specimen) is 0.6 KN and displacement of the specimen at maximum load is 12.82 mm. Coated SENTT specimen can take maximum load of 0.7 KN and displacement of the specimen at maximum load is 19.52 mm. Maximum load that can take from the coated then heat treated SENTT specimen is 0.6 KN and displacement of the specimen at maximum load is 16.45 mm. Carburized SENTT specimen can take maximum load of 1.0 KN and displacement of the specimen at maximum load is 12.88 mm. Normal condition SENTT specimen has less displacement at maximum load that can take from the specimen compared to other condition specimens. Hence it is stiffer compared to other condition specimens. Carburized SENTT specimen can take maximum load compare to other condition specimens. Hence it is stronger compared to other condition specimens. Coated SENTT specimen is more flexible compared to other condition specimens because it has more displacement at maximum load that can take from the specimen compared to other condition specimens. Coated then heat treated SENTT specimen will take same load with more displacement compare to normal condition specimen, but it will take less load compare to coated and carburized specimen. Hence coated then heat treated SENTT specimen is weaker as shown in Fig. 15. Coated layer peel off is more near the notch in coated then heat treated SENTT specimen compared to coated SENTT specimen. Bending at the notch in coated SENTT specimen is more compared to other condition SENTT specimens. Notch enlargement during bending is more in coated SENTT specimen compared to other condition SENTT specimens.

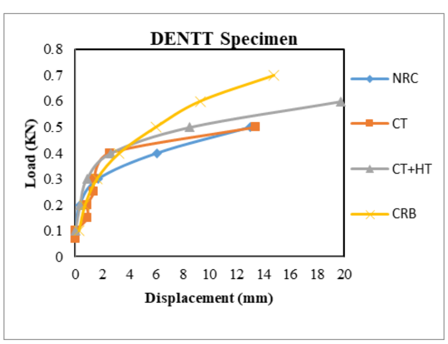

Fig. 17. Load vs. Displacement graph of DENTT specimen.

Normal condition specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction (DENTT specimen) can take maximum load of 0.5 KN and displacement of the specimen at maximum load is 13.01 mm. Coated DENTT specimen can take maximum load of 0.5 KN and displacement of the specimen at maximum load is 13.46 mm. Maximum load that can take from the coated then heat treated DENTT specimen is 0.6 KN and displacement of the specimen at maximum load is 19.77 mm. Carburized DENTT specimen can take maximum load of 0.7 KN and displacement of the specimen at maximum load is 14.81 mm. Normal condition DENTT specimen has less displacement at maximum load that can take from the specimen compared to other condition specimens. Hence it is stiffer compared to other condition specimens. Carburized DENTT specimen can take maximum load compare to other conditions. Hence it is stronger compared to other condition specimens. Coated then heat treated DENTT specimen is more flexible compared to other condition specimens because it has more displacement at maximum load that can take from the specimen compared to other condition specimens. Coated DENTT specimen will take same load with more displacement compare to normal condition specimen, but it will take less load compare to coated then heat treated and carburized specimen. Hence coated DENTT specimen is weaker as shown in Fig. 17. Coated layer peel off is more near the notch in coated DENTT specimen compared to coated then heat treated DENTT specimen. Bending at the notch in coated then heat treated DENTT specimen is more compared to other condition DENTT specimen. Notch enlargement during bending is more in normal condition DENTT specimen compared to other condition DENTT specimens.

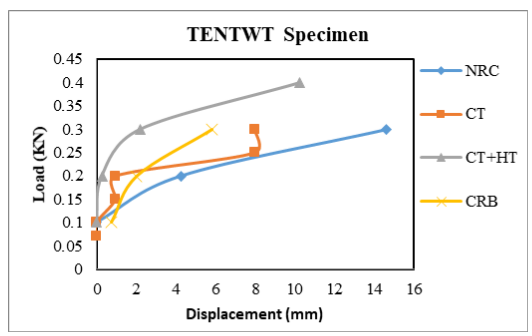

Fig. 18. Load vs. Displacement graph of TENTWT specimen.

