Design and Development of a Fork Tube for Motorcycle by Induction Hardening

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Abstract - A motorcycle fork connects a motorcycle's front wheel and axle to its frame, typically via a pair of triple clamps. It typically incorporates the front suspension and front brake, and allows the front wheel to rotate about the steering axis so that the bike may be steered. This vital part demands excellent ability to closely follow road contours through smooth operation and steady damping force, while retaining high rigidity. When the bike is riding on an uneven road conditions the fork is first to come in contact and respond to the road condition. It not only takes care of the ride comfort but also it takes care of the impact road which is generated due to the applied brakes at the high speeds due to the road conditions and if at all the basic function fails this may lead to accident. When the basic function of the fork fails while the vehicle is riding on bumping road condition, vehicle leads to collapse. Thus we need to study on the strength of the fork tube. The strength of the fork will be increased by introducing the induction Harding process.

Index Terms— Front Fork, Cam Drum Test, FEA Analysis, Induction hardening

I. INTRODUCTION

A motorcycle fork is a couple of front wheel and axle as a frame, as a pair of triple clamps. It includes the front suspension and brake, and bike to steer.

A telescopic forkis the most common form of fork commercially available, uses tubes which contain the coil springs and damper internally. It may or may not include gaiters for protection against abrasive elements on the suspension cylinders. The main advantages of the telescopic fork are that (i) Design is simple andless expensive to manufacture and assemble; (ii) it is light in weight than older designs it uses external components and linkage systems; and (iii) it has a clean and attractive in look.

Conventionally, the fork stanchions are clamped to a triple tree (also called a triple clamp or a yoke)at the top, and the sliders are attached to the bottom ofthe front wheel spindle. On some modern sport bikes and cross country bikes, this system is inverted by clamping the "sliders" (complete with the spring/damper unit) at the top to the yoke, while the stanchions are clamped at the bottom. This is done (i) to cut backunsprung weight by having the heavier components suspended, and (ii) the strength and rigidity of the assembly is improved by having the large-diameter and stronger "sliders" clamped with-in the yokes. The inverted system is referred to as an upside-down fork or "USD" for short. A disadvantage of this USD design is that the whole reservoir of damping oil is higher than the slider seal in order that, if the slider seal were to leak, the oil could drain out, rendering any damping ineffective.

II. PROBLEM STATEMENT

While driving on bumpy road condition the rider experiences less comfort and problems. The front fork which is one of the Suspension systems is designed mechanically to handle shock impulse and safety concern. It reduces the vibrations which increase in comfort and improved ride quality. The vehicle handling becomes very difficult and leads to uncomfortable ride when uncontrolled bouncing occurs. When the basic function of the fork fails while the vehicle is riding on bumping road condition, vehicle leads to collapse thus to avoid the accidents due to collapsing we need to solve the problem.

III. LITERATURE REVIEW (FAILURE HISTORY)

The current study is a fractured analysis, carried out on the fractured fork tube. Fork tube is an integral part of a motorcycle's front (telescopic) suspension system. It connects the front wheel and axle to its frame. Fork tube compresses and extends to adjust for inconsistencies on the road allowing the front tyre to maintain contact with the road for better handling and braking. The specimen was obtained from a local client. The motorbike was subjected to impact loading (in form of accident) cause of which the specimen underwent premature fracture. Hence the metallurgical analysis was needed to understand the cause of failure.

Components of a system can fail one of many ways, for example excessive deformation, wear, rupture, corrosion, burning-out, degradation of specific properties. The credibility of failure analysis lies in their ability to identify corrective actions by determining the causes of the failure.

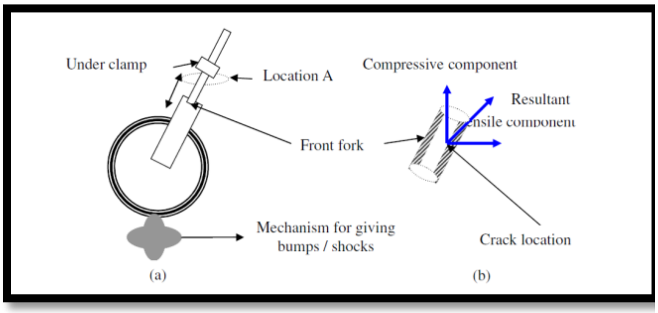

Fig1 a. Mechanism for testing Front fork pipe system of motorcycle or scooter by Cam drum testing machines,

b. Magnified view of the front fork pipe of location a showing area of the crack and forces acting it

