MICROSTRUCTRAL ANALYSIS OF BEARING CUP FOR VARIOUS HEAT TREATMENT

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ABSTRACT

Power transmission system has different constructive features according to the vehicle's driving type which can be front wheel drive, rear wheel drive or four wheel drive. In rear wheel drive system, elements of the system include clutch, transmission system, propeller shaft, joints, differential, drive shafts and wheels. Each element has many different designs and construction properties depending on the brands of vehicles. The carden shaft also called drive shaft is used to transmit motion from gear box to differential. The problem identified after critical analysis of the drive shaft assembly. In that bearing cup assembly was getting cracked during assembly operation in universal joint assembly.

This paper will highlight the methodology adopted for finalizing the solution highest rejection, hence it was decided to eliminate bearing cup failure in drive shaft assembly with cost effective solution.to this problem by means of Microstructural analysis using optical microscope. Various Heat Treatment processes are Observe found that Carbonitriding process is the optimum solution which will reduce the failure of bearing cup as well as reduce the overall manufacturing cost.

Keywords: *Banite And Pearlite, Core Micro, Case Micro*

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1. INTRODUCTION

1.1 ELEMENTS OF POWER TRANSMISSION SYSTEM

The movement of vehicles can be provided by transferring the torque produced by engines to wheels after some modification. The transfer and modification system of vehicles is called as power transmission system and has different constructive features according to the vehicle's driving type which can be front wheel drive, rear wheel drive or four wheel drive. Fig. 1 gives elements of a front wheel and a rear wheel drive power transmission system. The elements of the system include clutch, transmission system, propeller shaft, joints, differential, drive shafts and wheels. Each element has many different designs and construction properties depending on the brands of vehicles. The carden shaft also called drive shaft is used to transmit motion from gear box to differential. The universal joint consists of two forged-steel yokes or forks joined to the two shafts being coupled and situated at an angle to each other. Friction due to rubbing between the journal and the yoke bores is minimized by incorporating needle-roller bearings between the hardened journals and hardened bearing caps pressed into the yoke bores.

1.2 HISTORY OF PROPELLER SHAFT

The main concept of the universal joint is based on the design of gimbals, which has been in use since antiquity. One anticipation of the universal joint was its use by the ancient Greeks on ballistae. The first person known to have suggested its use for transmitting motive power was Gerolamo Cardano, an Italian mathematician, in 1545, although it's unclear whether he produced a working model. Christopher Polhem later reinvented it and it was called "Polhem knot". In Europe, the device is often called the cardan joint or cardan shaft. Robert Hooke produced a working universal joint in 1676, giving rise to an alternative name, the Hooke's joint.

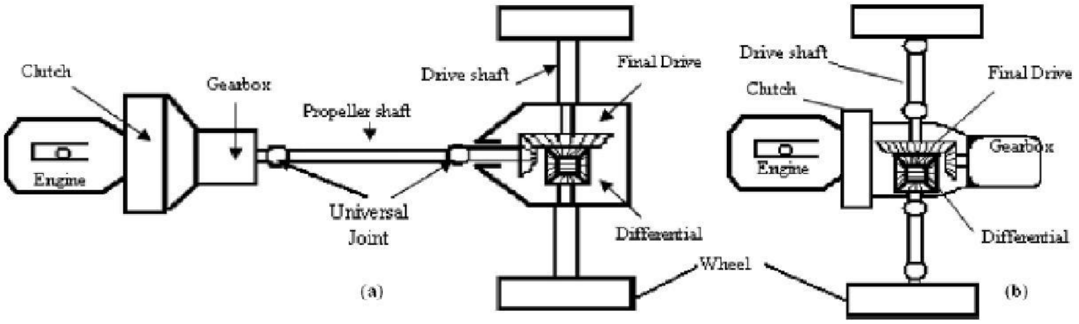


Fig. 1: Elements of Power Transmission System (a) Rear Wheel Drive (b) Front Wheel Drive.

1.3 MATERIAL SELECTION FOR PROPELLER SHAFT

The selection of optimum materials for the propeller shaft is based on ultimate strength, fatigue strength, and other functional and durability requirements for a given application as well as economical processing advantages.
Because of the large variety of applications, the yokes are made from number of different materials and by various processing methods. The most commonly used yoke materials are steel forgings made of plain medium carbon steels which are heat treated to a typical range of BHN 229~269. These yokes welded during assembly operations are generally machined from these forgings. Also these medium carbon steels allow certain surfaces to be surface hardened by induction hardening when necessary, if the yoke has for example, an integral spline on an external splined slip yoke. Yokes which are not subsequently welded to a connection member, as a tube or shaft, or if they are made integral with spline as in an internal splined slip yoke, are frequently made from either pearltic, spheroidal graphite or nodular iron castings. These castings when heat treated to a typical range of BHN 241~269 for pearlite, spheroidal graphite iron and BHN 241-285 for nodular iron, allow the machining of yokes having the equivalent strength of forged steel components. In some cases certain yokes are also formed from plain low carbon steel stampings or made by other means. Since cross serves the important function as the intermediate drive member of the cardan joint, it is generally made from a low carbon alloy steel forgings which is carburized to an adequate case depth and surface hardened to a typical Rc 60 minimum to provide the required wear characteristics and torsional strength. The trunnions are then finish ground. In some application the cross is also shot penned prior to finish grinding. The necessary case depth of the cross trunnion is determined by the size of the cardan joint and its application requirement.