Maximum load that can take from the normal condition specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction (TENTWT specimen) is 0.3 KN and displacement of the specimen at maximum load is 14.63 mm. Coated TENTWT specimen can take maximum load of 0.3 KN and displacement of the specimen at maximum load is 7.96 mm. Maximum load that can take from the coated then heat treated TENTWT specimen is 0.4 KN and displacement of the specimen at maximum load is

10.23 mm. Carburized TENTWT specimen can take maximum load of 0.3 KN and displacement of the specimen at maximum load is 5.82 mm. Carburized TENTWT specimen has less displacement at maximum load that can take from the specimen compared to other condition specimens. Hence it is stiffer compared to other condition specimens. Coated then heat treated TENTWT specimen can take maximum load compare to other condition specimens. Hence it is stronger compared to other condition specimens. Normal condition TENTWT specimen is more flexible compared to other condition specimens because it has more displacement at maximum load that can take from the specimen compared to other condition specimens. Normal condition TENTWT specimen will take same load with more displacement compare to coated and carburized specimen, but it will take less load compare to coated then heat treated specimen. Hence normal condition TENTWT specimen is weaker compared to coated, coated then heat treated, carburized specimen as shown in Fig. 18. Coated layer peel off is more near the notch in coated then heat treated TENTWT specimen compared to coated TENTWT specimen. Bending at the notch in normal condition TENTWT specimen is more compared to other condition TENTWT specimens. Notch enlargement during bending is more in normal condition TENTWT specimen compared to other condition TENTWT specimen.

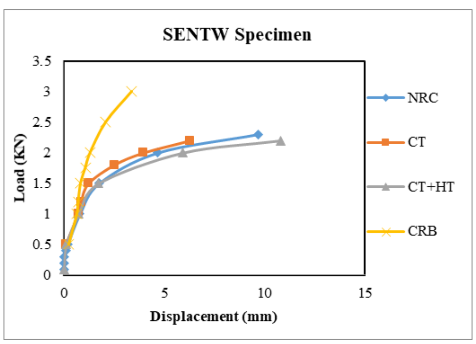

Fig. 19. Load vs. Displacement graph of SENTW specimen.

Normal condition specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction (SENTW specimen) can take maximum load of 2.3 KN and displacement of the specimen at maximum load is 9.68 mm. Coated SENTW specimen can take maximum load of 2.4 KN and displacement of the specimen at maximum load is 10.14 mm. Maximum load that can take from the coated then heat treated SENTW is 2.2 KN and displacement of the specimen at maximum load is 10.8 mm. Carburized SENTW specimen can take maximum load of 3.2 KN and displacement of the specimen at maximum load is 4.13 mm. Carburized SENTW specimen has less displacement at maximum load that can take from the specimen compared to other condition specimens. Hence it is stiffer compared to other condition specimens. Carburized SENTW specimen can take maximum load compare to other condition specimens. Hence it is stronger compared to other condition specimens. Coated then heat treated SENTW specimen is more flexible compared to other condition specimens because it has more displacement at maximum load that can take from the specimen compared to other condition specimens. Coated then heat treated SENTW specimen will take same load with more displacement compare to coated specimen, but it will take less load compare to normal condition and carburized specimen. Hence coated then heat treated SENTW specimen is weaker compared to normal condition, coated and carburized specimen as shown in Fig. 19.

