Thesis Report

On

PROCESS OPTIMIZATION

OF

428 POWER TRANSMISSION CHAIN FOR ACHIEVING WEIGHT REDUCTION

Submitted in partial fulfillment of the requirement for the award of the degree of

MASTER OF ENGINEERING
IN
PRODUCTION & INDUSTRIAL ENGINEERING

Submitted By

Gaurav Soni

Roll No. 801082007

Under the Guidance of

Dr. Ajay Batish

Professor & Head

Department of Mechanical Engineering

Thapar University, Patiala

Department of Mechanical Engineering,

Thapar University,

Patiala-147004.

JULY 2012

DECLARATION

I hereby declare that the work done in this thesis entitled **"PROCESS OPTIMIZATION OF 428 POWER TRANSMISSION CHAIN FOR ACHIEVING WEIGHT REDUCTION"** submitted towards partial fulfillment of the requirements for the award of the **Master of Engineering in Mechanical (Production and Industrial) Engineering** of **Thapar University, Patiala**, is an authentic record of work carried out by me under the supervision and guidance of **Dr. Ajay Batish, Professor & Head** of **Mechanical Engineering Department, Thapar University, Patiala**.

This matter embodied in this thesis has not been submitted in part or full to any other university or institute for the award of any degree.

(Gaurav Soni)

This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

Dr. AJAY BATISH

PROFESSOR & HEAD-MED

THAPAR UNIVERSITY, PATIALA

Countersigned by:

Dr. AJAY BATISH
PROFESSOR & HEAD-MED
THAPAR UNIVERSITY, PATIALA

Dr. S.K. MOHAPATRA
DEAN, ACADEMICS AFFAIRS
THAPAR UNIVERSITY, PATIALA

ACKNOWLEDGEMENT

Words are often less to reveal ones deep regards. With an understanding that work like this can never be the outcome of a single person. I take this opportunity to express my profound sense of gratitude and respect to all those who directly or indirectly helped me through the duration of this work.

I take the opportunity to express my heartfelt adulation and gratitude to my supervisor Dr. Ajay Batish, Professor and Head, Mechanical Engineering Department for *his unreserved guidance, constructive suggestions, thought provoking discussions and unabashed inspiration in the nurturing work. It has been a benediction for me to spend many opportune moments under the guidance of the perfectionist at the acme of professionalism. The present work is testimony to his activity, inspiration and ardent personal interest, taken by him during the course of his work in its present form.*

Necessity being the mother of all inventions, I would like to thank Rockman Industries Ludhiana, who had created the necessity of the work which help me create my basic platform and financially assisting me. Mr. A Shanmugam, Sr. Manager–R&D for assisting me whole heartedly throughout the work. Mr. SumitUtreja – Vice President for granting such a beautiful work.

No words acknowledge the support I received from my friends for their valorous help and co-operation. I would like to thank all the members and employees of Mechanical Engineering Department, Thapar University, Patiala for their everlasting support. Above all, I express my indebtedness to the "ALMIGHTY" for all his blessings and kindness.

Gaurav Soni

801082007

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. In drive chain, tempering 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, parameters such as temperature and time have been changed and improved results have been found in some cases. Attempts are also made to eliminate the tempering without compromising with the strength. Existing literature suggest that austempering may be another option. Trials reveal that, this process have capability to produce chain parts with better strength in reduced time.

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1.1 General

Today, in this competitive market where material, time, quality, processes are the main factor that contributes towards profit incurred to the company. Now trend has been changed significantly from the past where only quality was considered as the main goal. But now profit and quality both are considered as main concern. So this thesis work was aimed at reduction of weight of power transmission roller chain by optimizing the processes, time, material. It was achieved by introducing new processes such as austempering heat treatment method and performing tempering heat treatment method at different conditions [1].

1.2 Power Transmission Derives

Power transmission is the movement of energy from its place of generation to a location where it is applied to performing useful work [2].

Power is defined formally as units of energy per unit time In SI units:

Watt = joule/second = newton*meter/second

There are various method to transmit power from one place to another which are listed as:

1.2.1 Gears Drives

Gears are toothed wheels that are meshed together to transmit a twisting force (torque) and motion. They are usually attached to a shaft and can be considered a rotating lever. Utilizing leverage principles, gears can enhance or inhibit effort (force) or change effort (force) direction. Gears are either turned by a shaft or they turn the shaft. A large gear can apply more twisting force on a shaft to which it is attached than a smaller gear. Gears that have straight teeth (perpendicular to their facing) and that mesh together in the same plane with axles parallel are known as spur gears. Spur gears provide an important way of transmitting a positive motion between two shafts. They give a smooth and uniform drive. In the fig 1.1, one gear, labeled the driver (also known as the driving gear) is turned by a motor. As it turns, it turns the other gear, known as the driven gear. A basic rule concerning gears states that each gear in a series of gears reverses the direction of rotation of the previous gear [3].

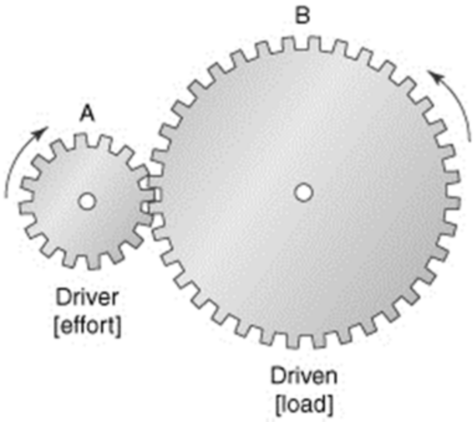

Fig 1.1: Gear drive [3]

1.2.2 Belts Drives

In machinery, a pair of pulley wheels attached to parallel shafts and connected by a flexible band of flat leather, rubber, or similar material is known as a belt drive. Like gear trains, a belt drive can be used to increase or reduce the speed and mechanical advantage (torque) of the pulley wheels they are attached to and modify rotational motion from one shaft to the other. Unlike gears, however, belt drives rotate in the same direction. A belt's top surface can also be used to convey materials across it, such as on a conveyor belt. Belts are installed under tension in order to create friction, which allows the belt to grip and turn the pulley wheels. Substantial tension also keeps the belt from slipping off the pulley wheels when rotating. Belt drives are better for greater distances with smaller forces since they are not directly joined [3].

There are two types of belt drives, positive and nonpositive. Positive belt drives (gear belts) consist of belts with teeth that mesh with pulley wheels that also have teeth. This type of belt drive does not allow the belt to slip. They are used in applications requiring a higher horsepower or torque capacity. A nonpositive belt drive system utilizes smooth belts and pulley wheels. The design of a nonpositive belt is in the shape of a "V.' These belts require less tension than do flat belts because they have more surface area in contact with the pulley wheels. Nonpositive belt drives are useful for connecting shafts that are in close proximity to one another. The V-belt found inside of an automobile engine is an example of the nonpositive type. Crossed (twisted) belts cause shafts to rotate in opposite directions [3].

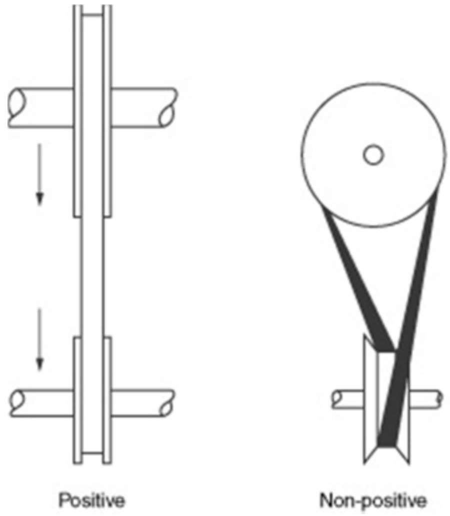

Fig 1.2: Belt drive [3]

1.2.3 Chain Drives

Chain drive is a way of transmitting mechanical power from one place to another. It is often used to convey power to the wheels of a vehicle, particularly bicycles and motorcycles. Most often, the power is conveyed by a roller chain, known as the drive chain or transmission chain, passing over a sprocket gear, with the teeth of the gear meshing with the holes in the links of the chain. The gear is turned, and this pulls the chain putting mechanical force into the system [3].

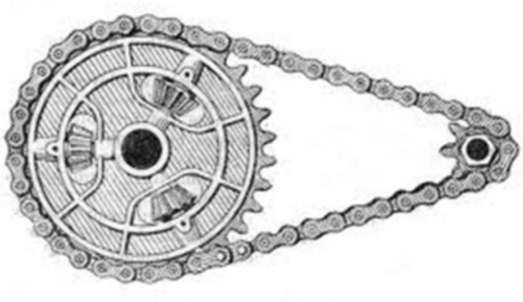

Fig 1.3: Chain drive [3]

1.3 Introduction to chain

A chain is a machine component, which transmits power by means of tensile forces, and is used primarily for power transmission and conveyance systems. The chains are mostly used to transmit motion and power from one shaft to another, when the centre distance between their shafts is short such as in bicycles, motor cycles, agricultural machinery, conveyors, rolling mills etc [2].

1.3.1 Classification of chains

The chains, on the basis of their use, are classified into the following three groups:

1. Power transmitting (or driving) Chains
2. Hoisting and hauling (or crane) chains
3. Conveyor (or tractive) chains

1. Power transmitting (or driving) Chains:

These chains are used for transmission of power, when the distances between the centres of shafts are short. These chains have provision for efficient lubrication. The power transmitting chains are of following three types.

a) Block or bush chains: A block chain was used in the early stages of development in the power transmission. It produces noise when approaching or leaving the teeth of the sprocket because of rubbing between the teeth and links. Such types of chains are used to some extent as conveyor chain at small speed [2].

b) Bush roller chain: A bush roller chain consists of outer plates, inner plate, pins, roller, and bushes. 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. A bush roller chain is extremely strong and simple in construction. It gives good services under severe condition. There is a little noise with this chain which is due to impact of the rollers on the sprocket wheel teeth. This chain may be used where there is a little lubrication. When one of these chains elongates slightly due to wear and stretching of the parts, then the extended chains is of greater pitch than the pitch of the sprocket wheel teeth. The rollers then fit unequally into the cavities of the wheel. The result is that the total load falls on the one teeth or on a few teeth. The stretching of the parts increases wear of the surfaces of the roller and of the sprocket wheel teeth. These chains are manufactured on the basis of pitch. These chains are available in single row or multi-row roller such as simple, duplex, or triplex strands [2].

c) Silent chains: A silent chain is also known as inverted tooth chain. It is designed to eliminate the evil effects caused by stretching and to produce noiseless running. When the chain stretches and the pitch of the chain increases, the link rides on the teeth of the sprocket wheel at a slightly increased radius. This automatically corrects the small change in the pitch [2].