The bearing cup is usually made of plain low carbon or low carbon alloy steel, which is carburized to an adequate case depth and surface hardened to a typical Rc 60 minimum to provide the required wear characteristics and strength. The necessary case depth is determined in a manner similar to that described for the cross trunnion. The cup is then finish ground. It can also be made of resulphurised medium carbon steel which is induction hardened in the bearing bore to an adequate case depth and a typical Rc 60 minimum surface hardness before finish grinding.

The needle rollers used are made of chromium steel which is hardened to a typical range of Rc 60-64 and finish lapped. In some joint bearing designs, components having low coefficient of friction are included, as desired to improve bearing performance. Typical examples are the plastic needle thrust washer and seal washer used at the needle roller ends. Also in certain cases a trunnion thrust washer is incorporated between the bearing cup and cross trunnion thrust surfaces. This component is generally made of plastic or plastic with metal backing material.

The dust seal or seal retainer used in the bearing seal design is usually made from plain low carbon steel stampings.

Bolts and cap screws are used not only to retain various bearing constructions, but also to fasten the end of flange yoke to another driveline member. Therefore these bolts and cap screw are generally made of carbon alloy steel and heat treated to conform to the SAE grade 8 bolt specifications.

2. HEAT TREATMENT

Selection of steel types and grades and appropriate heat treatment methods are very important to produce components of reliable quality. The control of a given alloy‘s chemical composition and the inclusion content of steel have an impact upon and can create variance in an alloy‘s properties. Other contributing factors impacting the quality and reliability of final components include refining, casting, rolling and cooling methods. Further strength, toughness, fatigue strength and wear properties result largely from the microstructure and hardness results created by heat-treatment condition and methodsapplied. As a result it is quite important to be cognizant of these factors and to ensure that appropriate methods are applied [7].

2.1 Carburizing

Carburizing is a case-hardening process in which carbon is dissolved in the surface layers of a low-carbon steel part at a temperature sufficient to render the steel austenitic stucture, followed by quenching and tempering to form a martensitic microstructure. The resulting gradient in carbon content below the surface of the part causes a gradient in hardness, producing a strong wear-resistant surface layer on a material, usually low-carbon steel, which is readily fabricated into parts. In gas carburizing commercially the most important variant of carburizing the source of carbon is a carbon-rich furnace atmosphere produced either from gaseous hydrocarbons, for example, methane (CH_4), propane (C_3H_3), and butane (C_4H_{10}), or from vaporized hydro-carbon liquids[7] [1].

Carburizing is a remarkable method of enhancing the surface properties of shafts, gears, bearings, and other highly stressed machine parts. Low-carbon steel bars are fabricated by forging and machining into finished shapes and then are converted by carburizing into a composite material consisting of a high-carbon steel case and low-carbon steel core. When this steel composite is quenched to martensite and tempered, the high hardness and strength of the case microstructure, combined with the favorable case compressive residual stress developed by interactions between the case and core during quenching produce very high resistance to wear, bending fatigue and rolling-contact fatigue.

At first glance, the microstructures of carburized steels appear to be quite straightforward. High-carbon martensite is gradually replaced by martensite of lower carbon content with increasing distance from the carburized surface. This view of the microstructures of carburized steel is essentially correct. Lightly tempered martensite is the dominant microstructural constituent of properly carburized steel. However the martensite changes in morphology, amount and properties as a function of distance from the surface. Other microstructural constituents may also be present and may significantly affect the performance of carburized parts. These other microstructural components include retained austenite, carbides of various origins, sizes and morphologies, inclusions, processing-induced surface oxides, prior austenite grain boundaries embrittled by phosphorus segregation; and nonmartensitic transformation products of austenite, such as bainite and pearlite [1].

2.2 Carbonitriding

Carbonitriding is a modified form of gas carburizing, rather than a form of nitriding. The modification consists of introducing ammonia into the gas carburizing atmosphere to add nitrogen to the carburized case as it is being produced. Nascent nitrogen forms at the work surface by the dissociation of ammonia in the furnace atmosphere; the nitrogen diffuses into the steel simultaneously with carbon. typically, carbonitriding is carried out at a lower temperature and for a shorter time than is gas carburizing, producing a shallower case than is usual in production carburizing.

In its effects on steel, carbonitriding is similar to liquid cyaniding. Because of problems in disposing of cyanide-bearing wastes, carbonitriding is often preferred over liquid cyaniding. In terms of case characteristics, carbonitriding differs from carburizing and nitriding in that carburized cases normally do not contain nitrogen, and nitrided cases contain nitrogen primarily, whereas carbonitrided cases contain both.

Carbonitriding is used primarily to impart a hard, wear-resistant case, generally from 0.075 to 0.75 mm (0.003 to 0.030in.) deep. A carbonitrided case has better hardenability than a carburized case (nitrogen increases the hardenability of steel; it is also an austenite stabilizer, and high nitrogen levels can result in retained austenite, particularly in alloy steels).Consequently, by carbonitriding and quenching, a hardened case can be produced at less expense within the case-depth range indicated, using either carbon or low-alloy steel. Full hardness with less distortion can be achieved with oil quenching, or, in some instances, even gas quenching, employing a protective atmosphere as the quenching medium [1].