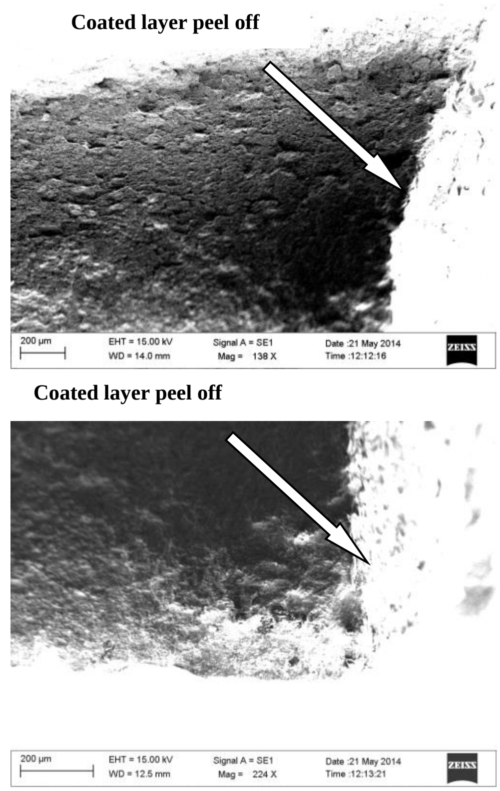

Fig. 20. SEM image of coated layer peel off near the notch of coated SENTW specimens

Coated layer peel off is more near the notch in coated then heat treated SENTW specimen compared to coated SENTW specimen. Bending at the notch in coated then heat treated SENTW specimen is more compared to other condition SENTW specimen. Notch enlargement during bending is more in normal condition SENTW specimen compared to other condition SENTW specimens.

B. Effect of coating on Bending Strength

Coated specimen without notch and the specimen will be loaded in the thickness direction (NBT specimen) can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 15.72 mm. Coated NBT specimen is more flexible compared to other condition NBT specimens because it has more displacement at maximum load that can take from the specimen compared to other condition NBT specimens. Coated NBT specimen will take more load compare to coated then heat treated NBT specimen, but it will take less load compare to normal condition and carburized NBT specimen as shown in Fig. 13.

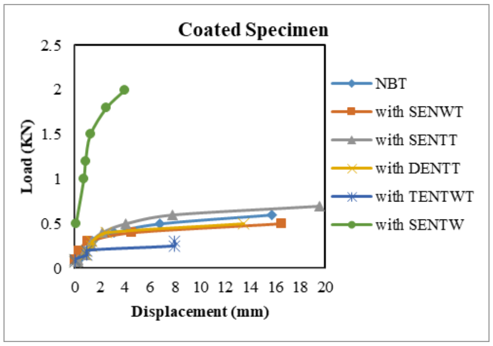

Fig. 21. Load vs. Displacement graph of specimens with coated condition.

Fig. 22. Three-point bending test of coated SENTW specimen

Fig. 23. Fractured surface of coated SENTW specimen due to three-point bending.

Coated specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction (SENWT specimen) can take maximum load of 0.5 KN and displacement of the specimen at maximum load is 16.53 mm. Coated SENWT specimen is more flexible compared to other condition SENWT specimens because it has more displacement at maximum load that can take from the specimen compared to other condition SENWT specimens. Coated SENWT specimen will take less load compare to other condition SENWT specimens as shown in Fig. 14.

Coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction (SENTT specimen) can take maximum load of 0.7 KN and displacement of the specimen at maximum load is 19.52 mm. Coated SENTT specimen is more flexible compared to other condition SENTT specimens because it has more displacement at maximum load that can take from the specimen compared to other condition SENTT specimens. Coated SENTT specimen will take more load compare to normal condition and coated then heat treated SENTT specimen, but it will take less load compare to carburized SENTT specimen as shown in Fig. 16.

Coated specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction (DENTT specimen) can take maximum load of 0.5 KN and displacement of the specimen at maximum load is 13.46 mm. Coated DENTT specimen has more displacement at maximum load that can take from the specimen compared to normal condition DENTT specimen, but it has less displacement compared to coated then heat treated and carburized DENTT specimen. Coated DENTT specimen will take same load with more displacement compare to normal condition DENTT specimen, but it will take less load compare to coated then heat treated and carburized DENTT specimen as shown in Fig. 17.