1.3.2 Basic Structure of Bush Roller Power Transmission Chain

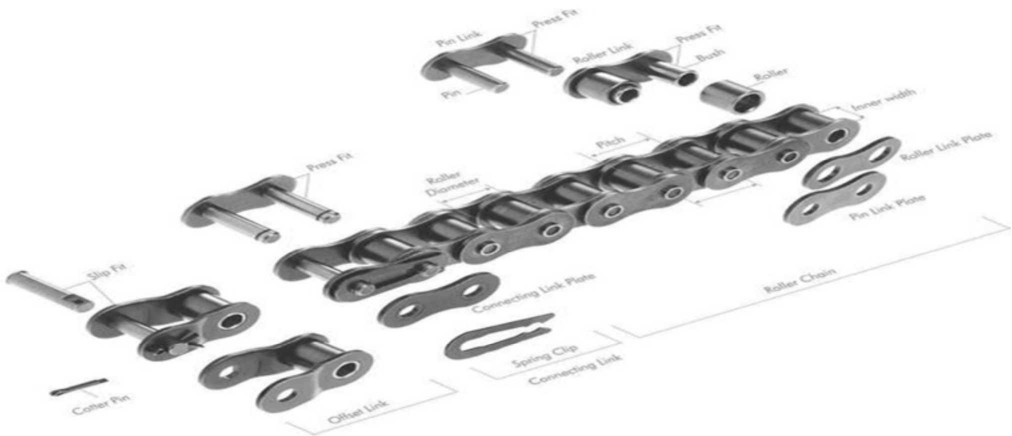

Fig 1.4: The Basic structure of bush roller power transmitting chains [4]

The figure1.4 shows the basic structure of bush roller power transmitting chains, it includes connecting, offset link, roller chain which after assembly, a desired chain is obtained.

1.3.3 The Basic Components of Transmission Chain are [4]:

a) Connecting link
b) Offset link
c) Roller chain

a) Connecting Link

This is the ordinary type of connecting link. The pin and link plate are slip fit in the connecting link for ease of assembly. This type of connecting link is 20 percent lower in fatigue strength than the chain itself. There are also some special connecting links which have the same strength as the chain itself. There are three types of connecting links: spring clip connecting link, cotter pin connecting link and spring pin connecting link [4].

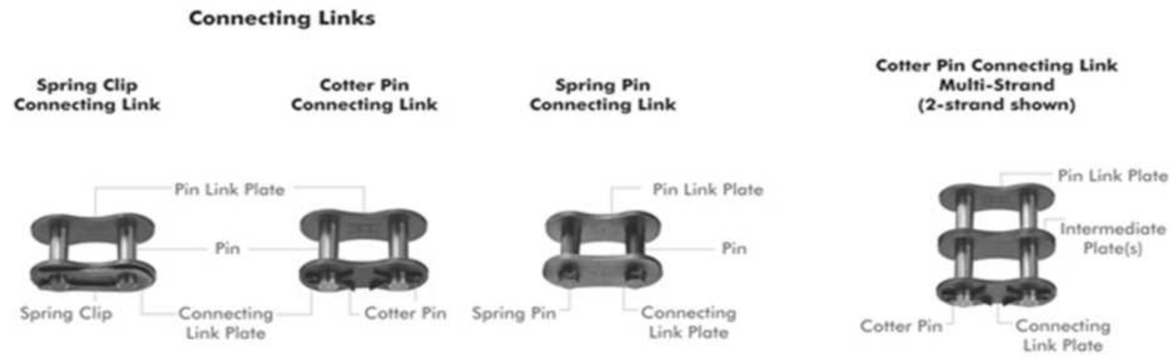

Fig1.5: connecting links [4]

b) Offset Link

An offset link is used when an odd number of chain links is required [4].

1.3.4 Various components of link are:

1. Inner plate
2. Outer plate
3. Bush
4. Roller
5. Pin

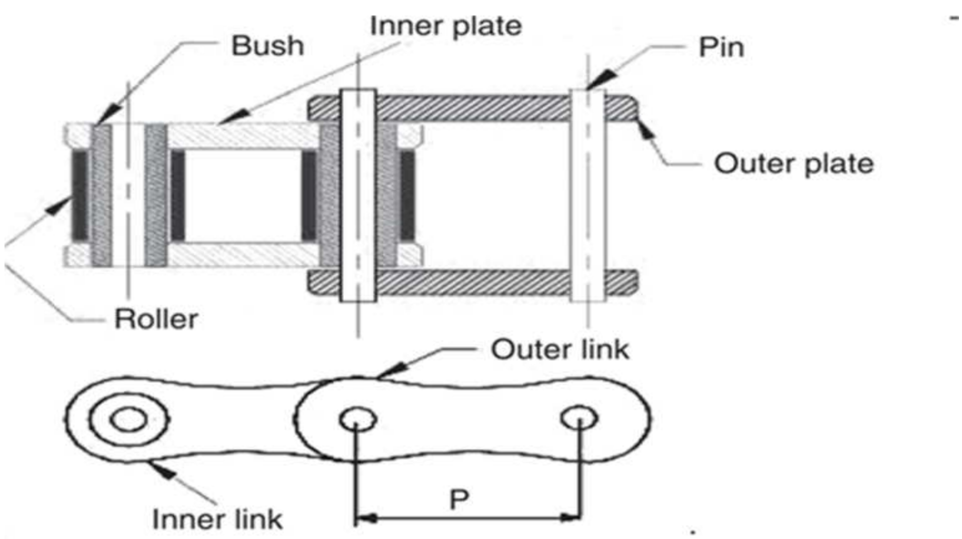

Fig 1.6: **Various components of link [4]**

1.3.5 Materials of drive chain elements

A chain is made up of various components such as inner plate, outer plate, pin, roller, bush. All components were of different material which were listed as:

Table 1.1: Materials of drive chain elements [1]

Sr. no.	Component	Material
1.	Inner plate	SAE 1050
2.	Outer plate	SAE 1050
3.	Pin	15B25
4.	Bush	16MnCr5
5.	Roller	C1018

Usually the SAE 1050 material which were used in order to make drive chain parts(I/O plate). But other material such as SAE 1040 and 1045 can replace 1050 material.

General characteristics and Chemical composition of SAE 1040

SAE 1040 steel has a higher (0.40%) carbon content for greater strength than the lower carbon alloys. It is hardenable by heat treatment, quench and tempering to develop 150 to 250 ksi tensile strength [5].

Chemical Composition of SAE 1040 [5]

Table 1.2: Chemical composition of SAE 1040

Elements	Carbon	Manganese	Phosphorus	Sulphur	Iron
%age	0.37-0.44	0.6-0.9	0.04	0.05	Balance

General Characteristics and Chemical Composition of SAE 1045

SAE 1045 is a low-cost alloy suitable for most engineering and construction applications. Medium-carbon steel with adequate strength and toughness characteristics, SAE 1045 is valuable for induction- or flame-hardened components [5].

Chemical Composition of SAE 1045 [5]

Table 1.3: Chemical composition of SAE 1045

Elements	**Carbon**	**Manganese**	**Phosphorus**	**Sulphur**	**Iron**
%age	0.43	0.6-0.9	0.04	0.05	Balance

General Characterstics and Chemical Composition of SAE 1050

SAE 1050 Steel is a plain carbon steel containing 0.50 wt% of carbon. Strain hardened, stress relieving material typically 100 KSI yield strength.1050 Steel is a plain carbon steel containing 0.50 wt% of carbon.Embrittlement diagram. Temper embrittlement. Treatment: Specimens hardened by heating to 830°C (1525°F) for 30 min and brine quenching. Prior to isothermal embrittlement treatment, all specimens were tempered by induction heating to 650°C (1200°F) for 5 s [5].

Chemical Composition [5]

Table 1.4: Chemical composition of SAE 1050

Elements	**Carbon**	**Manganese**	**Phosphorus**	**Sulphur**	**Iron**
%age	0.48-0.55	0.6-0.9	0.04	0.05	Balance

1.4 Heat treatment of chain elements

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. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics [6].

In heat treatment of chain components, various heat treatment processes are used such as hardening, tempering, Case hardening and austempering which is to be proposed.

1.4.1 Hardening

Hardening is a process of cooling a metal very quickly. This is most often done to produce a martensite transformation. In ferrous alloys, this will often produce a harder metal, while non-ferrous alloys will usually become softer than normal.To harden by quenching, a metal (usually steel or cast iron) must be heated above the upper critical temperature and then quickly cooled. Depending on the alloy and other considerations (such as concern for maximum hardness vs. cracking and distortion), cooling may be done with forced air or other gases, (such as nitrogen). Upon being rapidly cooled, a portion of austenite (dependent on alloy composition) will transform to martensite, a hard, brittle crystalline structure. The quenched hardness of a metal depends on its chemical composition and quenching method [6].

1.4.2 Tempering

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. It usually follows quenching from above the upper critical temperature; however, tempering is also used to relieve the stresses and reduce the hardness developed during welding and to relieve stresses induced by forming and machining. 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. Carbon atoms were trapped in the austenite when it was rapidly cooled, typically by oil or water quenching, forming the martensite. The martensite becomes strong after being tempered because when reheated, the microstructure can rearrange and the carbon atoms can diffuse out of the distorted body-centred-tetragonal (BCT) structure. After the carbon diffuses, the result is nearly pure ferrite with body-centred structure. Tempering results in an increase in softness, malleability, impact resistance and improved dimensional stability. Tempering is always performed be-low the lower critical temperature (A1) of the steel, which differentiates tempering from such processes as annealing, normalizing and hardening. When hardened steel is reheated, tempering effects start to occur as low as 212°F (100°C) and accelerate as the temperature increases. The minimum temperature time for tempering should be one hour. A good "rule of thumb" for furnace or oven tempering is that if the part is more than 1 inch (25 mm) thick, increase the time by one hour for each additional inch (25mm) of thickness [6].

Temper Colors

The use of temper color is one method of not only visually determining if a part has been exposed to the proper tempering temperature but to check if all parts in a given load reached a uniform temperature. When steel is heated and exposed to air (or an oxidizing atmosphere) for a short period of time, it will change color due to the presence of a thin, tightly adhering oxide. The temper color and thickness of the oxide layer varies with both time and temperature (Table 1.5). Different steel chemistries also result in slight color variations. The colors produced are typically not uniform because of surface condition and fluctuation of temperature [6].

Table 1.5: Temper colors [6]

Colour of Metal		Degrees C	Degrees F
Feint Straw		200	390
Very Faint Yellow		210	410
Light Yellow		220	430
Pale Straw Yellow		230	445
Golden Yellow/Dark Straw		240	465
Dark Yellow Brown		250	480
Brown Yellow/Purple		260	500
Brown Purple		270	520
Dark Purple		285	545
Full Blue		290	555
Dark Blue		300	570

Very Dark Blue		315	600
Greyish Blue		330	625
Dark Grey		427	800
Black Red/Red-grey		537	1000
Brown Red		600	1110
Blood Red		650	1200
Dark Cherry Red		715	1320
Medium Cherry Red		770	1420
Full Cherry Red		815	1500
Bright Orange Red		843	1550
Light Red		875	1610
Orange		930	1705
Orange Yellow		990	1815
Dark yellow		1050	1920
Bright Yellow		1093	2000
Light Yellow		1100	2010
White		1200	2190
Beginning to sparkle		1400	2550
Melting	N/A	1500	2730

1.4.3 Austempering

Austempering is a quenching technique. The part is not quenched through the Martensite transformation. Instead the material is quenched above the temperature when Martensite forms M_S. It is held till at this temperature till the entire part reaches this temperature. As the part is held longer at this temperature, the Austenite transforms into Bainite. Bainite is tough enough so that further tempering is not necessary, and the tendency to crack is severely reduced [7].