2.3 Nitriding

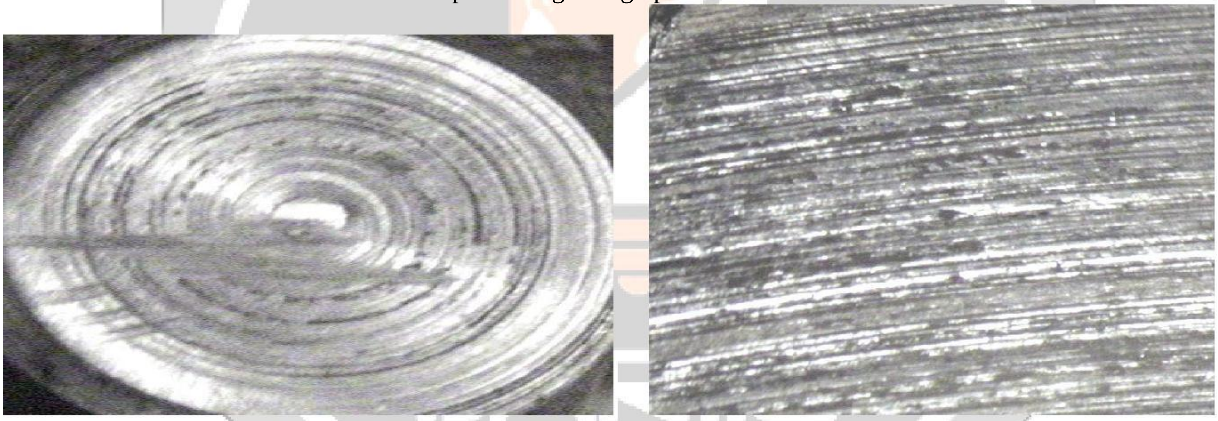
Gas nitriding is a case-hardening process whereby nitrogen is introduced into the surface of a solid ferrous alloy by holding the metal at a suitable temperature (below Ac1, for ferritic steels) in contact with a nitrogenous gas, usually ammonia. Quenching is not required for the production of a hard case. The nitriding temperature for all steels is between 495 and 565 °C (925 and 1050 °F).

The term liquid nitriding has become a generic term for a number of different fused-salt processes, all of which are performed at subcritical temperature. Operating at these temperatures, the treatments are based on chemical diffusion and influence metallurgical structures primarily through absorption and reaction of nitrogen rather than through the minor amount of carbon that is assimilated.

A typical commercial bath for liquid nitriding is composed of a mixture of sodium and potassium salts. The sodium salts, which comprise 60 to 70% (by weight) of the total mixture, consist of 96.5% NaCN, 2.5% Na2CO3, and 0.5% NaCNO. The potassium salts, 30 to 40% (by weight) of the mixture, consist of 96% KCN, 0.6% K2CO3, 0.75% KCNO, and 0.5% KCl. The operating temperature of this salt bath is 565 °C (1050 °F). With aging the cyanide content of the bath decreases and the cyanate and carbonate contents increase (the cyanate content in all nitriding baths is responsible for the nitriding action, and the ratio of cyanide to cyanate is critical). This bath is widely used for nitriding tool steels, including high-speed steels, and a variety of low alloy steels, including the aluminium-containing nitriding steels.

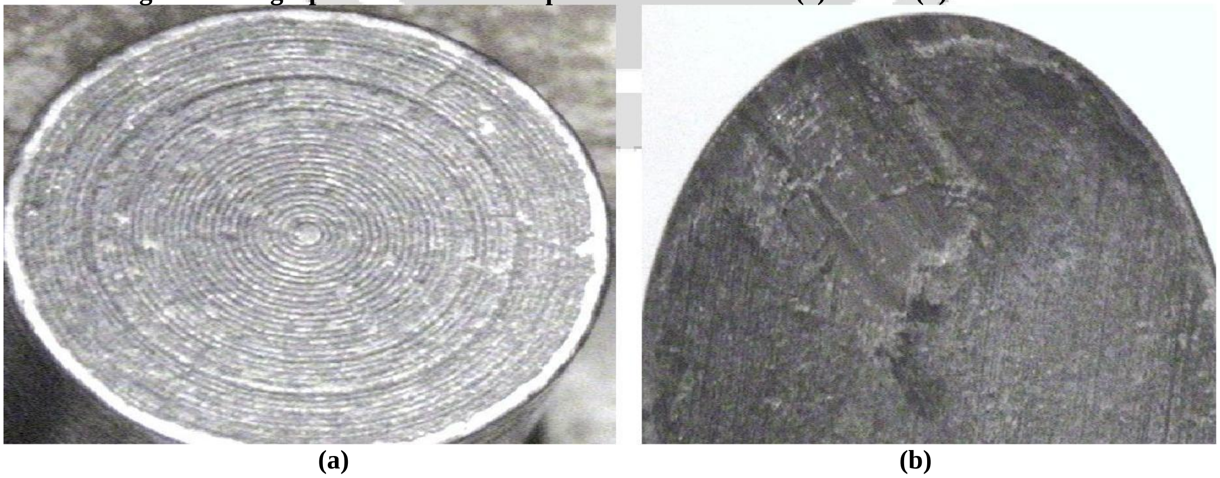
3. MACROSCOPIC ANALYSIS OF WORN SURFACES OF DIFFERENT HEAT TREATED SAMPLES OF SAE1117

In this study after wear test, wear scars of specimens were studied. The magnified pictures of worn surfaces were taken by stereo microscope for different surface treated sample test pins under study to understand the wear pattern. Fig. 2 shows macrograph of untreated sample (a) before wear test and (b) after wear test. From macrograph heavy wear was evident in case of untreated samples as high rough patches can be seen.



