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Effect of Tempering Heat Treatment Process Parameters on Power Transmission Chain Parts Made Up of SAE 1050

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Abstract

The process of Drive Chain Analysis is as important as its production. In today's era, it's an intelligent and profit making job to produce an optimum product. Today, in this competitive market where material, time, quality, processes are the main factor that contributes towards profit incurred to the company. In drive chain, tempering heat treatment is very important process which affects the mechanical properties of chain parts. Changes in the parameters involved in tempering would change the mechanical properties such as strength. In the present work, strength of the parts (outer and inner plate) made up of SAE 1050 of power transmission chain was investigated by UTM and the parameters such as temperature and time have been changed and graphs were plotted for breaking load versus chain sample and improved results have been found in some cases.

Keywords: Breaking load; Hardness; Tempering heat treatment process; Temperature; Soaking time.

Nomenclature

HRC: Rockwell hardness in C scale
VHN: Vickers hardness number
O/I Plate: Outer/Inner Plate
UTM: Universal Testing Machine
Chain no.: Chain number

1.0 INTRODUCTION

Chain drive is a way of transmitting mechanical power from one place to another. Power transmitting (or driving) chains are used for transmission of power, when the distances between the centres of shafts are short. A bush roller chain consists of outer plates, inner plate, pins, roller, and bushes as shown in figure 1. A pin passes through the bush which is secured in the holes between the two sides of chain. The rollers are free to rotates on the bush which protect wheel teeth against wear. The pins, bushes, and rollers are made of alloy steel. **[1]**

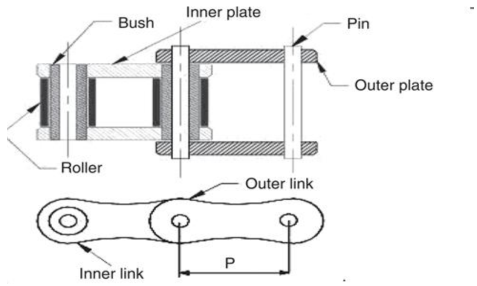

Figure 1: Components of chain link

Heat Treatment is the *controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape*. Heat Treatment is often associated with *increasing the strength of material*, but it can also be used to *alter certain manufacturability* objectives such as improve machining, improve formability, restore ductility after a cold working operation. Tempering of steel is a process in which previously hardened or normalized steel is heated to a temperature below the lower critical temperature and cooled at a suitable rate, primarily to increase ductility and toughness but also to increase the grain size of the matrix. Tempering is used to reach specific values of mechanical properties, to relieve quenching stresses, and to ensure dimensional stability. The resulting change of martensite during tempering into a mixture of cementite (Fe_3C) and ferrite typically results in an increase in grain size and a decrease in volume as a function of increasing tempering temperature. Tempering temperature, time at temperature, cooling rate from tempering temperature and steel chemistry are the variables associated with tempering that affect the mechanical properties and microstructure of the finished part. Changes to the microstructure by tempering typically decrease hardness and strength (tensile and yield) while increasing ductility and toughness. The brittle martensite becomes tough and ductile after it is tempered. Tempering results in an increase in softness, malleability, impact resistance and improved dimensional stability. **[2]**

The tempering heat treatment process is carrying out on inner and outer plate of power transmission chain which are made up of SAE 1050 material. SAE 1050