Hence the following study is an effort to understand the root cause of the failure in the fork tube of motorbike by carrying out various metallurgical observations in the form of SEM EDS analysis. The customer returned the fractured fork pipe samples after premature failure during testing. Fig. 1a shows the mechanism of testing the front shock absorber of a motorcycle. The shock absorber experiences repeated bumps or shocks while testing by a typical mechanism fitted at the bottom. There is an upper clamp bracket which holds the fork pipe.

The design of the system as indicated in fig.1 shows the nature of loading and stress experienced by the system. The load experienced by the front fork is purely shock load. In one revolution it experiences the four bumps/shocks. During inspection the speed of revolution used was 120 RPM. To pass the test it has to run for 100 hr minimum cycle without failure or leakage. Assembly has to withstand 2880000 numbers of bumps minimum so as to qualify the test.

Failures were reported during testing on Cam Drum testing machine. The details of failed fork pipes are indicated in the table 1. During testing it is found that one Left hand (LH) fork pipe was cracked after 20.50 hrs and other after 47.20 hrs. One failure was reported in right hand (RH) fork pipe after 23.54 hrs.

The investigations revealed that the fracture is not due to any material or processing defect. The brittle fracture of the tube is not due to any embrittlement as the hardness is not appreciable at the subsurface of the coating. The impact mark in macro examination and micro examination clearly indicates that the component undergone some impact with another either moving or stationery body. The type of fracture and the evidence of the microstructure grains indicate the gravity of the stress that the tube had undergone. This failure is not due to any embrittlement, defect in the raw material and the electro-chemical process carried out.

Table 1: Failure history of fork pipe

Sr. No	Discription	Hrs: min
1	LH fork pipe (F01/LH)	20:50
2	LH fork pipe (F01/LH)	47:20
3	RH fork pipe (F01/RH)	23:54

Failure analysis resulted that a new product should be developed as per the requirement and which can avoid the failure. As the stresses are independent of material thus we need to increases the strength of the material. This can be achieved by increasing its hardness of the material. As the hardness increases the strength of material and its stresses bearing capacity increases. The process is used to increase tensile strength of the material is Induction hardening. The process is described in next chapter. The FEA analysis of the model was tested in the ansys 15 and the part was manufactured. The required new properties for the front fork were as described below.

1) The mechanical properties of the material should be as specified

1. Tensile Strength :1130 N /mm^2
2. Yield Strength : 1030 N/mm^2
3. Hardness: HRC 40-43 HRC
4. Elongation : 8% Minimum
5. Ration of Y0ield Strength Ultimate Tensile Strength : 80%

2) Micro structure of induction hardened specimen.

1. The micro structure of the material should be martenstine structure.
2. It should be the tempered martenstine structure.

IV. CHARACTERIZATION OF FRONT FORK

Fig 2: telescopic front fork

This telescopic fork comprises a pair of aluminium sliders or outer tubes fitted over chromium plated steel stanchion or inner tubes clamped in yokes at the top and bottom of the steering column. The fork springs are usually of a small diameter, long, and fitted inside the stanchions. A hydraulic damping mechanism is incorporated in the outer tubes and the damping oil also serves as a lubricant.

A. Specifications of Inner tube(Raw Material):

1. Length: 557 mm
2. Inner diameter: 24 mm
3. Outer Diameter: 30mm
4. Hardness: 22 to 34 HRC

B. Material Specifications:

Raw Material used for machining of required of Inner tube is carbon Steel SAE 1541. The Specification and properties are as follows:

C. Micro Structure of raw material:

1. Grain Size: Ferrite grain size to be ASTM 7 or Higher
2. Uniform Equiax Structure ferrite + Pearlite
3. Bonding of ferrite or Perlite not allowed

D. Mechanical Properties of SAE 1541:

1. Tensile Strength :833 N/mm2
2. Yield Strength : 686 N/mm2
3. Hardness: HRC 22-29
4. Elongation : 15% Minimum
5. Ration of Yield Strength to Ultimate Tensile Strength : 85%