(a) **(b)**

Fig. 2: Macrograph of Untreated Sample of Steel SAE 1117 (a) Before (b) After Wear Test



(a) **(b)**

Fig. 3: Macrograph of Carburized Sample of Steel SAE 1117 (a) Before (b) After Wear Test

Fig. 3 shows wear pattern of carburised samples which shows less wear as compared to untreated sample which was in line with wear loss values noted during wear test.

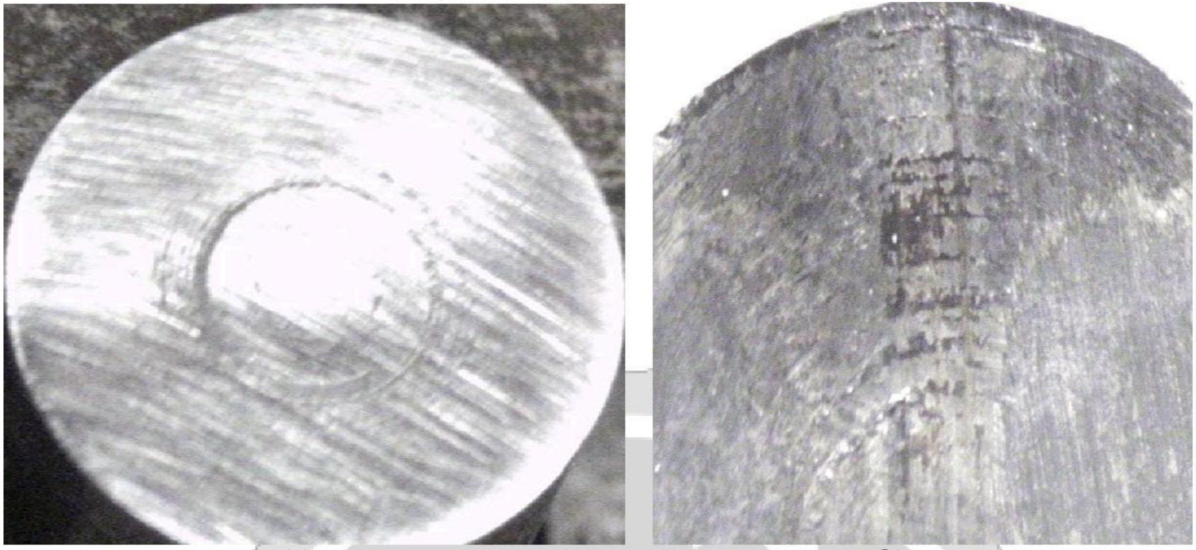

(a) (b)

Fig. 4: Macrograph of Carbonitrided Sample of SAE 1117 Steel (a) Before (b) After Wear Test

Fig. 4 shows wear macrograph of Carbonitrided sample which was similar to carburised sample and less than untreated samples.

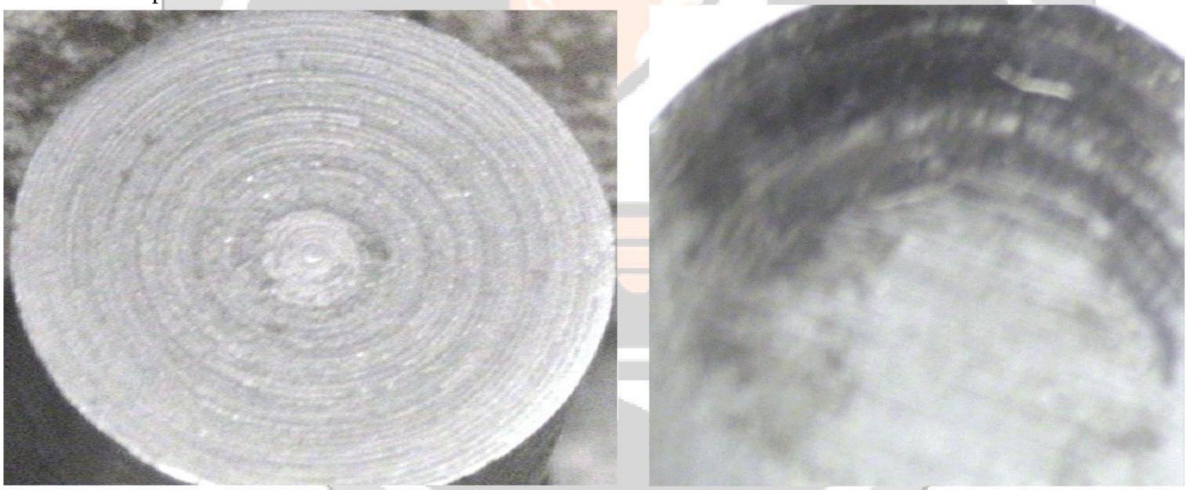

(a) (b)

Fig. 5: Macrograph of Nitrided Sample of SAE 1117 Steel (a) Before (b) After Wear Test

Fig. 5 shows wear macrograph of nitrided sample which was similar to carburised and carbonitrided sample and less than untreated samples. Comparison of macrographs images of different surface treated sample shows high wear pattern in untreated samples than other surface treated samples. In surface treated samples nitriding and carbonitriding samples shows consistent wear pattern than carburized samples.