Steel is a plain carbon steel containing 0.50 wt% of carbon. **[3]** . **ZOU *et al.* [4]** investigated the influence of tempering process on microstructural evolutions and mechanical properties of 00Cr13Ni4Mo super martensitic stainless steel (SMSS), specimens were tempered in the temperature range of 520–720 °C for 3 h followed by air cooling and an optimized tempering temperature was chosen to prolong holding time from 3 to 12 h. The results revealed that the superior mechanical properties were achieved by quenching at 1040 °C for 1h+ water cooling and tempering at 600 °C for 3 h + air cooling. Increasing isothermal tempering time could improve the toughness notably. **Wei *et al.* [5]** investigated the effect of heat treatment on properties of 1000 MPa ultra high strength steel. **Salemi & zadeh [6]** studied the effect of tempering temperature on the mechanical properties and fracture morphology of a NiCrMoV steel. All specimens were austenitized at 870 °C for 1 h, followed by oil quenching, and then tempered at temperatures in the range of 200–600 °C. The results of tensile testing indicated that the yield strength (YS) and ultimate tensile strength (UTS) decreased with increased tempering temperature. **Shi & Liu [7]** studied the flow stress property of a hardened steel at elevated temperature with tempering effect. For hardened steels in manufacturing processes such as heat treatment, grinding, and hard machining, their martensitic structures were often changed due to tempering at elevated temperatures, and thus their flow stress property changes accordingly. The tensile tests at elevated temperatures with various soaking times and heat treatment experiments were performed on hardened AISI 52100 steel. It was found that, at the same temperature level the flow stress was smaller for the specimens that received stronger tempering, and the decrease of strength due to tempering effect becomes more pronounced at high temperatures. **Chang *et al.* [8]** studied the effect of soaking time in hot isostatic pressing on strength of inconel 718 superalloy. The HIP temperature was maintained at 1453 K, pressure was kept 175 MPa and three different soaking time are 2, 3 and 4 h. The experiment results showed that HIP treatment at 1453K under the pressure of 175 MPa for 4 h for Inconel 718 superalloy was the optimum condition. It can decrease the porosity of Inconel 718 superalloy castings. it can reduce porosity about 86% after HIP treatment. For the tension test at a fast strain rate (0.001 s_1) that it increased the tensile strength by 31% at room temperature, 27% at 813 K, and 24% at 923 K. **Wangmooklang *et al.* [9]** investigated the effect of length of soaking time on the properties of Si_3N_4 Ceramics prepared from low cost β powder. Sintering was conducted at temperature of 1850˚C with varying soaking time of .5, 2 and 6 hr. Grain size was increased by increasing soaking time; however the grain aspect ratio was still low. The specimen with soaking time 2 hr showed the highest values of mechanical properties such as 544 MPa flexural strength and 5.9 MPa $m^{1/2}$ for fracture strength. In the present work, strength of the parts of chain was investigated by UTM and the parameters such as temperature and time have been changed and graphs were plotted for breaking load versus chain sample and improved results have been found in some cases.

2.0 Experimental Study

In the present study tempering heat treatment process was done on the chain parts (O/I plate) so that its strength can be changed. Then this strength was investigated by UTM.

Table 1. Initial Tempering conditions [10]

Element	Material	Thickness (mm)	Condition	
			Temperature(°C)	Soaking time(min)
Inner plate	SAE 1050	1.5	365	60
Outer plate	SAE 1050	1.5	365	60

Table 1 indicates the initial conditions of tempering of inner and outer plate. Both plates were tempered at 365°C and then these were held at this temperature for 60 minutes followed by air cooling. At this condition chains were breaking at 1950 Kg/f.

The improved tempering heat treatment conditions were carried out at different temperature and soaking time since temperature and soaking time were the two factors that could change the mechanical properties of material such as strength, wear, toughness etc.

The UTM is used to test the tensile stress and compressive strength of materials. The main parts of UTM are:

(1) Load frame, (2) Load Cell, (3) Cross head, (4) Extensometers, (5) Output devices, (6) Test fixture, specimen holding jaws.

Load frame is consisting of two strong supports for the machine. Load cell is a force transducer or other means of measuring the load. Cross head is controlled to move up or down. Extensometers are used to measure extension or deformation. Output device provides the test results. It may have dial or digital displays and chart recorders. Test fixtures are used to hold the workpiece or sample.

Figure 2: Universal Testing Machine

Universal Testing Machine, as shown in Figure 2 was used to test the breaking load of sample ie. cut piece chain of 19 links. The specimen was placed in the machine between the grips. Once the machine was started it begins to apply an gradual load on specimen. Throughout the tests, the control system and its associated software recorded the load of the sample.

Specification of Universal Testing Machine:

1. Make: MTS, USA
2. Fully computerized, servo controlled machine
3. 500 KN capacity
4. Resolution: 1N

In the present study, tempering heat treatment process was done on the chain parts and after this with the help of Rockwell hardness tester as shown in figure 3, hardness values of various parts of links such as inner plate, outer plate are found. The diamond indenter was used for indentation and the unit of hardness taken HRC. The maximum load applied during checking hardness was 150 Kgf. The main parts of rockwell hardness tester are
(1) Penetrator, (2) Colored segment on dial face, (3) large pointer, (4) Anvil, (5) Wheel, (6) Knurled collar, (7) Crank to release major load

Figure 3: Hardness Testing Machine

2.1 Experimental Procedure

Firstly all the components were examined for mechanical properties, chemical composition and surface hardness. After examining the existing components, raw material were procured. It included inner plate, outer plate, pin, roller, bush in soft form on which no heat treatment was done. After procuring raw material, heat treatment operation i.e tempering heat treatment process was applied. Tempering heat treatment process was completed on hardened inner and outer plate.