Coated specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction (TENTWT specimen) can take maximum load of 0.3 KN and displacement of the specimen at maximum load is 7.96 mm. Coated TENTWT specimen has more displacement at maximum load that can take from the specimen compared to carburized TENTWT specimen, but it has less displacement compared to normal condition and coated then heat treated TENTWT specimen. Coated TENTWT specimen will take same load with more displacement compare to carburized TENTWT specimen and it will take same load with less displacement compare to normal condition TENTWT specimen, but it will take less load compare to coated then heat treated TENTWT specimen as shown in Fig. 18.

Coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction (SENTW specimen) can take maximum load of 2.4 KN and displacement of the specimen at maximum load is 10.14 mm. Coated SENTW specimen has more displacement at maximum load that can take from the specimen compared to carburized SENTW specimen, but it has less displacement compared to normal condition and coated then heat treated SENTW specimens. Coated SENTW specimen will take same load with less displacement compare to coated then heat treated SENTW specimen, but it will take less load compare to normal condition and carburized SENTW specimen as shown in Fig. 19.

Coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction has less displacement at maximum load that can take from the specimen compared to other types of specimen. Hence it is stiffer compared to other types of specimen. And also it can take maximum load compared to other types of specimen. Hence it is stronger compared to other types of specimen. Coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction is flexible compared to other types of specimen because it has more displacement at maximum load that can take from the specimen compared to other types of specimen. Coated specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction will take less load compare to other types specimen. Hence it is weaker compared to other types specimen as shown in Fig. 21.

Coated layer peel off is more near the notch in coated specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction compared to coated then heat treated specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction. Bending in coated specimen without notch and the specimen will be loaded in the thickness direction is more compared to other condition specimen without notch and the specimen will be loaded in the thickness direction. Bending at the notch in coated specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction is more compared to other condition specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction and bending at the notch in coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction is more compared to other condition specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction. Notch enlargement during bending is more in coated specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction compared to other condition specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction and notch enlargement during bending is more in coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction compared to other condition specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction.

C. Effect of coating then heat treatment on Bending Strength Fractured

Coated then heat treated specimen without notch and the specimen will be loaded in the thickness direction (NBT specimen) can take maximum load of 0.5 KN and displacement of the specimen at maximum load is 12.86mm. Coated then heat treated NBT specimen has more displacement at maximum load that can take from the specimen compared to normal condition and carburized NBT specimens, but it has less displacement compared to coated NBT specimen. Coated then heat treated NBT specimen will take less load compare to other condition NBT specimens as shown in Fig. 13.

Coated then heat treated specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction (SENWT specimen) can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 10.73 mm. Coated then heat treated SENWT specimen has more displacement at maximum load that can take from the specimen compared to normal condition and carburized SENWT specimen, but it has less displacement compared to coated SENWT specimen. Coated then heat treated SENWT specimen will take same load with more displacement compare to normal condition and carburized SENWT specimen, but it will take more load compare to coated SENWT specimen as shown in Fig. 14.

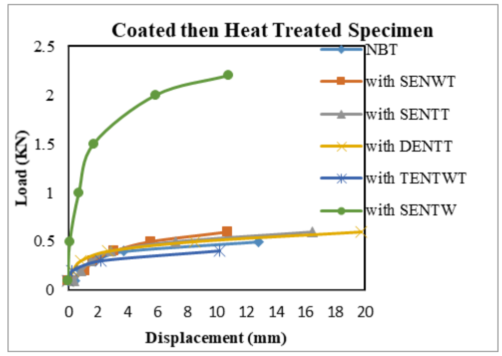

Fig. 24. Load vs. Displacement graph of specimens with coated then heat treated condition.

Fig. 25. Three-point bending test coated then heat treated NBT specimen.

