Microstructures of Mild Steel Spring after Heat Treatment.

O.R. Adetunji, Ph.D.*; S.I. Kuye, Ph.D.; and M.J. Alao, B.Eng.

Mechanical Engineering Department, College of Engineering, Federal University of Agriculture, Abeokuta (FUNAAB), PMB 2240, Abeokuta, Ogun State, Nigeria.

E-mail: adetunjior@funaab.edu.ng*

ABSTRACT

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. This study was carried out to investigate the micro structural evolution of mild steel springs after heat treatment. The springs were made from mild steel rod having a diameter of 6 mm. The springs were then subjected to various heat treatment processes which included; annealing, normalizing, hardening and tempering. The heat treated springs were then prepared for micro structural examination by grinding, polishing and etching. The results obtained were compared with that of as received springs. The micro structural analysis indicated that the annealed sample had a structure consisting of pearlite, when compared with the hardened samples which had a high concentration of martensite mixed with ferrite.

(Keywords: annealing, normalizing, hardening, pearlite, martensite, microstructures)

INTRODUCTION

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 (Harris, 2005; Loretta, 2000; Gillespie, 2009; and Sebastian et al., 2000).

Heat treatment of mild steel involves the heating and cooling of a solid metal or alloy in such a way as to obtain desired conditions or properties (James, 2000 and Kadrinm, 1992). The term heat treatment process is in and of itself only a very generic term, it covers all specific methods (George, 2006). Thus emphasis are made on those forms of heat treatment that are most commonly used in the spring industry these are; annealing, normalizing, hardening, and tempering.

Annealing is a generic term denoting a treatment consisting of heating-to, and holding-at a suitable temperature, followed by cooling at suitable rate, used primarily to soften metals. A spring maker may anneal the metal (or purchase it already annealed) so that it can be worked more easily due to the relatively low tensile strength of the material. In the simplest of terms, the material returns to a softened state that allows further cold working (Bartel, 2006).The tensile strength and hardness of steel produced by annealing are less than that produced by normalizing (Herring and Jenko, 2009).

As the steel is heated above the critical temperature, about 1335°F (724°C), it undergoes a phase change, nucleation of austenite grains, If the austenitic steel is cooled slowly (allowed to cool in the furnace), it will return to the pearlite structure (Berglund, 2006).

Normalizing/stress relieving involves heating to a suitable temperature, holding long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses. It relieves the stresses that occur as a result of the spring forming operation. It also returns the material to the strength levels prior to the forming operation and can actually increase the strength to levels greater than originally supplied (Fayol et al., 1985).

The normalizing of steel is carried out by heating approximately 100°F (38°C) above the upper critical temperature followed by cooling in air to room temperature (Qamar, 2009). Normalizing is often considered from both a thermal and a micro structural standpoint. In the thermal sense, normalizing is austenitizing followed by a relatively slow cool (Rajan et al., 1994).

Hardening/Water quenching can be done by plunging the hot steel in water. The water adjacent to the hot steel vaporizes, and there is no direct contact of the water with the steel. This slows down cooling until the bubbles break and allow water contact with the hot steel. Water quenching produces steel with a very high hardness but also results in very brittle and fragile steel with a low tensile strength also. As the water contacts and boils, a great amount of heat is removed from the steel. With good agitation, bubbles can be prevented from sticking to the steel, and thereby prevent soft spots. Water is a good rapid quenching medium, provided good agitation is done. However, water is corrosive with steel, and the rapid cooling can sometimes cause distortion or cracking (Htuni, 2009).

Tempering is usually done after quenching, it involves re-heating of the steel in order to reduce the hardness of the quenched steel and improve the ductility, toughness and strength of the spring. Tempering is usually done hand in hand with quenching and is usually a tradeoff between hardness and toughness/strength of steel.

It was reported that heat treatment of steel involves heating steel fairly slowly to some predetermined temperature, and then cooled, and it is the rate of cooling which determines the ultimate structure the steel will have (Zhen et al. (1997)). The subsequent rate of cooling, which determines the nature of the final structure, may vary between a drastic water-quench and slow cooling in the furnace.

The objective of this research work is to determine and illustrate the various microstructures evolved after heat treatment of mild steel springs.

MATERIALS AND METHODS

Materials

The springs were made from mild steel rod having a diameter of 6 mm whose chemical composition is contained in Table 1.

Table 1: The Chemical Composition of Steel Rod Used (wt. %).

C	Mn	Si	P	Al	Fe
0.21	0.272	0.016	0.005	0.034	99.3

Annealing

Three springs were heated to 550,700 and 850^{o}C respectively, after which they were allowed to cool in the furnace by switching off the furnace until the springs cooled down to room temperature.