After heat treatment, all components of link were assembled to form chain of 19-21 links. The assembled chains were tested on Universal Testing Machine by breaking it to determine the breaking load. Same test were applied on number of chains in order to get statistical data. The broken chains were analyzed in order to investigate the mode of failure and which part of chain actually broke during testing.

3.0 Results and Discussion

After completing Tempering heat treatment process at different conditions of temperature and soaking time, chain elements were assembled into complete chain. These chains were then taken for destructive testing to test for breaking load. The results obtained summarized below.

Table 2: Hardness of outer plate (OP) and inner plate (IP)

Stages	Hardness (VHN)	Hardness (HRC)
O/I plate Soft	243	21
O/I plate Hardened	498	49
O/I plate Tempered	442	45
O/I plate Finished	421	43

It can be observed from Table 2, that the hardness of outer and inner (O/P) plate increased from 21 to 49 after hardening and decreased from 49 to 45 after tempering. The change in hardness was due to the diffusion of carbon i.e. due to the metallurgical changes. When parts were hardened, martensite structure was obtained but when parts were tempered the carbon atom was diffused out of the body centered tetragonal (BCT) structure. After diffusion, the resulted structure was pure ferrite and body centered. During testing of chain, outer plate usually broke, so to improve the strength of outer plate, it was tempered at different conditions of temperature and soaking time. Temperature and soaking time are the variables associated with tempering that affect the mechanical properties and microstructure of material.

In order to examine this, 6 samples were made in 6 different conditions of temperature and soaking time.

3.1 Breaking load

After heat treatment, chains were assembled and breaking load was checked at different conditions by breaking the chain on Universal Testing Machine. The results of breaking load are summarized as.

Table 3: Results at 300°C, 45 min

Elements	Conditions		Trials	Breaking load(Kgf)	Element broken
	Temperature (°C)	Soaking time(min)			
Outer plate	300	45	1.	2116	Inner plate
			2.	2114	Inner plate
			3.	2087	Inner plate
			4.	2084	Inner plate
			5.	2077	Inner plate
			6.	2045	Inner plate
			7.	1991	Inner plate

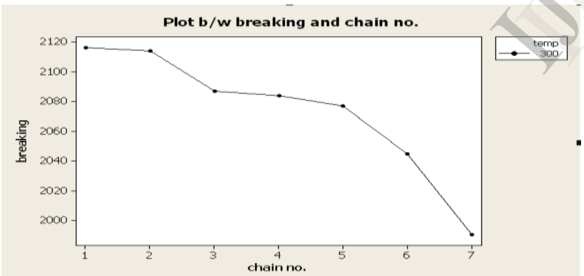

Fig 4: Plot between breaking and chain no.

Table 3, showed that after tempering at this temperature and soaking time, chain broke at maximum load of 2116 Kgf . At this condition the material became brittle due to increased hardness, which resulted brittle fracture of inner plate.

Table 4: Results at 300°C, 90 min

Element	Condition		Trials	Breaking load(Kgf)	Element broken
	Temperature (°C)	Soaking time(min)			
Outer plate	300	90	1.	2137	Inner plate
			2.	2137	Inner plate
			3.	2123	Inner plate
			4.	2093	Inner plate
			5.	2065	Inner plate
			6.	2040	Inner plate
			7.	2012	Inner plate

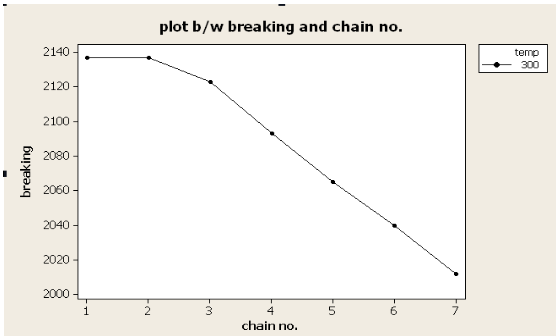

Fig 5: Plot between braking and chain no.

It can be observed from Table 4 that after tempering at this temperature and soaking time, chain broke at maximum load of 2137 Kgf. Since temperature was same but due to increase in soaking time the breakage of chain occurred at high load. It was due to the refinement of grains which occurred as the soaking time increases.