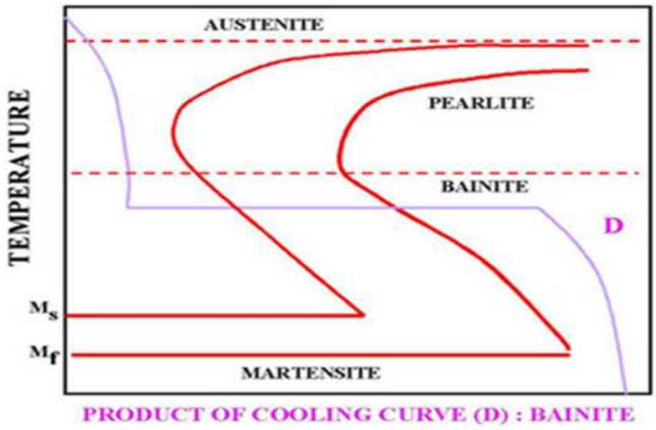

Fig 1.7: Austempering curve (D) [8]

The microstructure obtained from austempering heat treatment process is bainite which shown in fig 1.8:

Fig 1.8: Bainite microstructure [8]

The various types of salts that can be used in performing austempering process are:

a) **T.S. -150** :- T.S. – 150 The salt is used for quenching of steel from austenitizing temperature into the molten salt of T. S. -150 maintained at a temperature slightly above the martensite range.
Working Range :- 150^{o}C – 550^{o}C.
b) **T.S. – 220**: It is a tempering salt for alloy steels and high carbon steels. It is also used for Austempering and martempering of steel. it is also used for Austempering are martempering of steel. The salts are Nitrate / Nitrate based.
Working Range :- 220^{o}C – 550^{o}C.
c) Neutral salts

Difference between austempering and conventional quench and tempering

The most notable difference between austempering and conventional quench and tempering is that it involves holding the workpiece at the quenching temperature for an extended period of time. The basic steps are the same whether applied to cast iron or steel and are as follows:

Austenitizing

In order for any transformation to take place the microstructure of the metal must be austenite. The exact boundaries of the austenite phase region depend on the chemistry of the alloy being heat treated. However, austenitising temperatures are typically between 790 and 915°C (1455 to 1680°F). The amount of time spent at this temperature will vary with the alloy and process specifics for a through-hardened part the best results are achieved when austenitization is long enough to produce a fully austenitic metal microstructure (there will still be graphite present in cast irons) with a consistent carbon content. In steels this may only take a few minutes after the austenitizing temperature has been reached throughout the part section, but in cast irons it takes longer. This is because carbon must diffuse out of the graphite until it has reached the equilibrium concentration dictated by the temperature and the phase diagram. This step may be done in many types of furnaces, in a high temperature salt bath, via direct flame or induction heating. Numerous patents exist for specific methods and variations [9].

Quenching

As with conventional quench and tempering the material being heat treated must be cooled from the austenitizing temperature quickly enough to avoid the formation of pearlite. The specific cooling rate that is necessary to avoid the formation of pearlite is a product of the chemistry of the austenite phase and thus the alloy being processed. The actual cooling rate is a product of both the quench severity, which is influenced by quench media, agitation, load (quenchant ratio, etc.), and the thickness and geometry of the part. As a result, heavier section components required greater hardenability. In austempering the heat treat load is quenched to a temperature which is typically above the Martensite start of the austenite and held. In some patented processes the parts are quenched just below the Martensite start so that the resulting microstructure is a controlled mixture of Martensite and Bainite [9].

The two important aspects of quenching are the cooling rate and the holding time. The most common practice is to quench into a bath of liquid nitrite-nitrate salt and hold in the bath. Because of the restricted temperature range for processing it is not usually possible to quench in water or brine, but high temperature oils are used for a narrow temperature range. Some processes feature quenching and then removal from the quench media, then holding in a furnace. The quench and holding temperature are primary processing paramters that control the final hardness, and thus properties of the material [9].

Cooling

After quenching and holding there is no danger of cracking; parts are typically air cooled or put directly into a room temperature wash system [9].

Tempering

No tempering is required after austempering if the part is through hardened and fully transformed to either bainite or ausferrite. Tempering adds another stage and thus cost to the process [9].

Advantages

Austempering offers many manufacturing and performance advantages over traditional material/process combinations. It may be applied to numerous materials. One of the advantages that is common to all austempered materials is a lower rate of distortion than for quench and tempering. This can be translated into significant cost savings by adjusting the entire manufacturing process. The most immediate cost savings are realized by machining before heat treatment [9].

In steels above 40 Rc these improvements include:

- Higher ductility, impact strength and wear resistance for a given hardness
- A low distortion, repeatable dimensional response
- Increased fatigue strength
- Resistance to hydrogen and environmental embrittlement.

1.4.4 Carbonitriding

Carbonitriding is a metallurgical surface modification technique that is used to increase the surface hardness of a metal, thereby reducing wear. During the process, atoms of carbon and nitrogen diffuse interstitially into the metal, creating barriers to slip, increasing the hardness and modulus near the surface.. Surface hardness of carbonitrided parts ranges from 55 to 62 HRC.

Carbonitriding is similar to gas carburizing with the addition of ammonia to the carburizing atmosphere, which provides a source of nitrogen. Nitrogen is adsorbed at the surface and diffuses into the workpiece along with carbon. Carbonitriding (around 850 °C / 1550 °F) is carried out at temperatures substantially higher than plain nitriding (around 530 °C / 990 °F) but slightly lower than those used for carburizing (around 950 °C / 1700 °F) and for shorter times.

1.5 Complete cycle of Drive chain preparation [1]

1. Firstly the inner/outer plate are manufacturing by performing piercing and blanking operation then it goes to heat treatment furnaces for through hardening and tempering.
2. In case of pin, firstly wire is cutting into desired dimension then it goes to heat treatment furnaces for case hardening and tempering and then it goes for tumbling operation for polishing.
3. In case of roller, firstly wire is fed into the cold forging machine where roller is made then it goes to heat treatment furnaces for case hardening and tempering and then it goes for tumbling operation.
4. In case of bush, firstly coil is fed into the cutting and curling machine after which bush is obtained and then it goes to heat treatment furnaces for case hardening and tempering and then it goes for tumbling operation.

5. After manufacturing each component, then these components goes into the assembly machine for assembly of complete chain.

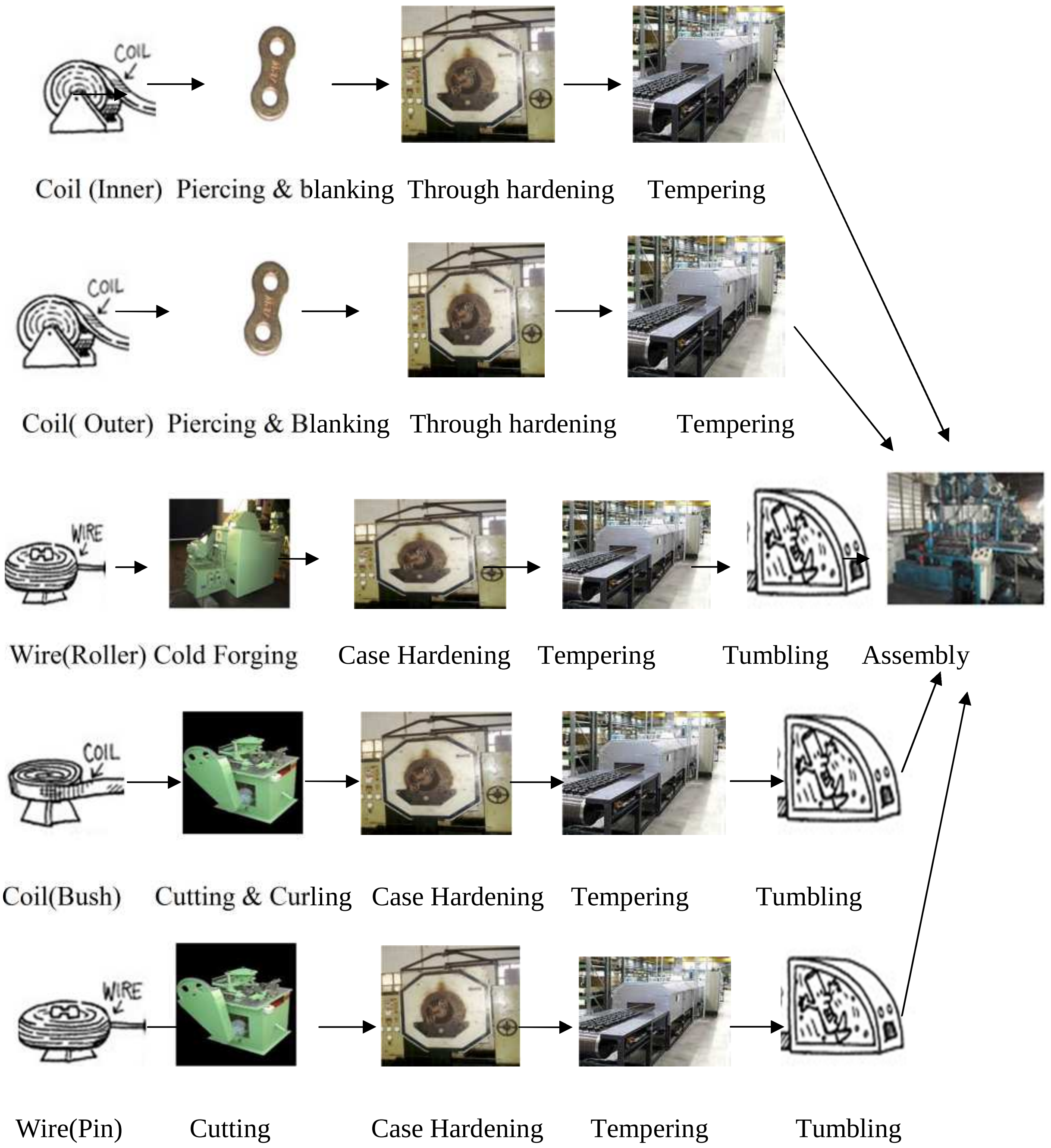

Fig 1.9: Complete cycle of drive chain preparation [1]

1.6 Introduction to Fine Blanking

Fine blanking is a specialized form of blanking where there is no fracture zone when shearing. This is achieved by compressing the whole part and then an upper and lower punch extract the blank. This allows the process to hold very tight tolerances, and perhaps eliminate secondary operations. A typical compound fine blanking press includes a hardened die punch (male), the hardened blanking die (female), and a guide plate of similar shape/size to the blanking die. The guide plate is the first applied to the material, impinging the material with a sharp protrusion or *stinger* around the perimeter of the die opening. Next a counter pressure is applied opposite the punch, and finally the die punch forces the material through the die opening. Since the guide plate holds the material so tightly, and since the counter pressure is applied, the material is cut in a manner more like extrusion than typical punching. Because the material is so tightly held and controlled in this setup, part flatness remains very true, distortion is nearly eliminated, and edge burr is minimal. Clearances between the die and punch are generally around 1% of the cut material thickness, which typically varies between 0.5–13 mm (0.020–0.51 in) [10].