Coated then heat treated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction (SENTT specimen) can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 16.45 mm. Coated then heat treated SENTT specimen has more displacement at maximum load that can take from the specimen compared to normal condition and carburized SENTT specimens, but it has less displacement compared to coated SENTT specimen. Coated then heat treated SENTT specimen will take same load with more displacement compare to normal condition SENTT specimen, but it will take less load compare to coated and carburized SENTT specimens as shown in Fig. 16.

Coated then heat treated specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction (DENTT specimen) can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 19.77 mm. Coated then heat treated DENTT specimen has more displacement at maximum load that can take from the specimen compared to other condition DENTT specimens. Coated then heat treated DENTT specimen will take more load compared to normal condition and coated DENTT specimen, but it will take less load compare to carburized DENTT specimen as shown in Fig. 17.

Coated then heat treated specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction (TENTWT specimen) can take maximum load of 0.4 KN and displacement of the specimen at maximum load is 10.23 mm. Coated then heat treated TENTWT specimen has more displacement at maximum load that can take from the specimen compared to coated and carburized specimen, but it has less displacement compared to normal condition TENTWT specimen. Coated then heat treated TENTWT specimen will take more load compare to other conditions specimens as shown in Fig. 18.

Coated then heat treated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction (SENTW specimen) can take maximum load of 2.2 KN and displacement of the specimen at maximum load is 10.8 mm. Coated then heat treated SENTW specimen has more displacement at maximum load that can take from the specimen compared to other condition SENTW specimens. Coated then heat treated SENTW specimen will take same load with more displacement compare to coated SENTW specimen, but it will take less load compare to normal condition and carburized SENTW specimen as shown in Fig. 19.

Coated then heat treated specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction has less displacement at maximum load that can take from the specimen compared to other types of specimen. Hence it is stiffer compared to other types of specimen. Coated then heat treated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction can take maximum load compare to other types of specimen. Hence it is stronger compared to other types of specimen. Coated then heat treated specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction specimen is flexible compared to other types of specimen because it has more displacement at maximum load that can take by the specimen compared to other types of specimen. Coated then heat treated specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction will take less load compare to other types specimen. Hence it is weaker compared to other types specimen as shown in Fig. 24.

Coated layer peel off is more in coated then heat treated specimen without notch and the specimen will be loaded in the thickness direction compared to coated specimen without notch and the specimen will be loaded in the thickness direction. In coated then heat treated condition, coated layer peel off is more near the notch in specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction compared to coated specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction, in specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction compared to coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction, in specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction compared to coated specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction and in specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction compared to coated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction. Bending at the notch in coated then heat treated specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction is more compared to other condition specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction and bending at the notch in coated then heat treated specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction is more compared to other condition specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction.

D. *Effect of carburizing on Bending Strength*

Carburized specimen without notch and the specimen will be loaded in the thickness direction (NBT specimen) can take maximum load of 1.0 KN and displacement of the specimen at maximum load is 12.52 mm. Carburized NBT specimen has more displacement at maximum load that can take from the specimen compared to normal condition NBT specimen, but it has less displacement compared to coated and coated then heat treated NBT specimen. Carburized NBT specimen can take maximum load compare to other conditions NBT specimens as shown in Fig. 13.

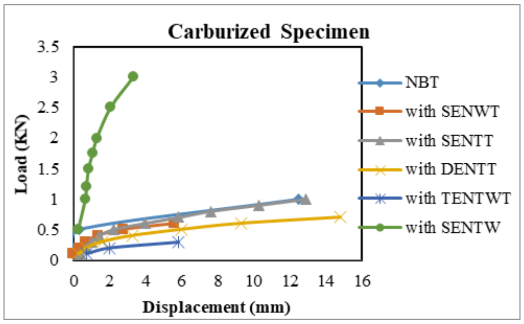

Fig. 26. Load vs. Displacement graph of specimens with carburized condition.

Fig. 27. Three-point bending test carburized SENWT specimen.

