Investigation of Heat Affected and Phase Transformation of Sorbite to Troostite on Decreasing Fracture Toughness of Cold Rolls

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Abstract: Cold steel rolls and too many other cold work dies are chosen of low alloy steel heat treated to about 60 RC in 50 millimeter depth on surface. Troostite phase which happens in some cases in tempered martensite has lower fracture toughness, although its ductility is a little more. In Industrial practical process condition, some technological problems seldom take place, and the part might be locally heated because of the accident. This effect may cause a phase change in metallurgical structure on the surface of the cold steel rolls or dies, named *Troostite*. However, the parts which subjected to this problem have no mechanical defect to be detected by NDT, but these kinds of affected part may be failed in working (rolling) by fracture, spalling or cracks. So Troostite is a harmful phase for rolls and other cold work tools which cause lots of losses to the companies. The following paper is a practical industrial approach to show and follow thermal instability of roll surface and metallurgical change of the surface from sorbite to troostite and its failure or fracture due to any improper usage.

Key words: Troostite, Cold Roll, Spalling, Failure Analysis, Fracture, Fracture Toughness, Cold Rolls, Steel Rolls Defects, Sorbite.

1. Introduction

Some alloy steels exhibit a phenomenon known as temper brittleness which is a loss of notched-bar toughness when tempered in the range of 540 to 680°C (1000 to 1250°F) followed by relatively slow cooling. A second form of embrittlement called “blue brittleness” occurs when steels are tempered at about 300°C after being hardened. [1, 2] If the primary requirement is toughness, the part is tempered above 425°C. If the part does not have any “stress raisers” or notches, the change in ductility may be a better indication of toughness. [3] Generally, for steels containing potent carbide formers such as chromium, tempering between 200 and 370°C should be avoided. [1]

The presence of hard second-phase particles, inclusions, retained austenite content and non-martensitic transformation products may act as stress raisers. Subsurface plastic strain builds up with increasing cycles until a crack is generated which is usually related to the presence of inclusions. [2] In general, over the broad range of tempering temperature, hardness decreases and toughness increases as the temperature is increased. This is true if toughness is measured by reduction of area in a tensile test. However, this is not usually true if the notched bar such as Izod or Charpy is used as a measure of toughness. Most steels actually show a decrease in notched bar toughness when tempered between 205- 425°C (400-800°F), even though the piece at the same time loses hardness and strength. The reason for this decrease in toughness is not fully understood. [2] The tempering range of 200 to 425°C is a dividing line between applications that require high hardness and those require high toughness. If the principal desired property was hardness or wear resistance, the part would be tempered below 200°C, else if the primary requirement was toughness, the part would be tempered above 425°C. [4]

When plain carbon steel is heated in the range of 40 to 205°C (100 to 400°F), the structure etches dark and is sometimes known as black martensite. The original as-quenched martensite is beginning to lose its tetragonal crystal structure by the formation of a hexagonal close-packed transition carbide (epsilon carbide) and low-carbon martensite. X-ray studies, Fig. 1, shows the decrease in c/a ratio as carbon is precipitated from martensite forming epsilon carbide.

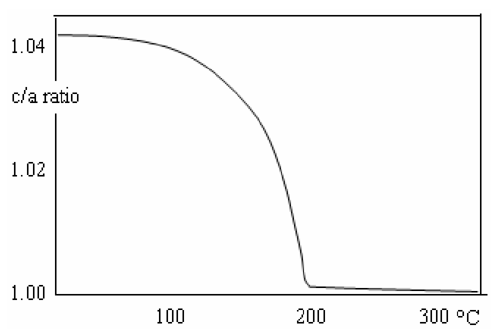

Fig. 1: The axial ratio c/a of martensite as a function of tempering temperature. When c/a =1.00, the martensite has decomposed into ferrite and carbide phase. [10]