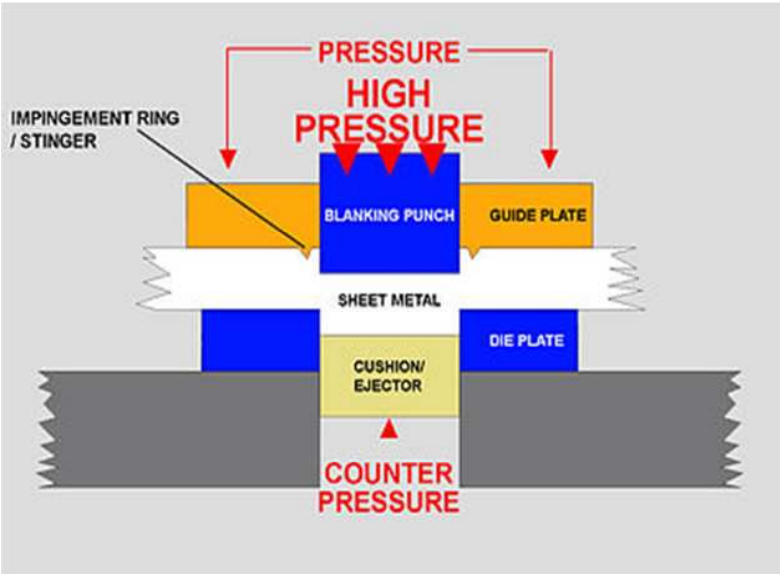

Fig 1.10: Fine blanking [10]

1.6.1 Advantages [10]

The advantages of fine blanking are:

- excellent dimensional control, accuracy, and repeatability through a production run.
- excellent part flatness is retained.
- straight, superior finished edges to other metal stamping processes.

1.6.2 Disadvantages [10]

The disadvantages are:

- Slightly higher tooling cost when compared to traditional operations.
- Slightly slower than traditional punching operations.

1.7 Overview of present work

This research work deals with fulfilling the desired objectives which includes reducing the weight of power transmission chain as well as improving the strength of chain parts. All these are achieved by carrying out tempering on chain parts at different conditions of temperature and soaking time or by introducing new process of austempering.

2.1 General

A lot of research work was carried out to improve the strength and other mechanical properties of various grades of steel by performing various heat treatment processes such as tempering, austempering and other process such as fine blanking, cold forging.

2.2 Tempering

ZOU *et al*. [11] 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. After heat treatments, microstructure examination was conducted by scanning electron microscope, X-ray diffraction examinations, hardness measurements and tensile tests. 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. It was believed that the property was correlated with the microstructure of tempered lath martensite and retained austenite. More retained austenite content was beneficial to the higher toughness of the SMSS.

Wei *et al*. [12] investigated the effect of heat treatment on properties of 1000 MPa ultra high strength steel. Two types of steel, C-Mn-Cr-Mo-B micro alloyed steel and C-Mn-Mo-Nb-Cu-B micro alloyed steel, were designed to develop 1000 MPa ultra-high strength steel. Two kinds of processes, thermo mechanical controlled process (TMCP) combined with traditional off-line quenching and tempering (QT) process versus controlled rolling process (CR) combined with direct quenching and tempering (DQ+T) process, were applied. The effect of heat treatment processing mode on the microstructure and mechanical properties was studied. The relationship between microstructure and mechanical properties was investigated by SEM and TEM. After tempering at 450 to 550°C for 1 h, the steel produced by TMCP+QT process showed combination of excellent strength and low temperature toughness. The yield strength was above 1000 MPa, elongation above 15% and impact energy at −40°C more than 30 J. After tempering at 450°C, a large number of ε-Cu particles precipitated in C-Mn-Mo-Nb-Cu-B steel produced by CR+DQ+T process lead to a significant increase in yield strength. And after tempering at 500 to 600°C, the yield strength of the steel was further improved to 1030 MPa because of precipitates, such as nitride or carbide of niobium, carbide of molybedenum and vanadium. When the tempering temperature was increased above 620°C, the yield strength was still higher than 1000 MPa and elongation was above 20% and impact energy at −40°C was more than 35 J. After tempering at above 500°C, the toughness of the steel treated by TMCP+QT process was superior to that of steel by CR+DQ+T process.

Salemi & zadeh [13] 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. However, UTS decreased at a higher rate compared with that for the YS.

Shi & Liu [14] 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. Furthermore, the tempering effect was modeled and expressed as a function of thermal history and material hardness. The modeling results agreed with the experiment reasonably well. Based on the model, the tempering effect on flow stress can be separated from the softening effect due to temperature rise, and both effects can be studied individually.

Sanij *et al*. [15] investigated the effect of double quenching and tempering (DQT) with conventional quenching and tempering (CQT) heat treatment processes on microstructure and mechanical behavior of a commercially developed hot rolled AISI 4140 type steel. The results indicated that the improvement of mechanical properties particularly impact toughness of DQT heat treated specimens was much higher than that of the CQT condition, and this observation was rationalized in terms of finer austenite grain size developed in the DQT condition providing much finer martensitic packets within the grains and a lower level of impurity concentration of sulfur (S) and phosphorus (P) near the prior austenite grain boundaries as well.

Sahin *et al*. [16] investigated the effect of martensite volume fraction (MVF) and tempering time on the abrasive wear of ferritic ductile iron with a dual matrix structure (DMS). Specimens were partially austenitized in the two-phase region ($\alpha + \gamma$) at temperatures of 795 and 815 ◦C for 20 min and then quenched in oil held at 100 ◦C to obtain different MVF. The specimens were subjected to tempering at a temperature of 500 ◦C for 1 and 5 h. Some specimens were also conventionally heat-treated (austenitized at 900 ◦C and then quenched + tempered) for comparison. Samples were tested for tensile strength, ductility and abrasive wear. The results showed that weight loss resistance and strength increased and ductility decreased with increasing MVF.

2.3 Austempering

Saxena *et al*. [17] Studied the influence of austempering parameters on microstructure and tensile properties of medium carbon-manganese steel. Austempering heat treatment practice helped in achieving high strength with good ductility and toughness by evolving a predominantly bainitic microstructure in the steel. Further, austempering practice can be modified to facilitate formation of some amount of ferrite and pearlite along with bainite which in turn enhances the ductility with some lowering of strength in the steel. The actual strength and ductility depends upon the relative amount of ferrite, pearlite and bainite present in the austempered steel.. Laboratory simulation studed on conventional austempering showed that a microstructure comprising predominantly bainite with up to 4% ferrite was evolved which imparted a tensile strength of 120 kg/mm^2 and elongation of 4% (at 150 mm gauge length) to the austempered steel. On the other hand, when the steel was subjected to modified austempering practice which included austenitising at different temperatures for a period of 2 min followed by controlled air cooling and quenching in a lead bath at 450 °C, variety of microstructures were obtained. Particularly, when the steel was austenitised at 870–900 °C, a microstructure comprising uniformly distributed fine pearlite and bainite in a matrix of ferrite was formed. This microstructure resulted in tensile strength of 95 kg/mm^2 and elongation of 9% (at 150 mm gauge length).

Sohi *et al*. [18] studied the role of austempering parameters on the structure and mechanical properties of heavy section of ADI. The effect of the austempering parameters on structure and mechanical properties of specimens made from 75mm ductile iron Y-block with the composition of 3.5% carbon, 2.5% silicon, 1.1% nickel, 0.6% copper, 0.23% molybdenum, and 0.3% manganese was studied. The austempering carried out at 315 and 350 ^{0}C for 30, 60, 120, 180, 240, and 360 min. The results showed that the austempering times for optimum mechanical properties of austempered materials at 315 and 350 ^{0}C were 240 and 180 min, respectively. The results also indicated that austempering at 350 C, in comparison with austempering at 315 ^{0}C, results in higher ductility and toughness and lower strength and hardness. It was also noticed that in a Y-block, the best mechanical properties were achieved near the bottom of Y-block.

Yang & Putatunda [19] studied the effect of novel two step austempering process on strength and toughness of austempered ductile cast iron. A nodular or ductile cast iron with predominantly pearlitic as-cast structure was processed by a novel two-step austempering process. Two batches of samples were prepared. All the specimens were initially austenitized at 927 C (1700 F) for 2 h. The first batch of samples were processed by conventional single-step austempering process at several temperatures such as 260 ^{0}C (500 ^{0}F), 273 ^{0}C (525 ^{0}F), 288 ^{0}C (550 ^{0}F), 302 ^{0}C (575 ^{0}F), 316 ^{0}C (600 ^{0}F), 330 ^{0}C (625 ^{0}F), 343 ^{0}C (650 ^{0}F), 357 ^{0}C (675 ^{0}F), 371 ^{0}C (700 ^{0}F), 385 ^{0}C (725 ^{0}F) and 400 ^{0}C (750 ^{0}F) for 2 h, whereas the second batch of samples were processed by the two-step austempering process. These samples were initially quenched for 5 min in a salt bath maintained at 260 ^{0}C (500 ^{0}F) and then austempered for 2 h at several austempering temperatures. These temperatures were 288 ^{0}C (550 ^{0}F), 302 ^{0}C (575 ^{0}F), 316 ^{0}C (600 ^{0}F), 330 ^{0}C (625 ^{0}F), 343 ^{0}C (650 ^{0}F), 357 ^{0}C (675 ^{0}F), 371 ^{0}C (700 ^{0}F), 385 ^{0}C (725 ^{0}F) and 400 ^{0}C (750 ^{0}F). Influence of this two-step austempering process on microstructure and mechanical properties of ADI was examined. Test results showed that this two-step austempering process has resulted in significant improvement in yield and tensile strengths and fracture toughness of the material over the conventional single-step austempering process.

Rivera *et al*. [20] studied the effect of conventional austempering (CA) and steeped austempering (SA). When CA was applied some intercellular areas remain untransformed even for long time; however when samples were subjected to SA those untransformed areas disappeared and instead finer ausferrite was found. Additionally mechanical properties values obtained from tensile and impact tests confirmed that for all times used, SA was superior to the CA.

Barbacki [21] studied the role of bainite in shaping mechanical properties of steel and concluded that the various microstructural factors and mechanical characterstics of bainite differ markedly from those of tempered martensite. The remarkable possibilities of attaining high strength and toughness were offered by carbide-free ferritic bainite and mixed (bainite+ retained austenite) or (bainite+ martensite) microstructure.