E. Chemical properties of SAE 1541:

Table 2: Chemical Analysis of raw material of Fork Tube

	% C	% Si	%Mn	%S	%P
Specified	0.36-0.44	0.25 Max	1.35-1.65	0.05 Max	0.04 Max
Observed	0.41	0.21	1.39	0.0036	0.019

F. Working

A. Contraction (Compression)

When the front wheel hits a bump, or any surface with a height greater than the plane of the road, the front fork compresses.The outer tube or slider slides upward (indicated hereafter by the large black arrow), thus the piston inside moves through the oil and compresses the main spring. Unlike a shock absorber, the piston head in the front fork does not hold the damping mechanism. Damping forces are created by the forced movement of oil through controlled orifices in the stem of the piston.

In the case of compression, as the outer tube moves upward, the volume of the region labeled as the compression chamber decreases. Consequently, the pressure increases. The incompressible oil present in this chamber is then forced through the compression holes and into the hollow piston stem where the pressure is low. By controlling the size (diameter and area) and number of compression holes, the desired value of compressive damping can be achieved.

The compression holes also have an entry chamfer. This allows a continuous or smooth flow of oil, and minimizes turbulence.

After flowing through the compression holes, the oil then flows into the hollow stem of the piston and exits into the inner tube and into the extension chamber through the piston head and the extension orifices respectively. In compression, there is no pressure differential across the extension orifices; therefore, they do not contribute to compressive damping.

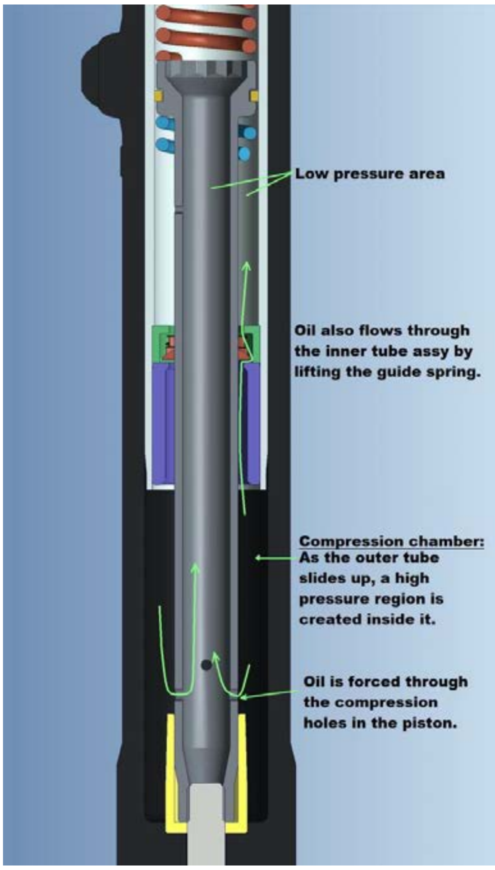

Fig 3a : Working of Inner Tube Compression

The oil also flows through another path to reach the extension chamber. This path is through the radial gap between the piston stem and the spacer oil lock. After flowing through this gap, the oil reaches the guide spring. The guide spring geometry is such that it blocks the gap between spacer oil lock and piston stem. But the force of the oil pushes the guide spring against the valve spring, causing the guide spring to lift and allow a passage for the oil.

Controlling the gap between piston stem and spacer oil lock, as well as the stiffness of the valve spring controls this flow. This flow does not create damping; however, it is necessary for creating the requisite volume of oil in the extension chamber for the subsequent extension stroke.

G. Extension (Tension)

Following the compression stroke, the front fork spring begins to extend. This causes the outer tube to slide downwards. Thus the piston also moves from top towards bottom.As it moves downward, a vacuum is created in the compression chamber because of an increase in its volume. This negative pressure causes oil to flow into the compression chamber. At the same time, the volume of the extension chamber decreases. Thus there is a buildup of pressure.