The precipitation of the transition carbide may cause a slight increase in hardness, particularly in high-carbon steels. The steel has high strength, high hardness, low ductility, and low toughness, and many of the residual stresses are relieved. Heating in the range from 230 to 750°C (450 to 750°F) changes the epsilon carbide to orthorhombic cementite (Fe_3C), the low-carbon martensite becomes bcc ferrite, and any retained austenite is transformed to lower bainite. The carbides are too small to be resolved by the optical microscope, and the entire structure etches rapidly to a black mass formerly called troostite (Fig. 2). [5]

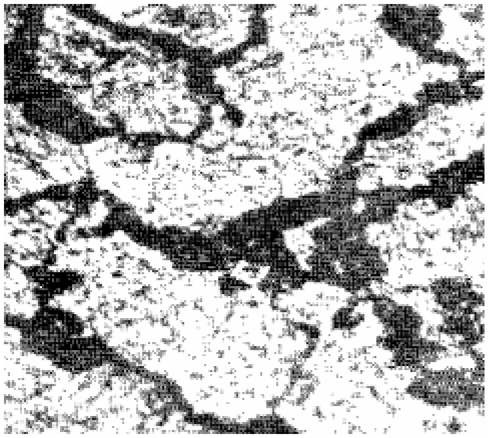

Fig.2: Nodular troostite in martensite (x400) [5]

If the sample is magnified 9000 times using the electron microscope, the carbide precipitate is clearly seen. Some of the carbides have come out along the original martensitic plate directions while the tensile strength has dropped; it is still very high and over 140 kg/mm² (200 ksi). The ductility has increased slightly, but the toughness is still low. Hardness has decreased to between Rockwell C 40 and 60 depending upon the tempering temperature.

Tempering in the range of 400 to 650°C (750 to 1200°F) continues the growth of the cementite particles. This coalescence of the carbide particles allows more of the ferrite matrix to be seen, causing the sample to etch lighter than the lower-temperature product. In this structure, formerly known as sorbite (Fig.3), the carbide is just about resolvable at 500X and is clearly seen in the electron micrograph.

Mechanical properties in this range are: tensile strength 88 – 140 kg/mm² (125-200 ksi), elongation 10-20 percent in 2 in. and hardness Rockwell C 20-40. The most significant is the rapid increase in toughness, as shown by Fig.4. [2]

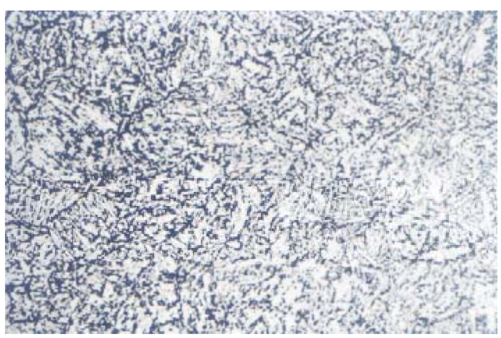

Fig. 3: Sorbite structure., [5]

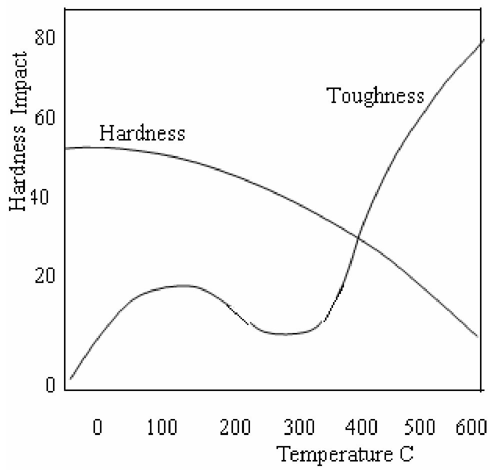

Fig. 4: Hardness and notched-bar toughness of 4140 steel after tempering 1 hour at different temperatures. [2]