Shaeri *et al*. [22] investigated that the presence of retained austenite gave rise to deterioration of the wear resistance and fracture strength of Cr-Mo steels in many cases. Thus, the effects of heat treatments including direct quenching, martempering, and austempering on the retained austenite existing in the microstructure of these steels were investigated. Specimens were austenized at 950 °C followed by direct quenching using compressed and still air. The specimens were also isothermally quenched in salt bath at 200 and 300 °C for 2, 8, 30, and 120 min. Microstructures of the specimens were studied using optical microscope (traditional black and white etching as well as color etching), scanning electron microscope (SEM), microhardness tester, and X-ray diffraction (XRD). The results showed that the lowest amount of retained austenite in the microstructure was obtained in the specimens quenched isothermally at 300 °C for 120 min.

Putatunda *et al*. [23] investigated the effect of austempering temperature on the microstructure and mechanical properties of a new low alloy and low carbon steel with exceptionally high strength and high fracture toughness. The influence of the microstructure on the mechanical properties and the fracture toughness of this steel was also studied. Test results showed that the austempering produces a unique microstructure consisting of bainitic ferrite and austenite in this steel. There were significant improvement in mechanical properties and fracture toughness as a result of austempering heat treatments. The mechanical properties as well as the fracture toughness were found to decrease as the austempering temperature increases. On the other hand, the strain hardening rate of steel increases at higher austempering temperature. A linear relationship was observed between strain hardening exponent and the austenitic carbon content.

Wen *et al*. [24] investigated the microstructure and mechanical properties of a GCr18Mo steel. The martensite/lower bainite (B_L/M) duplex structure with various B_L volume fractions (*f*BL) or that full of B_L were produced by austenitizing at 870 °C, quenching in nitrates at 230 °C and holding for different times. The steels with such structures exhibit higher strength–toughness than that of full martensite. When *f*BL is approximately 37.5% obtained by holding for about 60 min, the duplex-structured steel gave rise to the best combination of mechanical properties.

Chakraborty *et al*. [25] determined the optimum processing parameters for developing bainitic + martensitic microstructure in SAE 52100 bearing steel through appropriate austempering and quenching schedule, and obtaining improved mechanical properties of interest. Following austempering, the microstructure was characterized by optical/electron microscopy and X-ray diffraction and correlated with hardness and tensile/impact strength.

Hsu *et al*. [26] studied the effect of matrix toughening on fracture mechanics behavior when austempering heat treatment was applied on gray cast iron. Copper alloying was applied to increase the hardenability of the metal. The as-cast material was austenitized at 900°C for 1.5 h, and then austempered at 300°C/3 h or 360°C/2 h so as to obtain different matrix morphology, namely, lower ausferrite or upper ausferrite. A mixed ausferrite structure was also achieved by austempering at 360°C for 8 min followed by 300°C for 172 min. The results showed that the plane strain fracture toughness (K_{IC}) of the gray cast iron so heat-treated were increased from the as-cast of 12.3 MPa m to that of 16.0, 23.8, and 26.1 MPa m, respectively. These were marked improvement of 30, 93, and 112% over the as-cast material. Optical microscopy, scanning electron microscopy (SEM) and X-ray diffraction (XRD) techniques were applied to correlate the microstructural features to the properties attained.

Bakhtiari *et al*. [27] studied that 4340 steel bars were austenitized at 850 °C for 1 h followed by heating at 700 °C for 90 min and quenching into a salt bath at the temperature range of 300–450 °C for 1 h to obtain dual structures with 34 vol.% fraction ferrite and various bainite morphologies. SEM studies showed that by increasing the austempering temperature, bainite morphology varies from lower to upper bainite. Tensile, impact and hardness tests revealed that increasing the austempering temperature from 300 to 400 °C leads to a reduction in yield and ultimate tensile strength, hardness, uniform and total elongation and impact energy. But in dual phase steel produced by austempering at 450 °C, yield and tensile strength and hardness increased and severe reduction in total elongation and impact energy obtained. Fractography of tensile specimens showed brittle behavior for this austempering temperature. Fatigue test results showed that fatigue limit decreases with increasing austempering temperature from 300 to 400 °C. Finally, fractography studies showed cleavage fracture at the surface of fatigue specimens austempered at 400 °C, which confirms the tendency to brittle behavior.

Putatunda *et al*. [28] developed a new ausferritic steel with high strength and exceptionally high fracture toughness. The influence of the austempering temperature on the microstructure and mechanical properties of this steel at room temperature and ambient atmosphere has been examined. The effect of microstructure on the plane strain fracture toughness and on the magnetic, electrical, and thermal properties was also investigated. Compact tension and cylindrical tensile specimens prepared from the low alloy medium carbon steel with high silicon content were initially austenitized at 927 °C for 2 h and then subsequently austempered at several temperatures between 260 °C (500 F) and 400 °C (750 F) to produce different microstructures. The microstructures were characterized by X-ray diffraction, scanning electron microscopy and optical metallography. A combination of exceptionally high yield strength (1336 MPa) and a high fracture of toughness of 116 MPa√m (a value comparable to maraging steel) was obtained in this steel after austempering at 316 °C (600 F) for 2 h.

Chen *et al*. [29] developed a new type of Fe-C-Si-B alloy. The investigation on microstructure details and the mechanical properties were performed for different austempering combinations. The results indicated that the Fe-C-Si-B alloy comprises ferrite, pearlite and interdendritic eutectic borides in as-cast condition. The distribution of eutectic boride with a chemical formula of M2B (M represents Cr, Fe, Mn or Mo) and was much like that of carbide in high chromium white cast iron. Pure ausferrite structure that is consisted of bainitic ferrite and carbon-riched retained austenite can be obtained by austempering treatment to the Fe-C-Si-B alloy. No carbide would precipitate in the structure and there was not any morphology change of borides. The hardness of the Fe-C-Si-B alloy decreases with increasing of the austempering temperature, and decreases greatly in at the early stages (within 5 to 10 min) of austempering transformation. The transformation is almost finished after about 5 to 10 min when the hardness of the alloy did not change anymore. The Fe-C-Si-B alloy was a new kind of wear resistance material with bright application prospect.

Pérez *et al*. [30] tested a series of ductile iron samples alloyed with 0.66% Cu, 1.02% Ni, and 0.26% Mo for wear strength which were austempered at 315 and 370 °C for 5–240 min. A block-on-ring wear testing machine was used for this testing. The wear samples were tested under a load of 45 N and a displacement speed of 2.40 m/s. The experimental outcome indicated that the wear properties of the austempered ductile iron (ADI) were strongly influenced by the exhibited microstructure. In particular, optimal wear properties were found in samples austempered at 370 and 315 °C for 90 and 120 min, respectively. These heat treatment times were long enough to promote the development of a relatively high volume fraction of high carbon retained austenite concomitant with ferrite and a fine dispersion of carbides. After wear testing, scanning electron microscopy (SEM) observations on the wear samples did not show any evidence of a transformation-induced-plasticity (TRIP). Hence, the experimental evidence suggested that the dominant wear mechanism was delamination associated with sub-surface crack formation and final wear particle debris removal.

Abbaszadeh *et al*. [31] studied the effect of bainite morphology on mechanical properties of the mixed bainite-martensite microstructure in D6AC low alloy ultra-high strength steel. Samples austenitized at 910 °C for 40 min were quenched in three different ways. Some of the samples were directly oil-quenched, some others were quenched in salt bath at 330 °C and the remaining samples were quenched in salt bath at 425 °C for various holding times. All samples were tempered at 200 °C for 2 h. Microstructures were examined by optical microscopy (OM) and scanning electron microscopy (SEM). Fracture surfaces also were studied by SEM. Results showed that the mixed microstructure containing martensite and 28 vol.% of the lower bainite exhibited higher yield and tensile strengths than the fully martensitic microstructure. This could be mainly attributed to the partitioning of the prior austenite grains by the lower bainite and enhancing the strength of lower bainite in the mixed microstructure by plastic constraint. Charpy V-notch (CVN) impact energy and ductility were improved by increasing the volume fraction of the lower bainite. This was not the case about the mixed microstructure containing the upper bainite and martensite. As a result, the tensile and CVN impact properties of mixed upper bainite-martensite microstructure were lower than those of the fully martensitic microstructure. Finally, fractography studies showed cleavage fracture at the surface of CVN impact specimens with martensitic and upper bainitic microstructures confirming the tendency to brittle behavior.

Saeidi *et al*. [32] studied that different microstructures were produced by heat treatment of 4340 steel. These microstructures were bainite, martensite, ferrite–martensite and ferrite–bainite. Mechanical tests were carried out at room temperature. The results showed that steel with bainite–ferrite microstructure has better ductility and charpy impact energy than steels with martensite–ferrite and full bainite microstructures. But yield and tensile strengths of this steel were less than the yield and tensile strengths of the other two steels. Hardness measurements showed that their hardness was the same. Fracture surface observations of tensile specimens showed increase in toughness of bainite–ferrite in comparison to martensite–ferrite and full bainite microstructures.

Hsu *et al*. [33] investigated the microstructures and mechanical properties of lower bainite and tempered martensite in JIS SK5 steel. At equivalent hardness, the toughness and ductility of lower bainite were superior to those of tempered martensite. However, the lower bainite has a lower yield strength owing to that the bainite sheaf was larger than the tempered martensite plate. The fracture surface of lower bainite exhibits transgranular cleavage and differs considerably from that of tempered martensite. Tempered martensite embrittlement (TME) occurred in the tempered martensite, which was dominated by intergranular failure. It was caused by grain boundary segregation of phosphorus and grain boundary precipitation of carbide during tempering. Additionally, the size of the cleavage facet of lower bainite was demonstrated to be correlated with the width of the bainite sheaf. The results of electron back-scatter diffraction (EBSD) analysis indicated that not only that the sheaf boundary was a high-angle boundary, but also that the cleavage crack travels along the {0 0 1} ferrite plane, whose surface energy was low.

Zimba *et al*. [34] studied the effect of austempered ductile iron as an alternative material for earth moving components. ADI was obtained when ductile cast iron was accorded a special heat treatment known as austempering. The properties were compared with those quenched and tempered (Q&T) steel used in applications requiring wear resistance. When a load of 0.25 N was used, the relative abrasion resistance (RAR) of ADI austempered at 375ºC with an initial hardness of 315 Hv is 2.01, while that of a Q&T steel, of hardness 635 Hv is 2.02. The good wear resistance exhibited by ADI despite the low initial hardness can be attributed to the surface transformation of retained austenite to martensite during abrasion. This phenomenon has been positively confirmed by XRD.

2.4 Soaking Time

Chang *et al*. [35] 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. While at a very slow strain rate (0.0001 s_1), it increased the tensile strength by 24% at room temperature and 20% at 813 K. For a 3-point bending test, it showed that the optimum soaking time of HIP procedure could enhance the bending strength by 38% at room temperature and 26% at 813 K.