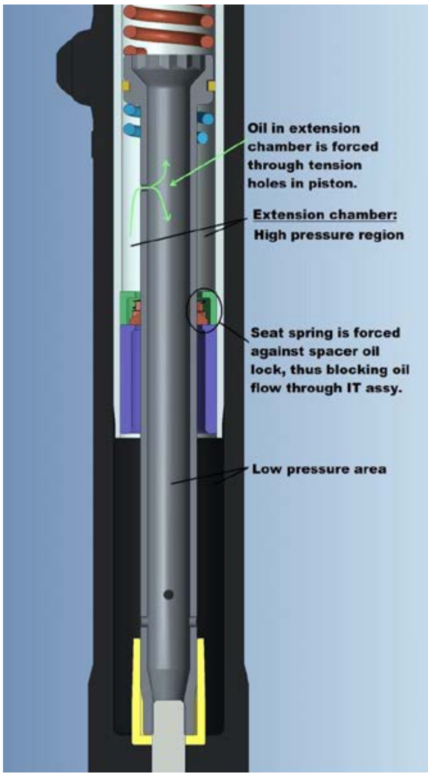

Fig 3b : Working of Inner Tube Compression

Due to the increase in pressure in the extension chamber and the drop in pressure in the compression chamber, a pressure differential is set up across the tension orifices in the piston. Oil is forced through these orifices, and tensile damping is created. The diameter and entry chamfer control the rate of oil flow and nature of flow respectively and hence control damping value.

In the compression stroke, oil also flows through the spacer oil lock. But when pressure in the extension chamber increases, the guide spring is forced downward onto the spacer oil lock. The guide spring inner diameter is also flush with the piston stem diameter. Therefore, this acts as a seal. However, due to surface irregularities or difference in dimensions, a gap may form between guide spring and piston stem or spacer oil lock. Thus, a small quantity of oil flows through this return path, into the compression chamber. This flow has a minimal impact on reduction in damping.

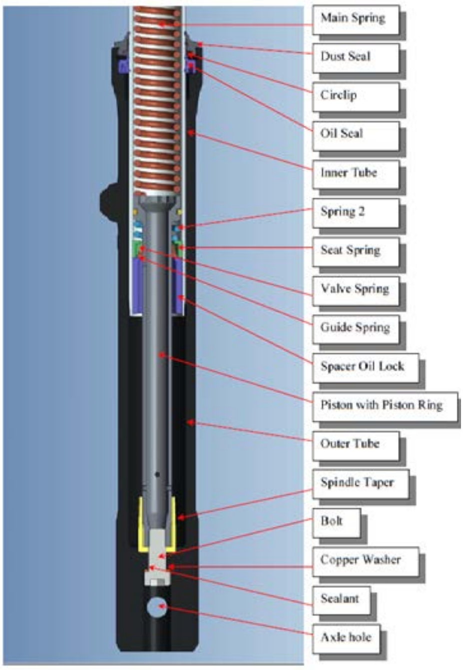

Fig 4: Damping mechanism of fork

Therefore, modifying the diameter and the number of extension orifices is what controls extension damping force or tensile damping force.

H. Damping Mechanism

The damping mechanism, illustrated above, consists of a piston, a spindle taper and the inner tube assembly, which comprises the spacer oil lock, the guide spring, the seat spring, and the valve spring.

The piston is a forged part and is integral with its stem. It is bolted to the lower end of the outer tube. A thread sealant is used to prevent any oil leak through the threads. Holes or vents are drilled through the stem of the piston near the head and the end portion. The piston is hollow, allowing the formation of an oil chamber within it. The head of the piston has a groove in which sits a piston ring. The piston ring creates a seal around the outer periphery of the piston head.

As can be seen from the illustration of the fork assembly, the piston head is located within the inner tube. Thus, the inner tube is slid over the piston, before bolting it to the end of the outer tube.

The end of the piston stem is housed in a hollow tapered cylindrical part called a spindle taper, the function of which is to create a hydraulic lock when the fork reaches the end of its travel in compression. This is discussed in detail later. The spacer oil lock prevents oil flow over its outer surface and allows it along its inner diameter.

The valve and guide spring function as a single check valve unit. The seat spring creates a seat for locating the main coil spring. These parts together constitute the inner tube assembly, and thus their assembly sequence is critical for proper functioning. The spring seat is located onto the step inside the end of the inner tube. The OD of the inner tube is spun over the end of the spacer oil lock to lock the inner tube assembly in place.