In rolling Industries, cold rolls are chosen of low alloy heat treated steel with about 60 RC in 50 millimeter depth on surface. The rolls should present an extremely hard surface, which is usually brittle, thermally unstable and sensitive to cracks.[6, 7, and 8] The basic characteristics of all rolls are their resistance to wear, spalling, and heating due to large deformation.[7] Rolls quality and its proper maintenance play very important roles in rolling technology. Any improper treatment causes problem or defect in rolls. These damages reduce the life time of the roll or can make the roll useless. [4]

Sometimes unfavorable treatment or defect could be a source for catastrophe; when, spalling or breaking of roll take place in rolling process and it can interrupt rolling production line for a while which leads to high economical losses. [3, 4] This phenomenon is more important in strip and foil cold rolling of Stainless steel, Copper and Aluminum. Because of the advanced surface finishing of roll strip products, any defect even a very small crack or pits on the rolls (even invisible) will be printed over the Aluminum strip and reduces the surface quality of product. So forged steel rolls made of a high quality alloy steels in an accurate making process are used in Aluminum rolling technology. [3, 4] Rolls are expected to have enough strength, hardness and excellent wear resistance at surface and a little ductility in the core. [9] Rolls should support very hard three dimensional stresses due to metal forming forces under fatigue conditions, thermal stresses and shocks, and impact forces especially in hot rolling. [9] Working rolls must have very high surface hardness and substantial depth of the hardened layer to the core. Materials chosen for forged steel rolls are low to high alloy steel; medium to high carbon content is used for cold work forged steel and low to medium carbon content alloy steel for hot work forged steel rolls. [4] Roll manufacturing process follows these stages: casting (sometimes ESR), forging, machining, and heat treating to a desired hardness by induction process to an accurate depth of about 50 mm (2 inches) from the surface. Finally roll will be grinding to a proper finishing with desired chamber or crown depending on the rolling technology. [3, 4, 10] The useful life of steel rolls for cold rolling mills is usually limited by roll discard, but sometimes catastrophic failure occurs. A

precise understanding of its causes is usually complex and depends on the metallurgical quality of the rolls, improper mill usage, practices and abnormal mill operating conditions. [11] The microstructure of the spalling surface presented tempered martensite. [6, 11]
This paper is focused on metallurgical change because of diffusion due to the thermal instability of surface rolls and any improper mill usage or inconvenient effect in rolling process.

2. Procedure and outline

In an Aluminum rolling factory, four rolls (Tow sets) of cold work forged steel rolls were damaged by some cracks on the barrels, and two of them had spalling. The rolls were investigated for the source of failure or any recommendation to prevent it. After some research it was found out that the cause of the failure is the phase transformation from martensite to the troostite. One year later a technical accident taken place on the cold Aluminum mill. The strip was chewed in the rolling process. The machine was shut down and the rolls surface was checked by nondestructive testing. There was no defect on the rolls surface. However, following investigation shows some tempered martensite phase transformed area on the barrel of the rolls. These rolls kept working while controlling regularly. After a few tonnage of normal rolling, cracks were appeared on the barrel of the rolls, as they are shown in Figure 5 schematically.

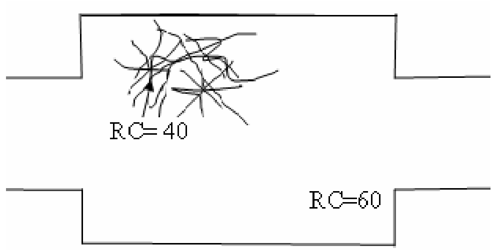

Fig5: schematic of cracks and locally decreased surface hardness of a cold work steel roll; 100 tons rolling after an inconvenient of chewing aluminum strip.