Wangmooklang *et al*. [36] 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. Density and mass loss of sintered specimens increased as function of soaking time. 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.

2.5 Fine Blanking

Thipprakmas [37] studied the effect of fine blanking on wear resistance of sprocket. Sprockets were conventionally fashioned by hobbing, followed by heat treatment. However, the fine-blanking process had recently seen increasing use by sprocket manufacturers. The process of fine-blanking has the possibility of reducing the number of process operations, thus reducing production time and cost, as well as improving part quality and process repeatability. The wear resistance of the fine-blanked sprocket was investigated because it was considered to be important for sprocket lifetime. The changes in material properties were also examined. With the special characteristic features of the fine-blanking process, a compressed and elongated grain structure along the contributed grain flow was generated within the shearing zone, resulting in an increase in surface hardness. This compressed and elongated grain structure feature was not generated in the sprocket fabricated by the hobbing process, therefore, the additional induction of heat-treatment was necessary to increase the surface hardness. The increase in surface hardness resulted in an improvement in wear resistance. This increased surface hardness and improved wear resistance for the fine-blanked sprocket SS400 was better than that of the commercial sprocket S50C.

Chen *et al.* [38] investigated the tearing failure in fine blanking process using coupled thermo-mechanical method. On the basis of the results of the simulation, the distributions of equivalent plastic strain and stresses in a fine-blanking process have been analyzed. It has been observed that the grains near the shearing edge were highly distorted within a narrow shearing zone. The formation of micro voids under large shear deformation supported the argument that material damage initiates and develops around this local area during the fine-blanking process. It was suggested that tearing failure could initiate from the damaged area of the workpiece adjacent to the tool tips where cracking occurs due to excessive local tensile stress produced by fine blanking attributes and interfacial friction.

2.6 Drive Chain

Binde & Covert [39] studied and made some analytical relations which helped in developing a better understanding of the mechanics of roller-sprocket impact. Various relative impact velocities were derived. These velocities may be used in impact energy relations for determining limiting sprocket speeds on the basis of roller breakage, noise, heating, and sprocket wear. Some experimental data on roller breakage were presented and used to illustrate a method of organizing data. Impact energy using a certain velocity correlates to some extent with roller breakage.

Conwell & Johnson [40] investigated the dynamic behavior of roller chain drives. A strain gage mounted on a link side plate was used to determine chain tension during normal operation over a wide range of linear chain speeds and preloads. The test machine also included specially instrumented idler sprocket that allowed the measurement of the horizontal and vertical components of the bearing reaction force. The roller-sprocket impact force was then computed by an experimental transfer function approach facilitated by a Bruel & Kjaer 2032 dual channel spectrum analyser. During investigation it was observed that as chain speed increases, dynamic effects become increasingly important. The tension in a chain link increased very rapidly as the link exits the driven sprocket. The increase from loose side to tight side average tension occurs over less than two sprocket teeth. The tension in a chain link decreased very rapidly as the link enters the drive sprocket. The decrease from tight side to average loose side tension occurs over less than two sprocket teeth. Transient spikes were present in the tension data at the point where the link exits the driven sprocket and at the point where the link enters the driven sprocket. Impact force tends to increased as chain tension increased, however the relationship was not monotonic. For a chain traveling in the horizontal direction, the vertical component of the impact force was much larger than the horizontal component. The magnitude of the horizontal component of the impact force increases more rapidly than the magnitude of the vertical component as the chain speed increases, indicated that the angle of impact (as measured from a vertical line) increases as chain speed increases.

2.7 Gaps in Literature review

1. In this thesis work it was proposed to use austempering heat treatment process on inner and outer plate of chain link at different conditions of temperature of holding in salt bath. This has not been done before.
2. No studies were reported on use of inner and outer plate of chain link in motorcycles having thickness less than 1.5mm.
3. No studies were reported on use of fine blanking operation in manufacturing power transmission chain parts such as inner and outer plate.
4. No studies were reported on use of low temperature tempering heat treatment process on power transmission chain parts such as inner and outer plate.

2.8 Objective of the present work

The objective of this thesis work is to reduce the weight of power transmission roller chain by reducing the thickness of inner and outer plate and other dimensions of chain parts such as pin, bush, and roller. Since weight reduction does not mean to increase the cost of manufacturing power transmission chain by using high strength, but costly materials. Proper selection of material is important so that it does not increase the cost. Process parameters related to the heat treatment such as austempering, tempering and other manufacturing methods such as fine blanking need to be identified to improve the performance of the chain parts.

3.1 General

The present work was undertaken as part of a sponsored project sanctioned by M/S Rockman Industry Limited, Ludhiana to Thapar University, Patiala with an objective to reduce the chain weight. Today, Rockman is a leading manufacturer of aluminum die cast parts, machined, painted assemblies and automotive chains for the automobile industry. To accomplish the aimed objectives of this research work as discussed in Chapter 2, heat treatment methods were applied in proper manner considering the strength constraints of chain. Tempering and Austempering were the two heat treatment method that applied on inner and outer plate of chain link at different conditions of temperature and soaking time. Firstly these were applied on existing design of link plates of chain link then after examining the former, the same were applied on improved design of link plates of chain link. After performing these processes, chains were assembled and then these were taken for destructive testing.

3.2 Heat Treatment Methods

The heat treatment methods were used on link plates of chain link in order to improve the mechanical properties of material such as strength, wear, impact strength etc. These methods are follows as:

- Tempering
- Austempering

3.2.1 Tempering

The tempering heat treatment method generally used to revive the mechanical properties of material. After hardening, the material becomes intense hard due to formation of martensite structure. Due to this structure, hardness increases and it results brittleness in the material. To reduce the brittleness, tempering process generally used.

Table 3.1 Existing Tempering conditions [1]

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

The Table 3.1 indicates the existing conditions of tempering of inner and outer plate. Both plate were tempered at 365^{o}C and then these were held at this temperature for 60 minutes followed by air cooling.

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.

Table 3.2: Trial tempering conditions

Element	Material	Thickness(mm)	Condition	
			Temperature(^oC)	Soaking time(min)
Outer Plates	SAE 1050	1.5	300	45
			300	90
			325	45
			325	90
			350	45
			350	90

Only outer plate was tempered at 6 different conditions of temperature and soaking time since during testing on Universal Testing Machine or operation only inner plate broke. These conditions are summarized in Table 3.2

3.2.2 Austempering

Austempering heat treatment method was different from other heat treatment method. In this no tempering was required after hardening. The conditions at which austempering was performed are listed in Table 3.3

Table 3.3: Conditions of austempering

Element	Material	Thickness(mm)	Conditions		
			Temperature(°C)	**Soaking time(min)**	**Salt**
Inner plate	SAE 1050	1.5	260-280	15	Neutral
Outer plate	SAE 1050	1.5	260-280	15	Neutral
Inner plate	SAE 1050	1.4	260-280	15	Neutral
Outer plate	SAE 1050	1.4	260-280	15	Neutral

3.3 Measuring Equipment used

The measurement equipments used were:

3.3.1 Universal Testing Machine

Universal Testing Machine, as shown in Figure 3.1 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 [1].

Specification of Universal Testing Machine:

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

Fig 3.1 Universal Testing Machine [1]

3.3.2 Scanning Electron Microscope (SEM) Machine

Microstructure of some selected samples was investigated on Scanning Electron Microscope, (model JSM-840A) of Joel, Japan, available in Material Testing lab of Thapar University, Patiala. The range of magnification from 10× to 3,00,000×. SEM of samples was investigated on three ranges, namely, 200×, 500× and 1000×

3.3.3 Surface Hardness Tester.

Surface hardness tester was used to find the hardness of various parts of links such as inner plate, outer plate. The diamond indenter was used for indentation and the unit of hardness taken HRC. The maximum load applied during checking hardness was 150 Kgf.

Fig 3.2: Surface hardness tester

3.4 Experimental Procedure

The experimental procedure was designed in order to achieve the objectives i.e. Weight reduction of chain without compromising the strength. The procedure followed is listed in the following steps:

1. Examining the existing components

Firstly all the components were examined for mechanical properties, chemical composition and surface hardness.

2. Procurement of raw material

After examining the existing components, raw material were procured from the M/S Rockman Industry Limited, Ludhiana. It included inner plate, outer plate, pin, roller, bush in soft form on which no heat treatment was done.

3. Performing heat treatment processes

After procuring raw material, heat treatment operations such as austempering and tempering were completed. Austempering heat treatment process was applied on soft inner plate and outer plate and tempering heat treatment process was completed on hardened inner and outer plate.

4. Assembly of chain parts into chains

After heat treatment, all components of link were assembled to form chain of 19-21 links.

5. Testing of assembled chain

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.

6. Analysis of breaking chains

The broken chains were analyzed in order to investigate the mode of failure and which part of chain actually broke during testing.

4.1 General

Using methodology as discussed in chapter 3, after completing heat treatment 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.

4.2 Mechanical properties of chain elements-Current process

The hardness of chain elements such as inner plate, outer plate, pin, bush, roller at every stage was measured using surface hardness tester. The hardness of chain parts increased after hardening and then the hardness values decreased after tempering. Hardness values of each part are summarized in Table below:

Table 4.1: 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

From Table 4.1, 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.

Table 4.2: Hardness of bush

Stages	Hardness (VHN)	Hardness (HRC)
Bush Soft	232	20
Bush Hardened	855	66
Bush Finished	830	65

From Table 4.2, the hardness of bush increased from 20 to 66 after case hardening as more carbon was absorbed by the material. During this process, atoms of carbon and nitrogen diffused interstitially into the metal, creating barriers to slip thus increasing the hardness near the surface.

Table 4.3: Hardness of pin

Stages	Hardness (VHN)	Hardness (HRC)
Pin(as cutting)	274	26
Pin(as hardened)	875	66
Pin(as tempered)	825	65
Pin(as finished)	797	64

From Table 4.3, the hardness of pin increased from 26 to 66 after case hardening as more carbon was absorbed by the material. After tempering, the hardness of pin decreased.

4.3 Testing of chain with outer plate tempered with proposed process

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. The conditions that were taken were believed to be optimized conditions.

4.3.1 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 4.4: 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 4.1: Plot between breaking and chain no.