4. CHEMICAL AND METALLURGICAL ANALYSIS

Specimens of diameter 12 and length 25 mm were cut of SAE 1117 material and subjected to different heat treatment procedures like carburising, carbonitriding and liquid nitriding. These samples were tested for chemical ,metallurgical analysis and hardness test. Chemical analysis was performed by spectrometry for various heat treated samples.

Carburized and Hardened Samples

Bearing cup samples and test pin specimens were surface treated by carburising at 920ºC and hardening at 820ºC and tempering at 180ºC in vertical retort furnace. Chemical analysis was performed by spectrometry. Chemical compositions are tabulated in Table 1, material composition confirms to SAE117.

C	Mn	P	S	Si	Al
0.19	1.20	0.009	0.102	0.19	0.027

Microstructure:

Microstructure of carbursied sample has been examined and following conclusions have been drawn. Micrograph at 100 % magnification etched with 3% nital solution was taken with optical microscope as shown in Fig 6. It was observed that the microstructure near surface was fine tempered martensite with some amount of retained austenite. Fig 7 shows core microstructure at 100% magnification which shows hardened and tempered structure with upper transformation product i.e. banite and pearlite.

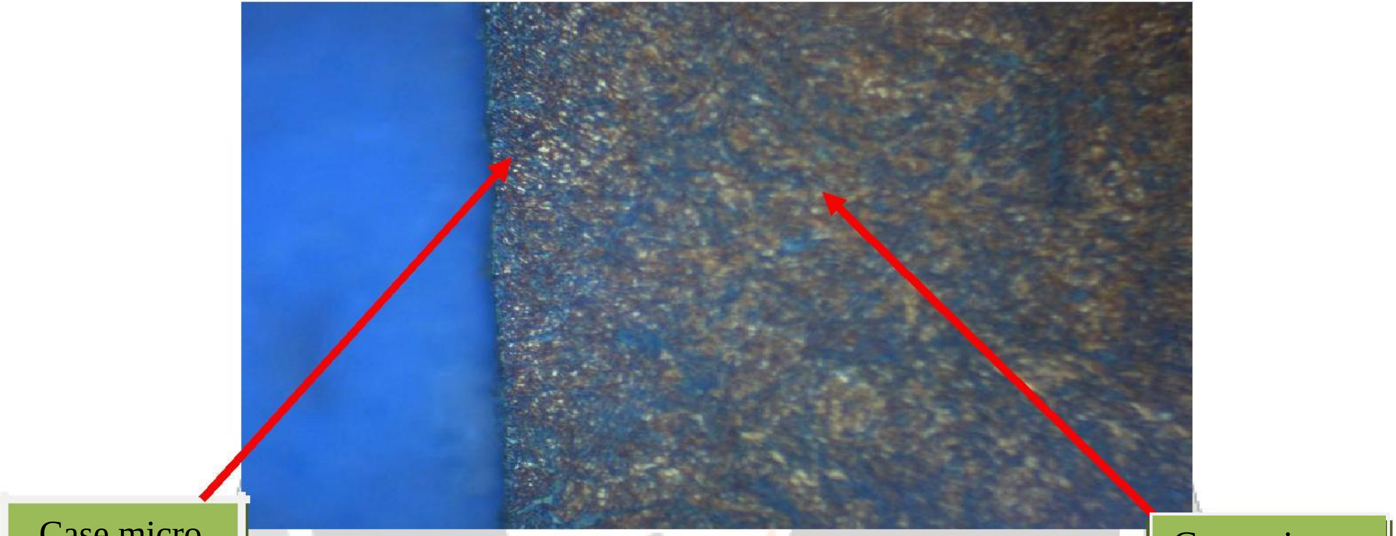