3. Result and Discussion

Local heating on the surface of the cold rolls, dies and any cold tool steels due to any inconvenient in rolling process can be a cause for increasing temperature. Depth, width and time of heating depend on the different factors in rolling process. Any locally heating more than 200°C on surface of cold work steel rolls will cause more tempering and it may lead to martensite to troostite phase transformation due to increasing diffusion rate. In this case, its toughness (impact test) is lower and so more sensitive to any impact in rolling process. Such a roll is sensitive to any impact which is occurred seldom in cold rolling and usually in slab hot rolling.
This phase transformation is a metallurgical defect for rolls; however it can not be detected by nondestructive testing which is usually used in detecting roll defects.

Such a treated roll may be cracked, spalled, or broken in the rolling process. In the latter case it would be a catastrophe. So such roll should be changed, investigated and prepared to eliminate metallurgical improper treatment.

4. Conclusion

In process of using cold tool steels, dies or in strip cold rolling, after any inconvenient, improper usage, or abnormal operating conditions, such as a mistake in pass schedule, problem in coolant or lubricant, falling an undesired particle in rolling process (like: bolt, nuts, sand or any other particles); the process must be shut down immediately and following procedure is useful to be done.

1- The die (rolls) must be changed.

2- The treated die (rolls) must be checked to find any mechanical (cracks or pin holes) or metallurgical (phase transformation) defects.

3- These defects on treated die (roll) must be eliminated.

4- Metallurgical defects (phase transformation) on cold work forged steel rolls, are very important and must be investigated; however it could not be detected by nondestructive testing.

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References

1. American Society for Materials, metals handbook, 10th Ed, vol.4, heat treatment, printed in the United States of America

2. Avner, Sidney H, Introduction to Physical Metallurgy, Mc Graw-Hill, Inc, 1997

3. A. A. Mottahedi, "detection of metallurgical defects in forged steel rolls", unpublished research report

4. A. A. Mottahedi, "investigation of using cold work forged steel rolls in hot rolling of Aluminum Technology", unpublished research report,

5. www.physicsarchives.com

6. C.R.F. Azevedo, I. Belotti Neto, Failure analysis of forged and induction hardened steel cold work rolls, laboratory for failure analysis, institute de pesquisas tecnologicas de estado de sao Paulo, Elsevier, Engineering Failure Analysis, Nov.2004.

7. Defects on rolls for cold rolling, http://www.kaker.com/defects_on_rolls/contacts/contacts.html

8. Karl Heinz Ziehenberger, Michael Windhager, Recent developments in HSM rougher rolls risks and chances, research and development, Dep. Eisen werk sulzau-werfen, Tenneck, Austria, Iron & Steel Technology.

9. Yang, Znou, Peng Yan, Experimental investigation on elimination of roll defects for HC reversing cold mills, iron & steel, 2006, ISSN : 0449-749 .
10. A. A. Mottahedi, [Investigation of locally defected of cold work forged Steel rolls in nonferrous rolling technology], KMCM2007, International Joint conference on Knowledge management for composite material, Düsseldorf, Germany, 3-6 July 2007
11. Ray AK, Mishra KK, Das G, Chaudhary PN, Life of rolls in a cold rolling mill in a steel plant – operation versus manufacture. Eng Fail Anal 2000; 7:55-67
12. Roll mark detector, struck innovative systeme GmbH. Harksheider str., 102 AD-22399 Hamburg Germany, www.struck.de.
13. Automatic nondestructive roll defect inspection system, United States Patent 4495587.
14. Nakagawa M, Hoshi A, Asano A, Nambu Y. Causes and Countermeasures of spalling of cold work rolls. Iron steel Eng 1981, 58(3): 44-9.
15. Frolish MF, Fletcher DI, Begnon JH. A qualitative model for predicting the morphology of surface initiated rolling contact fatigue craks in back-up roll steels. Fatigue Fracture Engineering Materials Strucl 2002, 25: 1073-86.
16. Ray A., Mukherjee D., Sarkar B., Mishra S, influence of microstructure on the premature failure of a second- intermediate Sendzimir mill drive roll, JMEPEG 1990; 3; 649-56