Hardening Characteristics of 16MnCr5 Metals for Engine Block

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Abstract—Crankpin is a mechanical part which links the crankshaft to the connecting rod to each cylinder. Normally, crankpins are made up of low carbon material which results in unexpected fracture on the crankpin material due its chemical composition, high engine temperature, high operating oil temperature, improper lubrication and lower hardness. Recently, researchers are developing crankpins with different materials for the better performance such as alloy steel and the mild steel materials which have similar chemical compositions of low carbon material. The primary object of this study is to develop an improved crankpin which will alleviate the current crankpin used in the connecting rod. In this work we have selected 16MnCr5 as a replacement of the presently used crankpin in the connecting rod. 16MnCr5 is a low carbon steel widely used for several applications in many of the automobile industries. 16MnCr5 is hardened by a case hardening process which is carried out through the sealed quench furnace for the set of process parameters. The results of the prepared material were analyzed using hardness, microstructure examination and the economic conditions of the materials. In future, another set of two materials such as SCM420H and EN1A will be used for alternating material for crankpin which are processed with the same set of parameters and compared with the 16MnCr5 material to check the suitable crank pin material to avoid unexpected damage.

Keywords— Crankpin, low carbon steel, alloy steel, mild steel, crankshaft.

1. INTRODUCTION

High-performance engines, lightweight designs, component dependability, and low-cost manufacturing requirements are all satisfied by crankpin. The connecting rod and crankshaft are moved up and down by crankpins [1]. Through a bearing, the connecting rod's large end is attached to the crankpin of the crankshaft. [2]. Vibrations caused by the application of bearings, incorrect lubrication, high engine temperature, high operating oil temperature, and wear owing to lesser hardness are some of the possible causes of crankpin failures [3]. In recent developments, crankpin is to be changed with different materials for better performance. There are specific materials which are carbon steel, alloy steel and forged steels were used for crankpin. Through case carburizing, nitriding, or induction hardening, the crankpin's surface is made harder. Case carburizing is also a case hardening which apts crankpin for hardening. Case hardening can be done by Sealed quench furnace and most of the crankpin hardeningis done on sealed quench furnace [4-5]. A wide literature survey has been carried out to understand the work philosophy carried out in the past and carry forward relevant inputs if needed. A brief outcome of major literature has been explained as follows, S Arunkumar

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(2020) investigation is involved in heat treating the shaft made of 16MnCr5 to three distinct levels of hardness at three different temperatures. Following this, tensile tests for the material with various hardness levels were conducted. There was a thorough calculation that encompassed the shaft. and in light of the outcomes. A comparison was done in order to achieve the highest yield strength and hardness. The 16MnCr5 optimal value has been chosen. [6]. KritiSrivastava (2020) From this study is about the influence of heat treatment on toughness and hardness of EN8 steel, By using various quenching medium such as water, oil and air for the heat treatment by muffle furnace. Charpy impact and Rockwell hardness testing were done. As per the results, here they consider oil quench medium has better results and achieved their requirements. Oil quench is far better than others in this study [7]. HaojieWang (2018) In this work, gear steel's low-pressure carburizing procedure was optimized. Low-pressure carburization and conventional atmospheric carburization are contrasted. and reaped the benefits of no surface oxidation and consistently fine carbides. After the carburizing process is completed. The microstructure was observed by optical microscope, SEM and TEM. Finally, it is discovered that the depth of the actual layer is quite comparable to the necessary design depth by altering the diffusion coefficient model and comparing the hardness with various methods. [8]. Saicai (2021) According to this study, the surface hardness of the carburizing, quenching, and hardening layer is the key factor contributing to the fracture of the 16MnCr5 gear shaft during the heat treatment process. They came to the conclusion that the fracture occurs because of reduced hardness because no martensite microstructure is created. [9]. Manchaozhang (2015) In this study is to optimize residual stresses and roughness during path-controlled crank pin grinding. The findings demonstrate how surface roughness and residual stresses are dispersed during induction hardening using path-controlled grinding. Finally, it was proposed that the path control grinding hardened by induction surface hardening can use lower crankshaft rotational speed, lower grinding depth, and higher wheel speed [10]. M. P.Prabakaran (2021) In this study, effects of post-weld heat treatment on austenitic stainless steel to low carbon steel joints that were laser welded together at different temperatures. In the laser welding method, the dissimilar metals are joined with austenitic stainless steel and low carbon steel [11]. The effects of pre pre-weld heat treatment process on different metals are analyzed. The chemical analysis was successfully done with dissimilar weld zones and microstructure is good for the dissimilar sheet joint at both conditions of welded and heat-treated joints. Shaohong Li (2014) the effects of heat treatment influencing factors on microstructure and mechanical properties of a low carbon steels. The influence of heat treatment on low carbon steels' mechanical characteristics and microstructure. Investigated were the effects of various heat treatment settings on the microstructural modifications and mechanical characteristics of low carbon martensitic steel. These analyses came from x-ray diffraction, optical microscope, and transmission electron microscopy. According to the results, quenched and tempered bearing steel undergoes heat treatment, which increases hardness and tensile strength while reducing toughness. Although tempering at a high temperature during this cryogenic heat treatment can partially change any remnant austenite into martensite [12]. Gurmeetsingh (2020) From this study, the effects of heat treatment on the properties of mild steel and also the tensile properties. Cooling at room temperature during full anneals has a large microstructure. When increasing the tempering temperature, the ductility of steel grade increases. [13]. Choonyoo (2019) studied about the analysis on the microstructure and hardness change after carburizing of chromium molybdenum alloy steel for automobile parts. Gas carburization process is used for hardening the material. Observed microstructure shows that the before carburization was composed of pearlite and ferrite mixed structure. After carburization, the needle shape structure gradually decreases from the surface to the interior. Hardness was tested for SCM15, SCM420 and also effective case depth. As a result, comparison is necessary to adjust the correction factors such as the effect of retained austenite on the surface hardness and the effect of various fine carbides on the hardness [14]. In this work we have selected 16MnCr5 as a replacement of the presently used crankpin in the connecting rod. 16MnCr5 is a low carbon steel. It is largely used for various applications in many of the automobile industries. It gives more effective performance and several operations can take place. Components like gear, pin, shaft, cam shafts, drive wheels, clutch plates etc., are manufactured by this material. 16MnCr5 is hardened by a case hardening process which is carried out through the sealed quench furnace for the set of process parameters. The results of the prepared material were analyzed using hardness, microstructure examination and the economic conditions of the materials. In future, another set of two materials such as SCM420H and EN1A will be used for alternating material for crankpin which are processed with the same set of parameters and compared with the 16MnCr5 material to check the suitable crank pin material to avoid unexpected damage.