Fig. 6: Microstructure of SAE 1117 Carburised & Hardened Specimen Nital 3% 100X

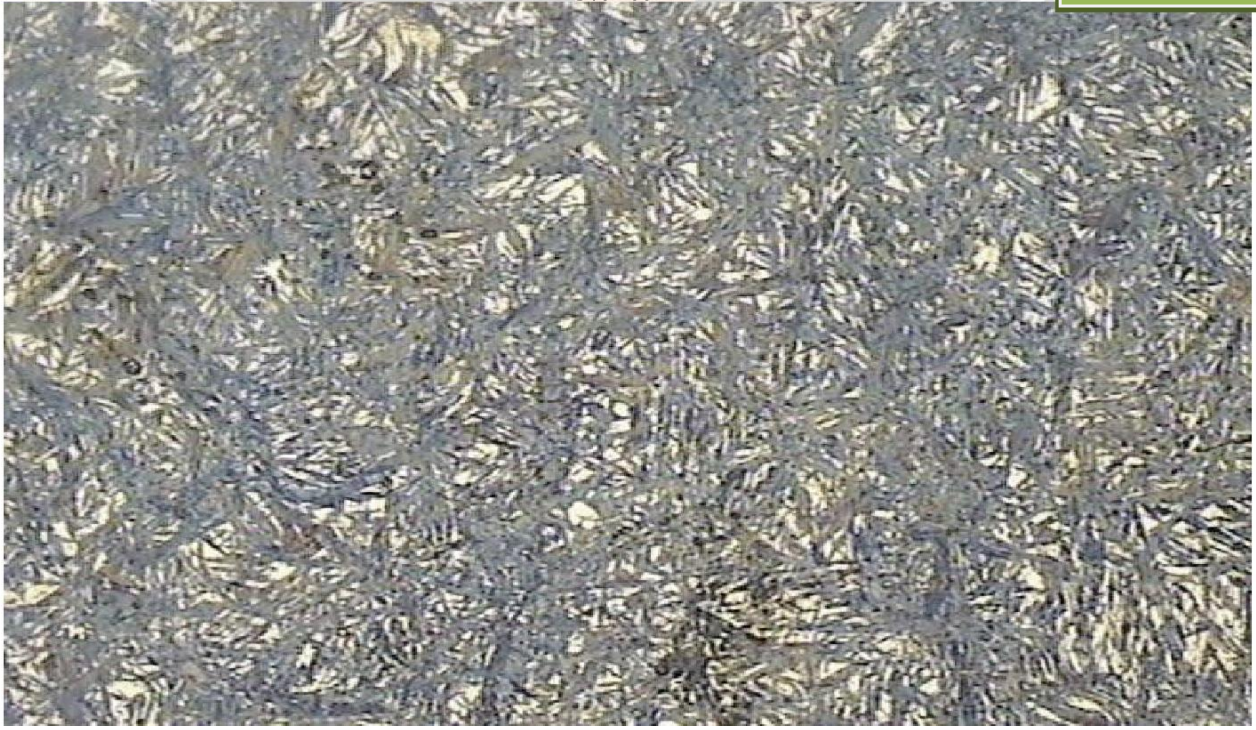


Fig. 7: Core Microstructure of SAE 1117 Carburised Specimen Nital 3% 100X

Hardness Measurements:

Hardness measurement of carburised bearing cup samples was done on rockwell hardness tester with 150 kg load and diamond indenter following readings were taken for sample.

Surface hardness – Observed value - 62 HRC Specification – 58 /64 HRC.
Core Hardness – 42 RC Specifications: 30 HRC max.

Hardness measurement of specimen was done on straight line from surface to core by interval of 0.1 mm under load of 1 Kg on Shimadzu micro hardness tester. Fig 8 shows hardness distribution of specimen which shows high hardness values till 0.7 to 0.8 mm. This shows that it becomes through hardening at groove area of bearing cup assembly. which may lead to brittle failure in impact loading.

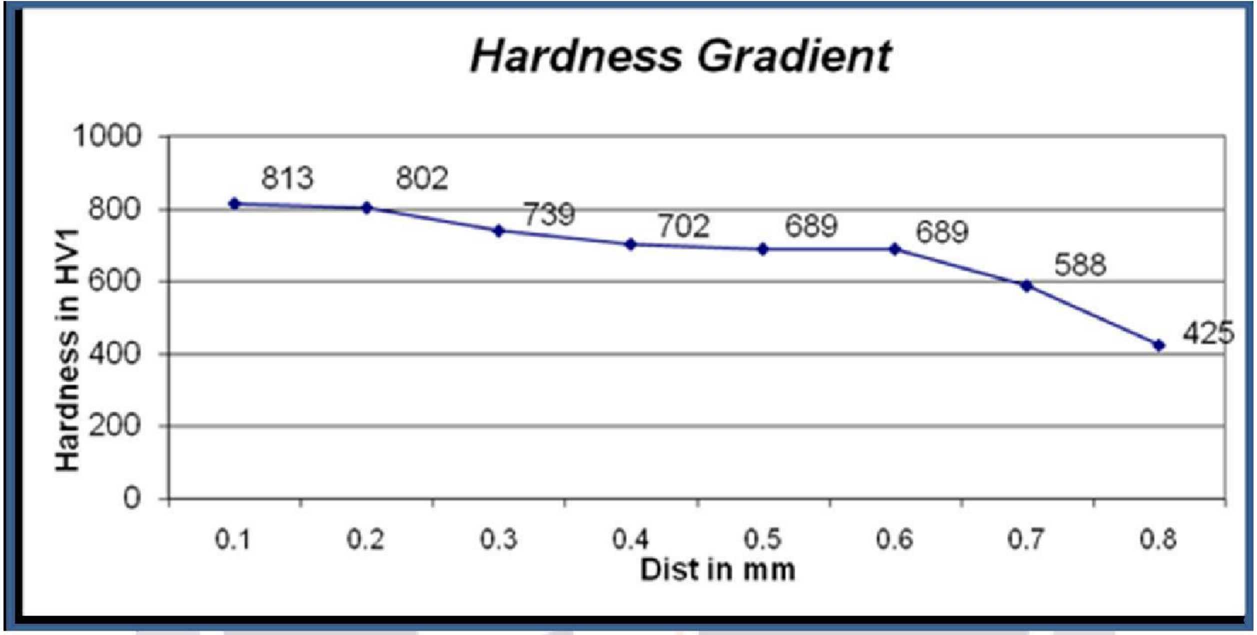


Fig. 8: Hardness Distribution for Carburized Specimen

Carbonitrided Samples

Bearing cup samples and test pins were surface treated by Carbonitriding at 810ºC and hardening at 740ºC Tempering at 180ºC in vertical retort furnace. Chemical analysis was performed by spectrometry. Chemical compositions are tabulated in Table 8.11, material compositions confirms to SAE1117.