V. EXPERIMENTATION

The hardness of the tube was checked by Rockwell hardness test. The section shows the experimental results and its discussion. After the analysis results the part was manufactured and the physical testing was carried out. The following process was adopted for induction hardening in the machine as specified in above chapter.

The sequence was as follows

- Manufacturing the whole component
- Induction hardening
- Hardness and dimension check
- Cam drum testing

The manufacturing process was modified and was adopted. The process of manufacturing and the methodology of solution are described in this chapter in following sections.

A. *New modified manufacturing process*

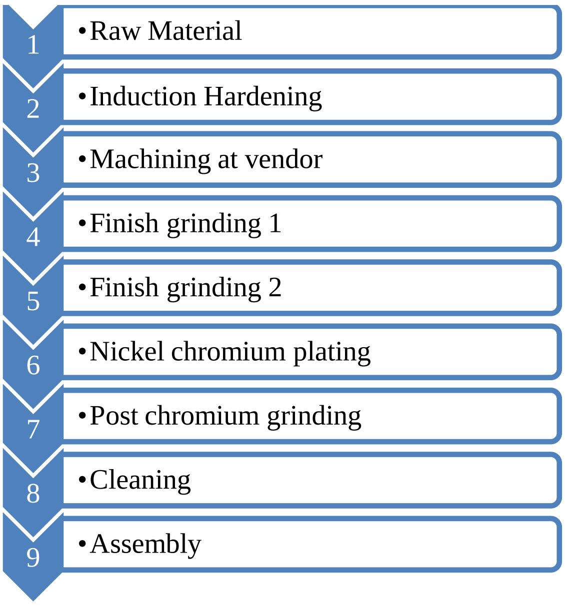

Chart 1: New Modified Manufacturing Process

B. *Induction hardening.*

Induction is a form of heat treatment in which a metal part is heated by induction heating and then quenched. The quenched metal undergoes a martensitic transformation, increasing the hardness and brittleness of the part. Induction hardening is used to selectively harden areas of a part or assembly without affecting the properties of the part as a whole. Induction heating is a non-contact heating process which utilizes the principle of electromagnetic induction to produce heat inside the surface layer of a work-piece. By placing a conductive material into a strong alternating magnetic field, electrical current can be made to flow in the material thereby creating heat due to the I2R losses in the material. In magnetic materials, further heat is generated below the Curie point due to hysteresis losses. The current generated flows predominantly in the surface layer, the depth of this layer being dictated by the frequency of the alternating field, the surface power density, the permeability of the material, the heat time and the diameter of the bar or material thickness. By quenching this heated layer in water, oil or a polymer based quench the surface layer is altered to form a martensitic structure which is harder than the base metal.

C. *Definition*

Induction hardening is a widely used process for the surface hardening of steel. The components are heated by means of an alternating magnetic field to a temperature within or above the transformation range followed by immediate quenching. The core of the component remains unaffected by the treatment and its physical properties are those of the bar from which it was machined, whilst the hardness of the case can be within the range 37/58 HRC. Carbon and alloy steels with equivalent carbon content in the range 0.40/0.45% are most suitable for this process.

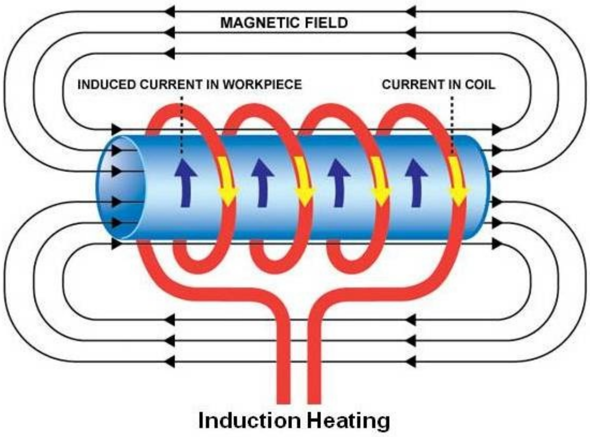

Fig 10: Working of induction hardening

A source of high frequency electricity is used to drive a large alternating current through a coil. The passage of current through this coil generates a very intense and rapidly changing magnetic field in the space within the work coil. The workpiece to be heated is placed within this intense alternating magnetic field where eddy currents are generated within the workpiece and resistance leads to Joule heating of the metal.