Table 5: Results at 325°C, 45min

Element	Condition		Trials	Breaking load(Kgf)	Element broken
	Temperature(°C)	Soaking time(min)			
Outer plate	325	45	1.	2152	Inner plate
			2.	2076	Inner plate
			3.	2071	Inner plate
			4.	2062	Inner plate
			5.	2036	Inner plate
			6.	1969	Inner plate

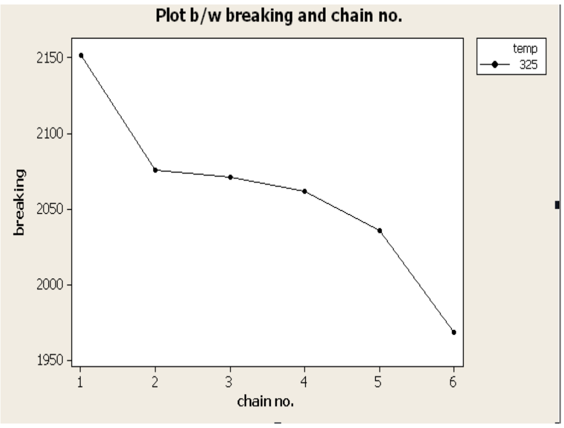

Fig 6: Plot between breaking and chain no

Table 5 showed that, after tempering at this temperature and soaking time, chain broke at maximum load of 2152 Kgf. Now the temperature was high due to which brittleness decreased hence resulted breakage of chain at this high load.

Table 6: Results at 325°C, 90 min

Element	Condition		Trials	Breaking load(Kgf)	Element broken
	Temperature(°C)	Soaking time(min)			
Outer	325	90	1.	2159	Inner plate
			2.	2121	Inner plate
			3.	2106	Inner plate
			4.	2100	Inner plate
			5.	2058	Inner plate
			6.	2057	Inner plate
			7.	1985	Inner plate
			8.	1982	Inner plate

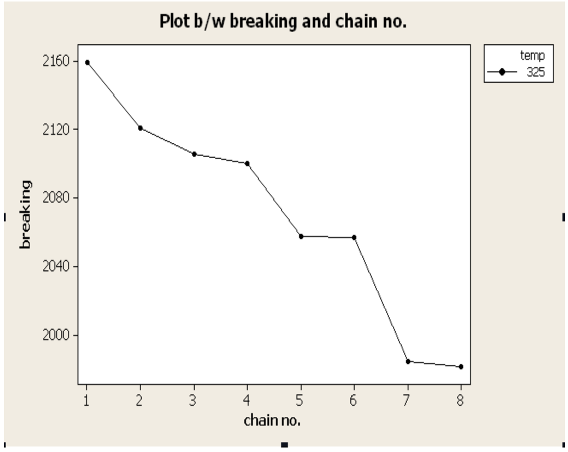

Fig 7: Plot between breaking and chain no.

Table 6 showed that, after tempering at this temperature and soaking time, chain broke at maximum load of 2159 Kgf. It was due to the both high temperature and soaking time. At this temperature when more soaking time was given, it resulted more refinement of grains due to which breakage of chain occurred at this high load.

Table 7: Results at 350°C, 45 min

Element	Conditions		Trials	Breaking load(Kgf)	Element broken
	Temperature(°C)	Soaking time(min)			
Outer plate	350	45	1.	2099	Inner plate
			2.	2090	Inner plate
			3.	2065	Inner plate
			4.	2055	Inner plate
			5.	2052	Inner plate

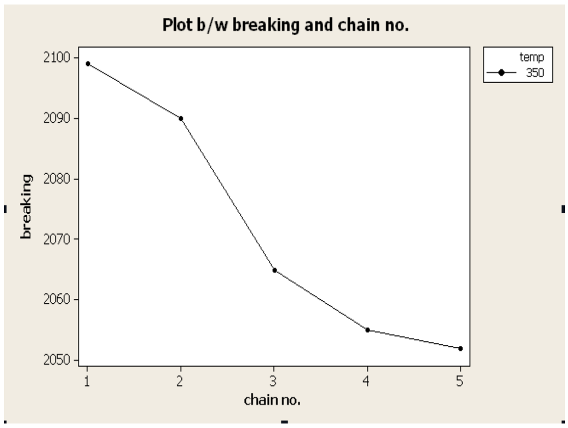

Fig 8: Plot between breaking and chain no.

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Table 7 showed that after tempering at this temperature and soaking time, chain broke at maximum load of 2099 Kgf. It was due to this temperature at which the hardness of material decreased. Due to decreased hardness, strength thus breaking load decreased.