Table 2: Chemical composition in (wt%) SAE 1117

C	Mn	P	S	Si	Al
0.19	1.20	0.009	0.102	0.19	0.027

Microstructure:

Microstructure of carbonitrided sample has been examined and following conclusions have been drawn. Micrograph at 100 % magnification etched with 3% nital solution was taken with optical microscope as shown in Fig 6. It was observed that the microstructure near surface was fine tempered martensite with some amount of retained austenite. Fig 7 shows core microstructure at 100% magnification and Fig. 8 shows core microstructure at 500% magnification which shows hardened and tempered structure with upper transformation product i.e. banite and pearlite. Carbonitrided sample has better hardenability as nitrogen increases hardenability of steel. Nitrogen is also austenite stabiliser therefore carbonitrided case contains more retained austenite than carburised samples.

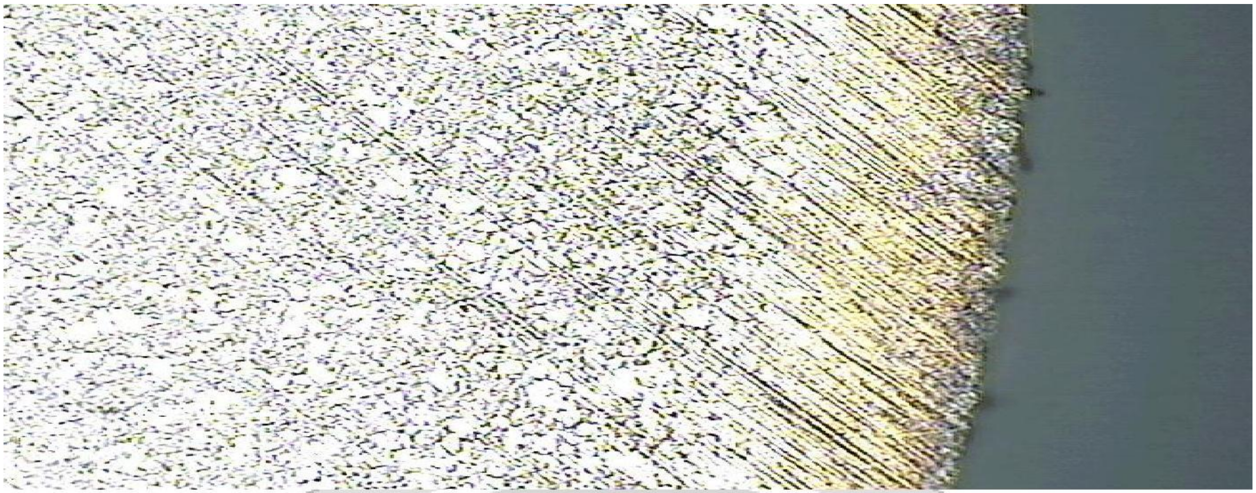


Fig. 9: Case Microstructure of Carbonitrided Specimen Nital 3 % 100 X

Fig. 10: Core Microstrucure of Carbonitrided Specimen Nital 3 % 100

Fig. 11: Core Microstrucure of Carbonitrided Specimen Nital 3 % 500 X

Hardness Measurements:

Hardness measurement of carbonitided bearing cup samples was done on Rockwell hardness tester. With 60 kg load and with diamond indenter following readings were taken for sample.

Surface hardness – Observed value – 80.1– 83.4 HRA Specification – 81.8 – 82.8 HRA
Core Hardness – 36 RC Specifications: 30 HRC max.

Hardness measurement of specimen was done on straight line from surface to core by interval of 0.1 mm under load of 1 Kg on Shimadzu microhardness tester. Fig 10, shows hardness distribution of specimen, which shows high hardness values till 0.4 mm this shows that it has less case depth than carburised samples and does not make bearing cup through hardened at groove area.