Normalizing/Stress Relieving

In normalizing, the springs were heated to 550, 700, and 900^{0}C, respectively, after the desired temperature had been obtained they were removed from the furnace and allowed to cool in air till room temperature was obtained.

Hardening (Water Quenching)

In water quenching the springs were heated to about 850^{0}c to ensure conversion to austenite had been achieved. The springs were then taken out of the furnace and placed in a bath of water to ensure that rapid cooling of the spring occurred.

Tempering

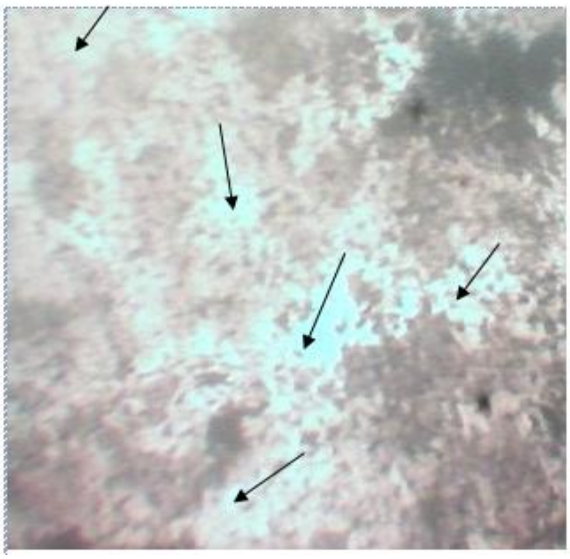
In tempering the three water quenched steel were heated to 300, 500, and 600 ^{0}C, respectively, and were then allowed to cool down gradually. This was done to relieve some of the stress that occurred during water quenching and to also reduce the hardness of the steel rod, thus making it tougher. The remaining three springs were not subjected to any heat treatment and shall thus be used for comparison with the other heat treated springs.

Microstructural Analysis

Microstructural analyses were carried out on some of the heat treated spring samples using an optical microscope. The cross sections of the Mild Steel Springs were taken for analysis. The results are contained in Plates 1 to 4.

RESULTS AND DISCUSSION

The results obtained from microstructural analysis of some Spring Samples showed cementite in ferrite matrix for annealed and normalized samples with finer grains for the latter. The hardened samples contained martensite structures while tempered samples contained granular form of fine ferrite and cementite.



X 400

Plate 1: Photomicrograph of Water Quenched Sample at 850^{o}C of the Actual Spring.

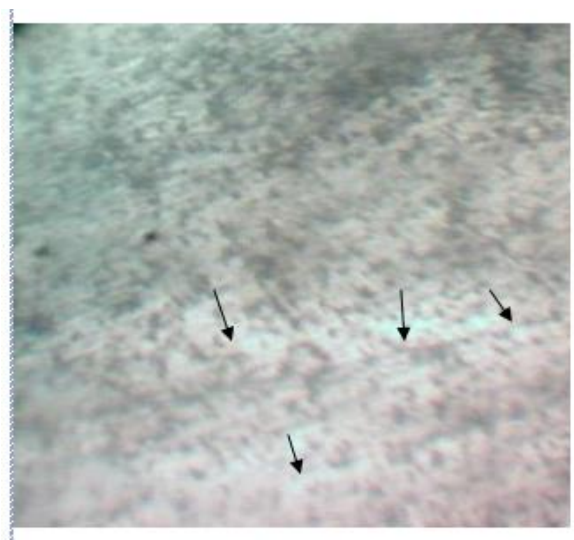
In Plate 1, the steel microstructures compose of martensite (light area marked by arrows) distributed in the ferrite (dark area) matrix. The volume fraction (Vm) of martensite increased with growing water quenching temperature which is responsible for the hardness of the water quenched steel rod.

In Plate 2, during this stage, retained austenite transforms to fine ferrite and austenite. Another name given to this stage is medium temperature tempering. Ductility and toughness increased by this treatment with a corresponding decrease in hardness and strength.