Fig. 28. Fractured surface of carburized SENWT specimen due to three-point bending.

Carburized specimen with a notch at the one of the edge along the width and the specimen will be loaded in the thickness direction (SENWT specimen) can take maximum load of 0.6 KN and displacement of the specimen at maximum load is 5.62 mm. Carburized SENWT specimen has less displacement at maximum load that can taken from the specimen compared to other condition SENWT specimens. Carburized SENWT specimen can take same load with minimum displacement compare to normal condition and coated then heat treated SENWT specimen, but it can take more load compare to coated SENWT specimen as shown in Fig. 14.

Carburized specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the thickness direction (SENTT specimen) can take maximum load of 1.0 KN and displacement of the specimen at maximum load is 12.88 mm. Carburized SENTT specimen has more displacement at maximum load that can take from the specimen compared to normal condition SENTT specimen, but it has less displacement compared to coated and coated then heat treated SENTT specimen. Carburized SENTT specimen can take maximum load compare to other condition SENTT specimens as shown in Fig. 16.

Carburized specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction (DENTT specimen) can take maximum load of 0.7 KN and displacement of the specimen at maximum load is 14.81 mm. Carburized DENTT specimen has more displacement at maximum load that can take from the specimen compared to normal condition and coated DENTT specimen, but it has less displacement compared to coated then heat treated DENTT specimen. Carburized DENTT specimen can take maximum load compare to other condition specimens as shown in Fig. 17.

Carburized specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction (TENTWT specimen) can take maximum load of 0.3 KN and displacement of the specimen at maximum load is 5.82 mm. Carburized TENTWT specimen has less displacement at maximum load that can take from the specimen compared to other condition TENTWT specimens. Carburized TENTWT specimen can take same load with less displacement compare to normal condition and coated TENTWT specimen, but it can take less load compare to coated then heat treated TENTWT specimen as shown in Fig. 18.

Carburized specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction (SENTW specimen) can take maximum load of 3.2 KN and displacement of the specimen at maximum load is 4.13 mm. Carburized SENTW specimen has less displacement at maximum load that can take from the specimen compared to other condition SENTW specimens. Carburized SENTW specimen can take maximum load compare to other condition SENTW specimens as shown in Fig. 19.

Carburized specimen with a notch at the one of the edge along the thickness and the specimen will be loaded in the width direction has less displacement at maximum load that can take from the specimen compared to other types of specimen. Hence it is stiffer compared to other types of specimen. And also it can take maximum load compared to other types of specimen. Hence it is stronger compared to other types of specimen. Carburized specimen with a notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction specimen is flexible compared to other types of specimen because it has more displacement at maximum load that can take by the specimen compared to other types of specimen. Carburized specimen with a notch at the two of the edges along the thickness and a notch at the one of edge along width and the specimen will be loaded in the thickness direction will take less load compare to other types specimen. Hence it is weaker compared to other types specimen as shown in Fig. 26.

4. Conclusions

Based on experimental analysis carried out on the spring steel material with different condition, the following conclusions have been drawn.

- Carburized with a v-notch at the one of the edge along the thickness and the specimen will be loaded in the width direction specimen is stronger.
- Normal condition with a v-notch at the two of the edges along the thickness and a v-notch at the one of edge along width and the specimen will be loaded in the thickness direction specimens is weaker.
- Carburized with a v-notch at the one of the edge along the thickness and the specimen will be loaded in the width direction specimen is stiffer.
- Coated then heat treated with a v-notch at the two of the edges along the thickness and the specimen will be loaded in the thickness direction specimen is more flexible.
- Coated layer peel off is more in coated then heat treated without v-notch and the specimen will be loaded in the thickness direction specimen compared to all other specimens and other conditions.
- Coated layer peel off is less near the v-notch in coated with a v-notch at the two of the edges along the thickness and a v-notch at the one of edge along width and the specimen will be loaded in the thickness direction specimen compared to all other v-notched specimens and other conditions.

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