Induction hardening is one of the most widely employed to improve component durability. It determines in the work-piece a tough core with tensile residual stresses and a hard surface layer with compressive stress, which have proved to be very effective in extending the component fatigue life and wear resistance.

Induction surface hardened low alloyed medium carbon steels are widely used for critical automotive and machine applications which require high wear resistance. Wear resistance behavior of induction hardened parts depend on hardening depth and the magnitude and distribution of residual compressive stress in the surface layer.

D. Process of Induction Hardening

The raw material was cut as per the measure of length and was send to induction hardening as per the manufacturing process. The induction hardening was done only to the specified length of the tube. The specifications were mention by the respective staff. The specimen was hardened in the following manner as shown in the fig. Induction hardening starts at 186 mm. the 10 mm before and after are the transition zones and ended up to 286 mm. Transition zone are provided due to the heat transfers to surface also.

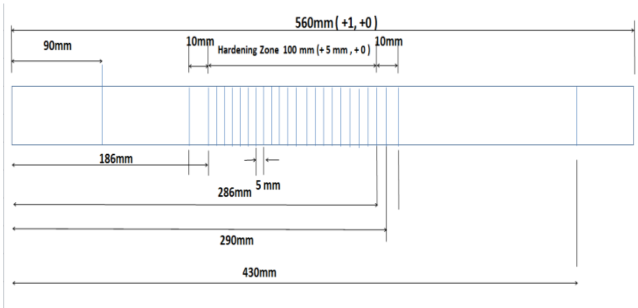

Fig 11: Induction Hardened Inner tube with Marking for Position wise hardness checking in Hardness zone

VI. INDUCTION HARDENING SAMPLE ANALYSIS REPORT.

Following are the test results of the specimen after induction hardening. The results include the following analysis:

A. Chemical composition of specimen after Induction Hardening

Chemical Composition was checked of the specimen to ensure the chemical composition of the specimen after Induction Hardening

Table 4: Chemical composition check of Induction Hardened Sample

Description	Specification	Observation	Remarks
Chemical Composition			
%C	0.36 – 0.44	0.381	OK
%Mn	1.30 – 1.60	1.355	OK
%Si	0.35 Max	0.162	OK
%S	0.04 Max	0.001	OK
%P	0.04 Max	0.015	OK

B. Surface Hardness

Surface Hardness after induction hardening was checked at ID and OD of five different specimens. The readings and graph of those five specimens is plotted bellow. The procedure to check hardness is as follows

1. Select the load & indentor on hardness testing m/c.
2. Check the standerdised test block on hardness tester.
3. Mark the hardning zone of inner tube with the help of height gauge on surface plate.
4. Keep the inner tube on fixture of hardness testing m/c.
5. Rotate the wheel & set indentor on surface of inner tube on which hardness is to be check.
6. Apply the load on inner tube with the help of lever.
7. Release the load on inner tube with the help of lever.
8. Note the reading on scale which is in BLACK letters.

Fig 12: specimen mounted on hardness tester

Fig 13: Induction hardened fork tube as specimen used for check of hardness after induction hardening.

Table 5: Readings of hardness at outer edge of the specimen

Length of inner tube from top side	Specimen					
	S1	S2	S3	S4	S5	S6
186mm	28.8	29.5	25.6	27.9	27.0	26.9
188mm	38.2	36.8	35.2	33.6	39.0	36.0
190mm	38.8	38.9	37.1	39.1	37.6	38.5
200mm	38.0	38.8	38.2	41.2	41.8	40.3
210mm	40.2	37.1	41.5	40.8	41.3	40.3
220mm	40.5	40.0	41.3	42.7	41.2	41.3
230mm	38.3	39.3	41.6	42.6	42.2	41.2
240mm	40.4	38.7	39.8	40.5	38.2	37.8
250mm	40.7	40.5	40.2	40.1	38.9	39.4
260mm	37.4	38.4	40.3	41.4	38.4	39.9
270mm	38.4	39.4	38.1	41.8	40.3	40.0
280mm	38.8	39.2	40.9	41.7	41.0	40.6
290mm	40.1	41.8	40.9	41.4	41.2	41.5
292mm	37.9	34.8	32.0	33.3	37.4	34.7
295mm	28.4	27.5	27.8	27.7	28.4	26.2

Experimentally the fork is tested by Cam drum test. The hardness of the tube is checked by Rockwell hardness test. The microstructure check is also checked.