X 400 (Arrows Indicate Ferrite)

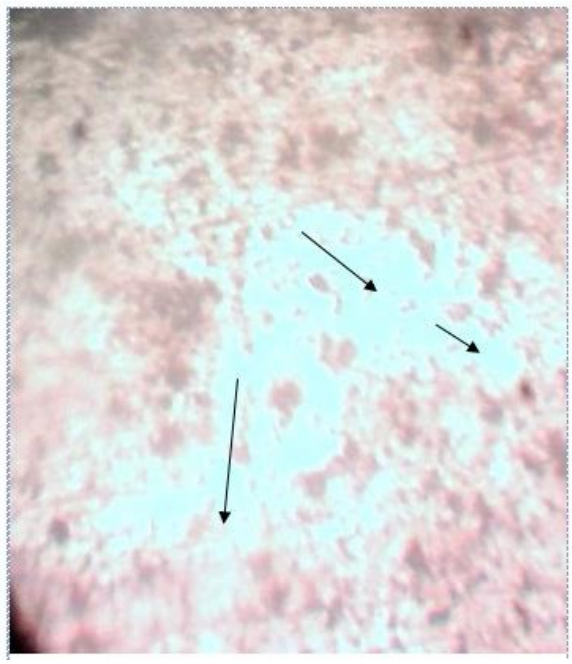
Plate 2: Photomicrograph of Tempered Spring at 500^{o}C.

The microstructure of the as received spring when compared to the other heat treated spring has cementite in ferrite matrix as revealed by Plate 3.



X 400 (Arrows indicate Cementite).

Plate 3: Photomicrograph of as Received Spring.



X 400 (Arrows indicate Ferrite).

Plate 4: Photomicrograph of Tempered Spring at 300^{0}C.

Annealed Springs

Fully annealed carbon steel consists, in addition to impurities and other alloyed elements, of a mechanical mixture of iron and iron carbide. The iron takes the crystalline form ferrite, and the iron carbide takes the crystalline form cementite. The overall structure consists of bands of these two components and is known as pearlite. In this state the steel is soft and workable, this accounts for an increase in the softness of the annealed steel spring and as the steel is heated above the critical temperature, about 1335°F (724°C), it undergoes a phase change with nucleation of austenite grains.

Continued heating to the hardening temperature, 1450-1500°F (788-816°C) ensures complete conversion to austenite. At this point the steel is no longer magnetic, and its color is cherry-red, as the annealing temperature is increased at this temperature the structure of steel changes from body centered cubic to face centered cubic. Cooling of the steel gradually at this temperature results in a very soft steel (i.e. it will return to the pearlite structure) followed only by spherodized steel as seen in the results above. This thus explains why annealed springs have a greater % elongation than the other heat treated springs and are also the softest.

Normalized Springs

As the steel is heated above the critical temperature, about 1335°F (724°C), it undergoes a phase change, nucleating as austenite grains. Continued heating to the hardening temperature, 1450-1500°F (788-816°C) ensures complete conversion to austenite. At this point the steel is no longer magnetic, and its color is cherry-red, normalizing has a faster rate of cool than annealing, which resulted in finer grains of pearlite and consequently springs having a greater strength than the annealed spring, and also accounts for it being harder and less ductile than the annealed springs.

Hardening and Tempering

As the steel is heated above the critical temperature, about 1335°F (724°C), it undergoes a phase change, nucleating as austenite grains (i.e. it changes from body centered cubic to face centered cubic). Continued heating to the hardening temperature, 1450-1500°F (788-816°C) ensures complete conversion to austenite, the springs are then cooled suddenly by quenching in a bath of water, a new crystal structure, martensite, is formed as seen in the microstructural analysis above. Martensite is characterized by an angular needle-like structure and very high hardness, as seen from the hardness test carried out. While martensitic steel is extremely hard, it is also extremely brittle and will break, chip, and crumble with the slightest shock. Furthermore, internal stresses remain in the spring from the sudden quenching; these will also facilitate breakage of the spring. Tempering relieves these stresses and causes partial decomposition of the martensite into fine ferrite and cementite.

The amount of this partial phase change is controlled by the tempering temperature. The tempered steel is not as hard as pure martensite, but is much tougher. This can be observed from the result contained in Table 2 where by the water quenched springs have the highest hardness and are the least ductile from all the springs, but after the water quenched steel were tempered it was observed that the hardness of the spring reduced, the toughness increased and the ductility increased when compared to the water quenched springs.

Table 2: Rockwell Hardness (RC) Values of Heat Treated Mild Steel Springs.

S/N	Spring Samples	Hardness (RC)
1	Annealed at 850^{o}C	20
2	Normalized at 850^{o}C	38
3	Water quenched at 850^{o}C	50
4	Tempered at 850^{o}C	30

CONCLUSION

In summary, the carrying out of heat treatment on springs results in a change in the microstructure of the steel. The following conclusions were drawn from the result of the study. The micro-structural analysis indicated that the annealed sample had a microstructure consisting of pearlite, when compared with the hardened samples which had a high concentration of martensite mixed with ferrite.

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SUGGESTED CITATION

Adetunji, O.R., S.I. Kuye, and M.J. Alao. 2013. "Microstructures of Mild Steel Spring after Heat Treatment". *Pacific Journal of Science and Technology*. 14(2):11-15.

Pacific Journal of Science and Technology