Table 4.4, 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 4.5: 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

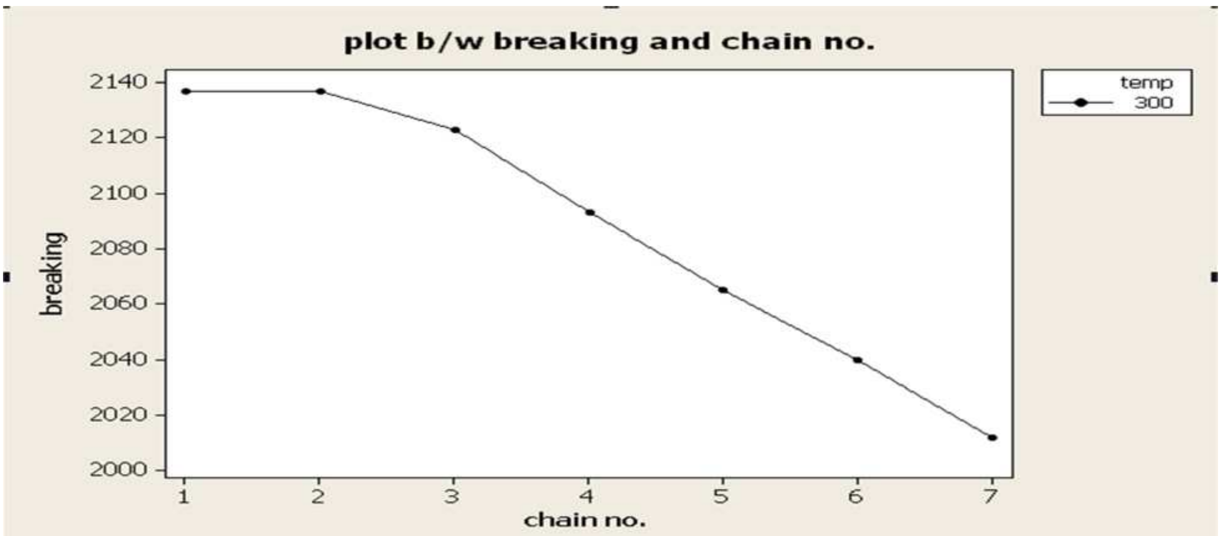

Fig 4.2: Plot between braking and chain no.

Table 4.5, showed 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 4.6: Results at 325^{o}C, 45min

Element	Condition		Trials	Breaking load(Kgf)	Element broken
	Temperature (^{o}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

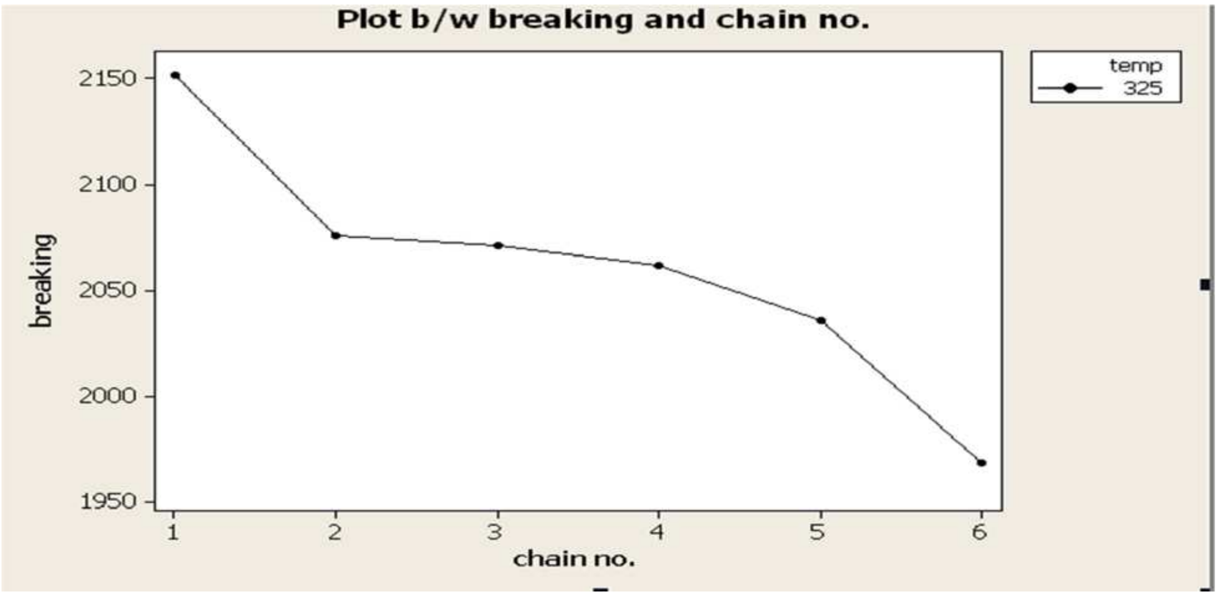

Fig 4.3: Plot between breaking and chain no

Table 4.6 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 4.7: Results at 325^{o}C, 90 min

Element	Condition		Trials	Breaking load(Kgf)	Element broken
	Temperature (^{o}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

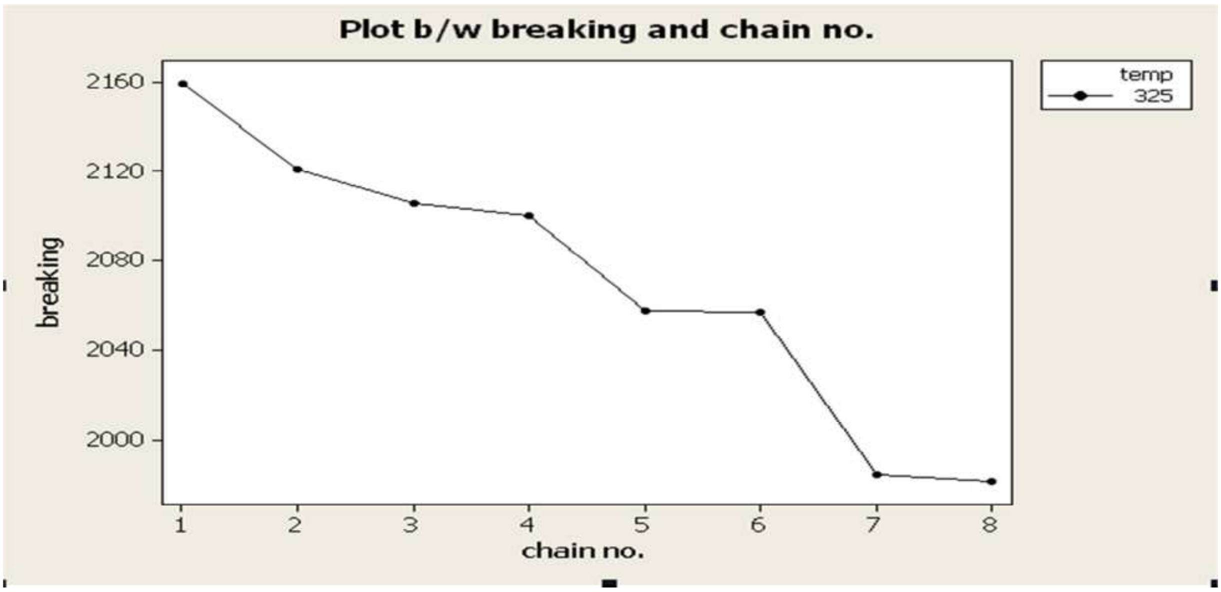

Fig 4.4: Plot between breaking and chain no

Table 4.7 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 4.8: Results at 350^{o}C, 45 min

Element	Conditions		Trials	Breaking load(Kgf)	Element broken
	Temperature (^{o}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

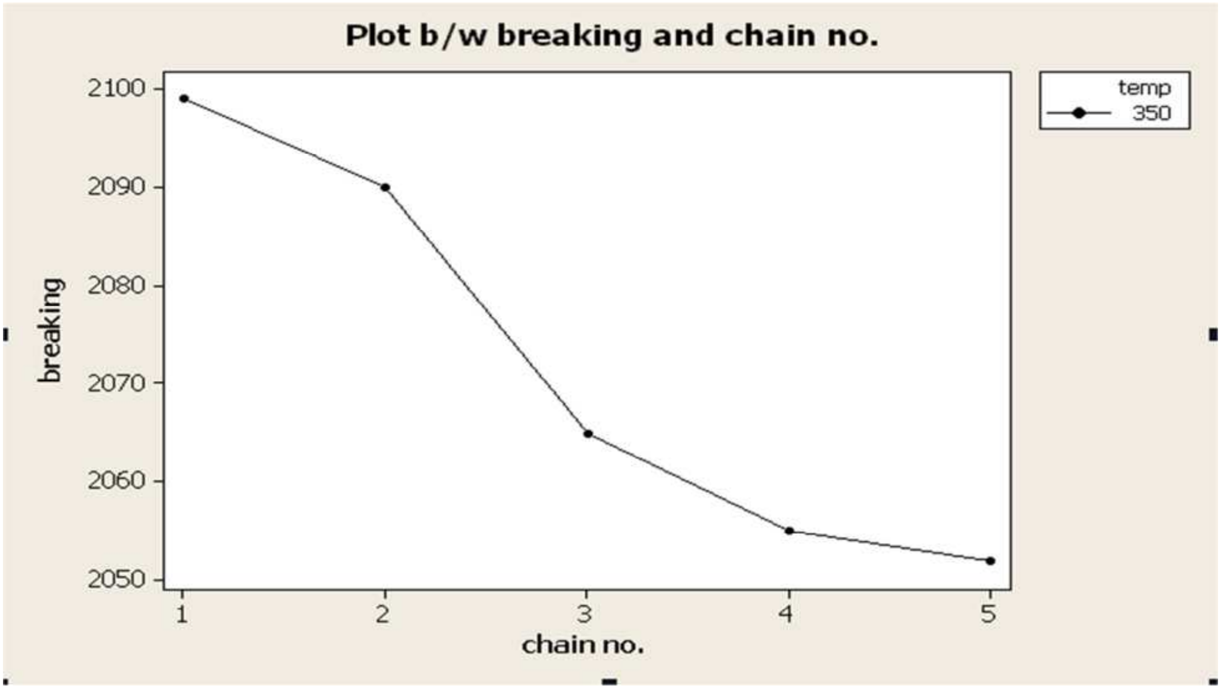

Fig 4.5: Plot between breaking and chain no.

Table 4.8 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 4.9: 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

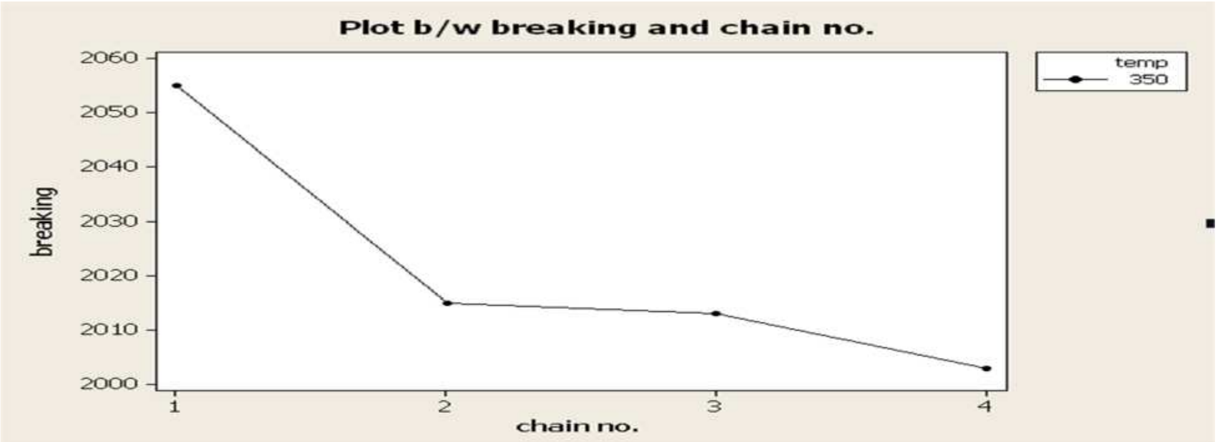

Fig 4.6: Plot between breaking and chain no.