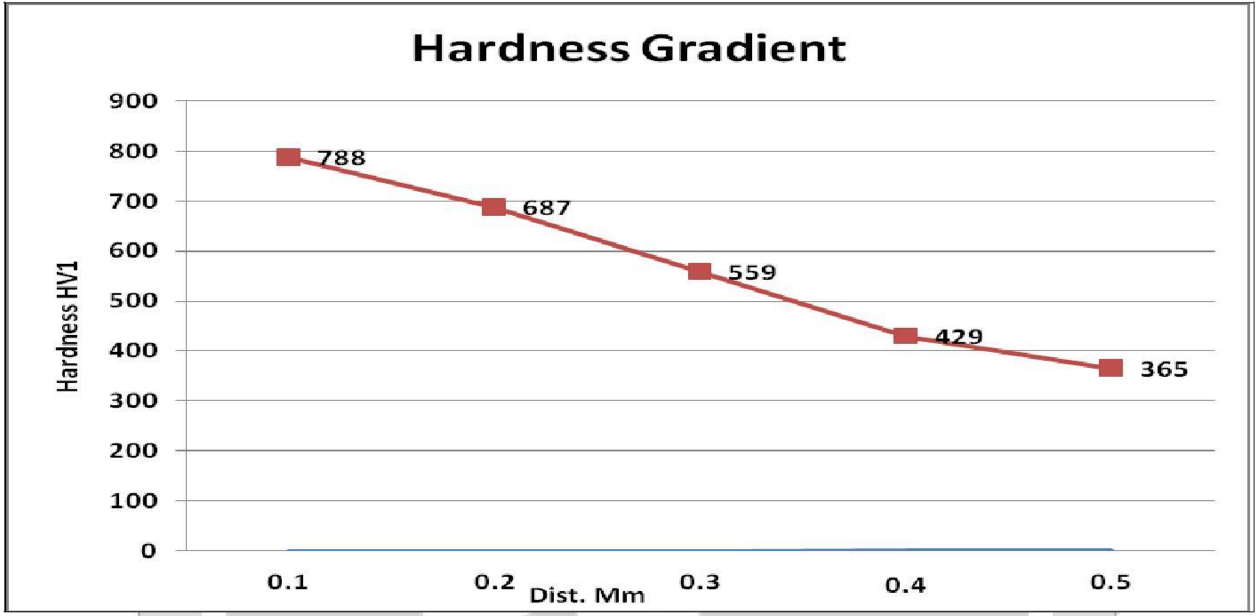


Fig. 10: Hardness Distribution for Carbonitrided Specimen

Liquid Nitrided samples

Bearing cups and test pin were liquid nitrided chemical analysis was performed by spectrometry. Chemical compositions were tabulated in Table 3, material confirms to SAE117 steel.

Table 3: Chemical Composition in (wt%) SAE 117

C	Mn	P	S	Si	Al
0.19	1.20	0.009	0.102	0.19	0.027

Microstructure:

Microstructure of nitrided sample has been examined and following conclusions have been drawn. Micrograph at 100 % magnification etched with 3% nital solution was taken with optical microscope as shown in Fig 11. It was observed that the microstructure near surface was fine tempered martensite with some amount of retained austenite. Fig. 12,shows core microstructure at 100% magnification which shows hardened and tempered structure with upper transformation product i.e. banite and pearlite.

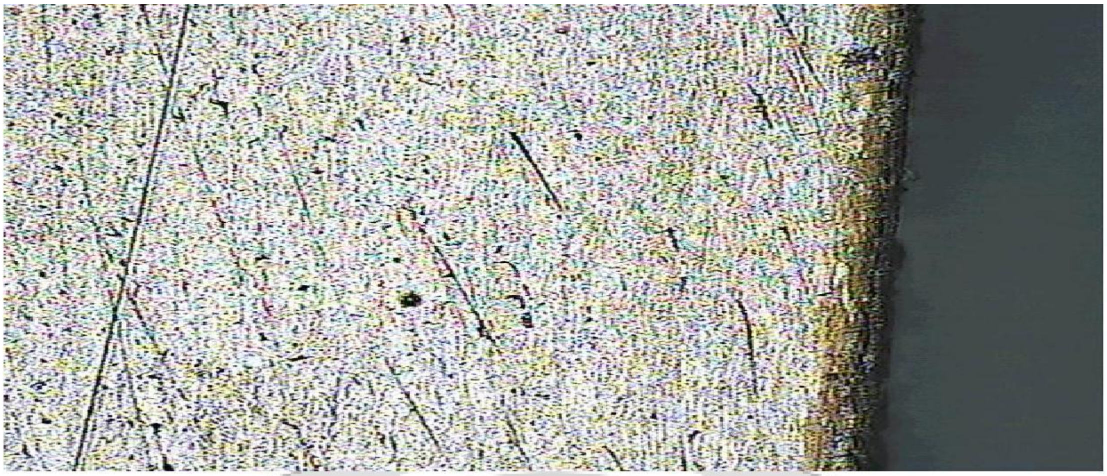


Fig.11: Case Microstructure of Nitrided Specimen Nital 3 % 100 X

Fig. 12: Core Microstructure of Nitrided Specimen Nital 3 % 100

X Hardness Measurement:

Hardness measured on micro hardness tester at load 1 gm with diamond indenter Following reading were taken

Surface Hardness – Observed value – 566 Hv1. **Core Hardness** – 32 RC Specifications: 30 HRC max.

Case Depth Measurement: 8 – 10 microns.

From these readings it was observed that for nitrided sample case depth is less as compared to carburized and carbonitrided samples.

5. CONCLUSIONS

In this study failure analysis of bearing cup was carried out using optical micro. Bearing cup assembly was produced from SAE1117 low carbon carburising steel and was surface treated by carburising, hardening and tempering processes. Cause and effect diagram was made to find out root cause of the failure. Analysis revealed that bearing cup was failing due to through hardening at groove, as wall thickness was less in this area which results into brittle failure during assembling process. Alternate heat treatment processes like carbonitriding and nitriding were tested on various tests like chemical analysis, microstructure study, hardness measurement.From results and discussion following conclusions can be drawn.

1.Carburising and hardening processes achieve good results to achieve martensite structures which gives good wear resistance. Hardness achieved at surface was within range of 58-62 RC. Case depth achieved was high, 0.8 -1.1mm.
2.Carbonitriding and hardening processes show good results to achieve martensite structures which gives good wear resistance. Hardness achieved at surface was within range of 58-62 RC; case depth achieved was less (0.3-.045mm) as compared to that achived by carburising and hardening (0.8 to 1.1mm).

3.Nitriding process achieves good surface hardness @ 566 Hv1. However case depth achieved is less than 10 microns. Core hardness was 30 RC. Case microstructure was fine tempered martensite.

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