VII. RESULTS AND DISCUSSION

The experimentally the new modified front fork was able to withstand the stress and successfully passed the acceptable criteria.

Thus the fork was manufacture as per the new modified process and the results were obtained as per the required range of 33 to 45 HRC. The obtained range was 33.6 – 41.7 HRC. Induction hardening increased the strength of the portion and was in the required specification.

The table below shows the hardness of the raw material and hardness of specimen after induction hardening.

The strength obtained after the induction hardening was as follows

1. Tensile Strength :1130 N /mm2
2. Yield Strength : 1030 N/mm2
3. Hardness: HRC 40-43 HRC
4. Elongation : 8% Minimum
5. Ration of Y0ield Strength Ultimate Tensile Strength : 80%

Table 9: Comparison of Raw Material & Hardened Material hardness

Description	Specification	Observation
Raw Material	24 – 32 HRC	25.6 – 27.8 HRC
Specimen 1	37 – 43 HRC	37.5 – 41.7 HRC
Specimen 2	37 – 43 HRC	36.8 – 41.8 HRC
Specimen 3	37 – 43 HRC	35.2 – 40.9 HRC
Specimen 4	37 – 43 HRC	33.6 – 41.4 HRC
Specimen 5	37 – 43 HRC	39.0 – 41.5 HRC
Specimen 6	37 – 43 HRC	36.0 – 41.2 HRC

VIII. FUTURE SCOPE

Microstructure check and experimental testing is to be carried out on the modified specimen. 1

IX. REFERENCE

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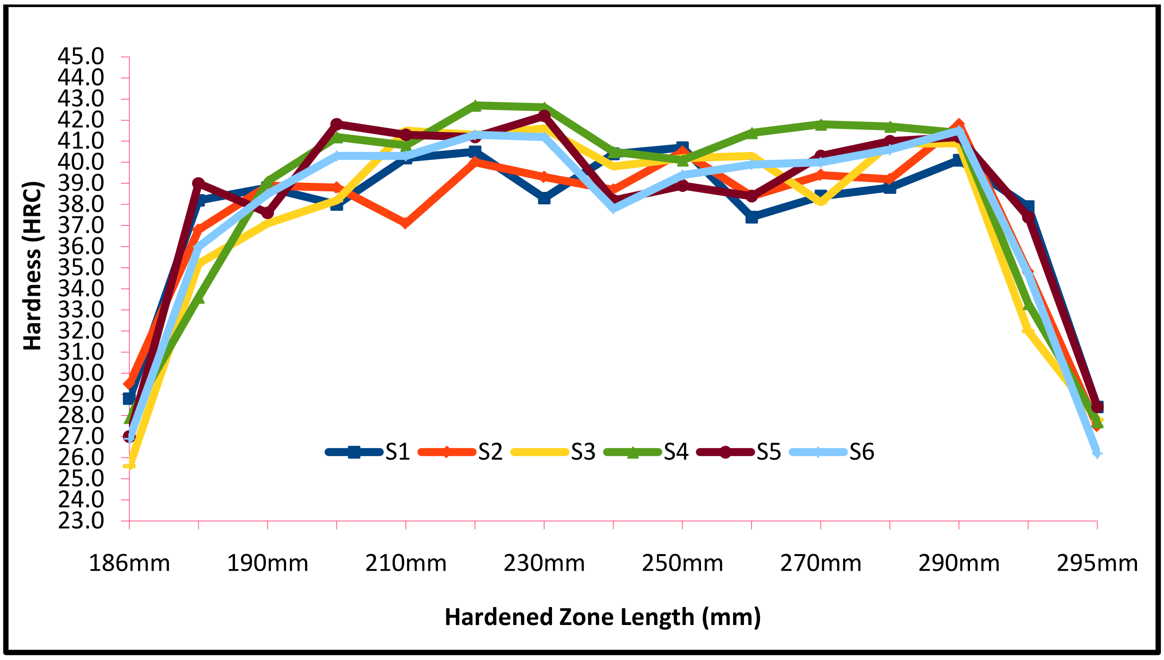

Graph: Surface Hardness along length @ Hardened Zone