Table 4.9, 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 4.6 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°, 90 min resulted more hardness that were summarized in Table 4.10 so it was the (d) condition i.e.

325^{o}C, 90 min that would be considered as best condition.

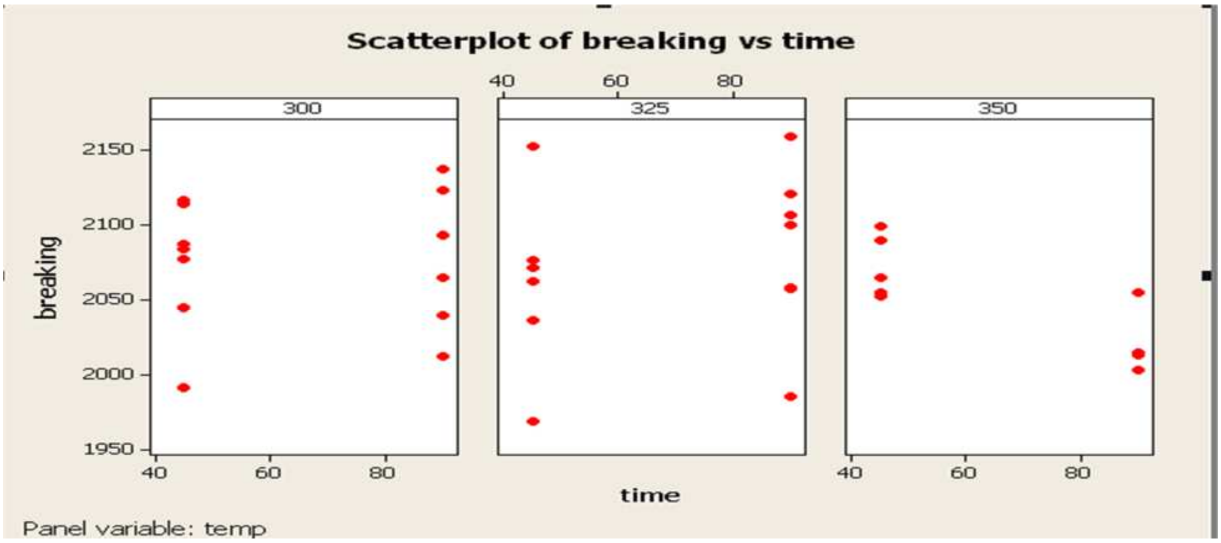

Fig 4.7: Scatter plot between breaking load and time, temperature as paneled variable

The hardness of sample at different condition of temperature and soaking time are summarized in Table 4.10

Table 4.10: hardness of outer plate at different conditions of temperature and soaking time

Element	Condition		Hardness(HRc)
	Temperature(^{o}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

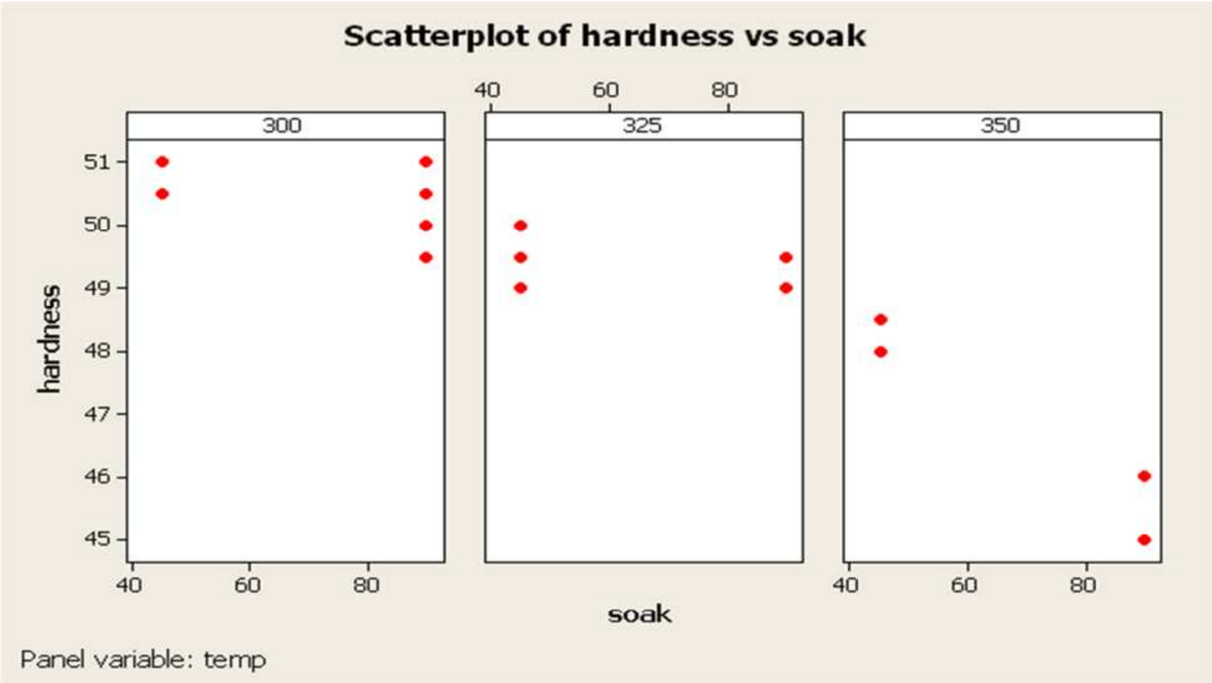

Fig 4.8: Scatter plot between hardness and time, temperature as paneled variable

From Fig 4.7, 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 Fig 4.8, 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.

4.4 Testing of chain with austempered inner and outer plate of existing design

The austempering was applied on inner and outer plate of chain link in an existing design. It consist of cooling the austenitised steel with a rate exceeding the critical cooling rate in a molten bath held at some constant temperature between the nose of TTT Diagram and Ms temperature holding at this temperature for a sufficient period for the completion of bainitic transformation and cooling to room temperature at any desired rate. The conditions at which this process was applied shown in Table 4.11

Table 4.11: Results of austempered link plate of existing design

Element	Condition			Trials	Breaking load(Kgf)	Element broken
	Temperature(^{o}C)	Soaking time(min)	Salt bath			
Inner and Outer plate	260-280	15	Neutral	1.	2232	-------------
				2.	2223	Inner plate
				3.	2143	Inner plate
				4.	2142	Outer plate
				5.	2066	-------------
				6.	2052	Outer plate
				7.	2037	Outer plate
				8.	2028	Inner plate

After performing austempering process on material, the microstructure changed to martensitc bainitic. Since this microstructure was more superior than tempered martensitic microstructure. The microstructure obtained was shown in Fig 4.9

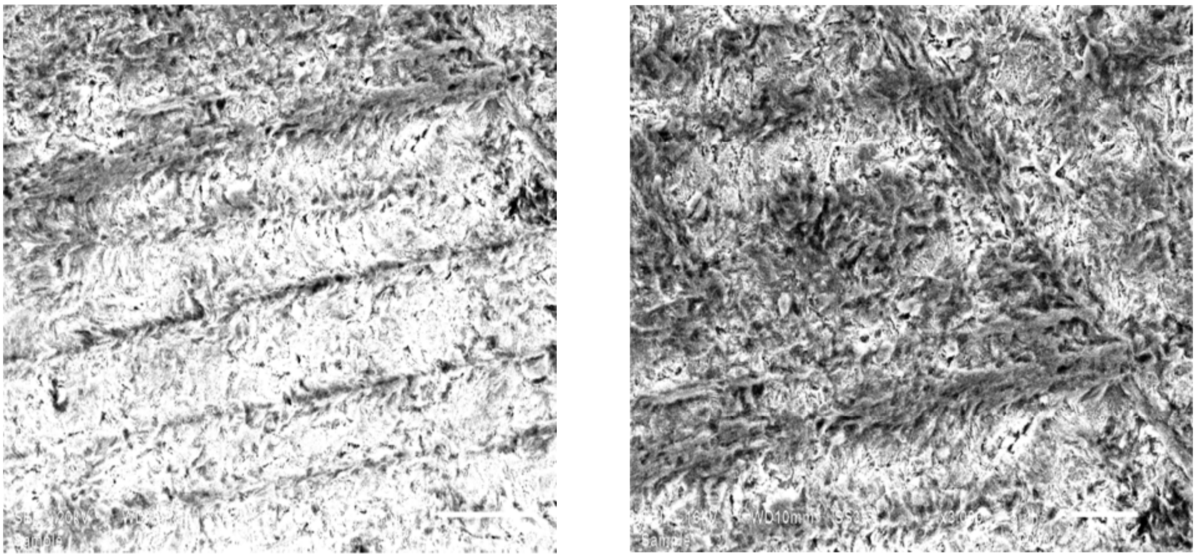

Fig 4.9: Bainitic+Martensitic microstructure

The microstructure thus obtained was Bainitic+martensitic which was believed to be more superior than tempered martensite. This microstructure has high hardness, tensile strength, impact strength and also good toughness.

4.5 Testing of chain with austempered inner and outer plate on improved design

After that, austempering process was applied on improved design of link plates. The obtained results is summarized in Table 4.12

Table 4.12: Results of austempering on improved design

Element	Condition			Trials	Breaking load(Kgf)	Element broken
	Temperature (^{o}C)	Soaking time(min)	Salt bath			
Inner and Outer plate	260-280	15	Neutral	1.	1715	Inner plate
				2.	1654	Outer plate
				3.	1654	Outer plate
				4.	1633	--------------

The minimum Breaking load required for 428 drive chain was 1750 Kgf but after performing austempering process on reduced dimension of 428 drive chain the breaking load was obtained 1715 Kgf so it can’t be considered as failure but it requires little more improvement in order to improve the strength of chain.

5.1 Conclusions

The following conclusions were drawn from the present study.

- 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.
- From the present study it was concluded that using austempering process, desirable tensile strength can be achieved without using tempering which would result saving of process time. After austempering the existing link plate maximum breaking load of 2232 Kgf was achieved.
- From the present study it was concluded that, after austempering the improved design of link plate, a maximum breaking load of 1715 Kgf was achieved which is less than the minimum required breaking load of 1750 Kgf but it can be improved.

5.2 Future Scope of Work

In this thesis work, tempering and austempering heat treatment processes were used in order to achieve the desired objectives. But other processes such as cold forging, fine blanking could be used for improving the strength of chain of reduced weight. Since work has been done upto thickness of 1.4mm of inner and outer plate that can be more reduce without losing much strength.

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