Table 8: Results at 350°C, 90 min

Element	Condition		Trials	Breaking load(Kgf)	Element broken
	Temperature(°C)	Soaking time(min)			
Outer plate	350	90	1.	2055	Inner plate
			2.	2015	Inner plate
			3.	2013	Inner plate
			4.	2003	Inner plate

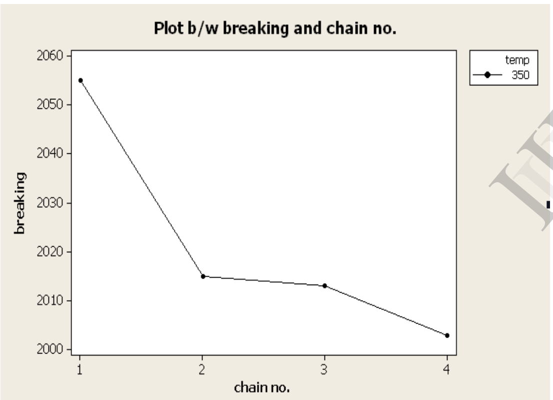

Fig 9: Plot between breaking and chain no.

Table 8, showed that, after tempering at this temperature and soaking time, chain broke at maximum load of 2055 Kgf. It was due to the both temperature and soaking time that resulted more decreased in hardness thus breakage of chain occurred at this load.

Scatterplot of breaking vs time (all sample together)

After examining individual samples, it was important to compare the breaking load of each sample in order to find the conditions of temperature and soaking time that would give best results. Figure 10 showed that there were two conditions which would give best results in terms of breaking load, that was (b) and (d) conditions. But the sample at condition (b) i.e. 300°C, 90 min resulted more hardness that were summarized in Table 9 so it was the (d) condition i.e. 325°C, 90 min that would be considered as best condition.

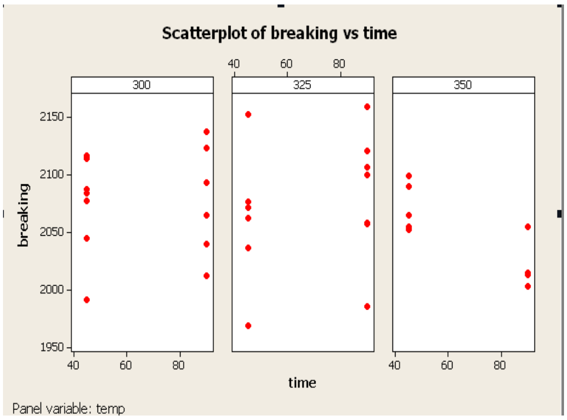

Fig 10: Scatter plot between breaking load and time, temperature as paneled variable

The hardness of sample at different condition of temperature and soaking time are summarized in Table 9

Table 9: hardness of outer plate at different conditions of temperature and soaking time

Element	Condition		Hardness(HRc)
	Temperature(°C)	Soaking time(min)	
Outer plate	300	45	51, 51, 51, 50.5, 50.5, 50.5
	300	90	51, 50.5, 50, 50, 49.5
	325	45	50, 49.5, 49.5, 49
	325	90	49.5, 49.5, 49, 49, 49
	350	45	48.5, 48.5, 48, 48, 48
	350	90	46, 46, 46, 45, 45, 45

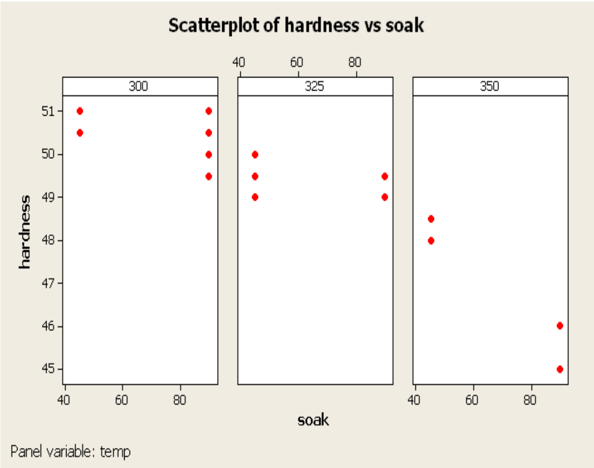

Fig 11: Scatter plot between hardness and time, temperature as paneled variable

From Figure 11, scatter plot between hardness and soaking time where temperature taken as paneled variable, it can be judged that as the temperature decreased, the hardness of samples were increased but for same temperature, high soaking time resulted decrease in hardness. From Figure 11 , it was clearly seen that the minimum hardness was obtained at 350°C, 90 min condition but this hardness values increased on lowering of temperature upto 325°C, 90 min. The maximum hardness was obtained in case of 300°C condition.

4.0 CONCLUSIONS

(1). From the present study it has been concluded that as the temperature decreased, the strength increased but it also resulted brittleness in the material due to increased hardness. Brittleness however, can be reduced by increasing the soaking time. Due to this, results of breaking load were good when low temperature of 325°C and large soaking time of 90 minutes was used as compared to other conditions of temperature and soaking time. In this condition, the hardness achieved was of 49 HRC with reduced brittleness as compared to other conditions.

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