II. MATERIALS AND METHODS

16MnCr5 steel is purchased from the local market. It is an engineering material commonly used to create levers, camshafts, piston bolts, and other parts for vehicles and mechanical engineering. Table I and Table II shows physical and chemical properties of the 16MnCr sample. The purchased material is machined by lathe process with the size of 19 mm in outer diameter and 65 mm in length.

Table I. Physical properties:

Property	Value	Unit
Thermal expansion	10-10	e-6/k
Thermal conductivity	25-25	W/m.K
Specific heat	460-460	J/kg.K
Melting temperature	1450-1510	C
Density	7700-7700	kg/m^3
Resistivity	0.55-0.55	$Ohm.mm^2/m$

Table II. Chemical composition of the base metal (asm.matweb.com)

C	Si	Mn	P	S	Cr
0.14-0.19%	0.40%	1.00-1.30%	0.025%	0.035%	0.80-1.10%

A. Case hardening for 16MnCr5

The sample of 16MnCr5 material is purchased from a local vendor at Chennai, and then material is machined by lathe process with the size of 19 mm in outer diameter and 65 mm in length.

B. Pre washing

Pre-washing is the first step of the process. In this step to clean the specimen for removing cooling lubricants, cutting fluids or rust preventive oils form a carburizing barrier, components are used to clean by alkali DM water with respect to temperature and time. Table II shows Pre pre-washing temperature of the 16MnCr sample.

Table III. Pre-washing temperature.

	Set	Actual
Alkali temp.	70	70
Jog time	10	10
Spray time	10	10

C. Preheating

Preheating has several goals, including lowering the likelihood of hydrogen cracking, lowering the hardness of the weld heat-affected zone, lowering cooling-induced shrinkage stresses, and enhancing the distribution of residual stresses. Table IV shows Preheating temperature and time of 16MnCr sample.

Table IV. Preheating temperature and time

Temperature	350 C
Time	30 min

D. Hardening

In the hardening process, there are three major process parameters such as Temperature, Time and CP (carbon potential). Until the correct internal structure takes shape, the metal is kept at the proper temperature throughout the activation or soaking stage. In order to raise the steel's carbon content and ultimately harden the specimen, diffusion takes place between a low-carbon steel and a carbon-rich environment. Secondary soak is the purpose of changing core structure and hardness, Quenching is not possible during activation or soaking stage (930c). After diffusion, cooling starts then diffusion temperature drops from 930c to 860c (secondary soak). And also controlling retained austenite by CP drops. Table V shows hardening parameters of the 16MnCr sample.

Table V. Hardening parameters

Parameters	Activation	Diffusion	Secondary soak
Temperature	930C	930C	860C
CP	1%	0.85%	0.7%
Time	230 min	135 min	30 min

E. Flow rate

For flow rate, CO_2, LPG and Air pressure are used for the process. Table VI shows flow rates used for 16MnCr samples.

Table VI. Flow Rates

Co2 (lpm)	LPG (lpm)	Air pressure (Kg/Cm2)
1.0	3.0	6.5

F. Quenching

Oil quenching is more effective than another quenching medium. Salsol Q001 grade for oil which is fast oil or cold oil. Oil temperature is set, quenching time takes 45 mins. Agitator is used to spread oil uniformly to maintain the temperature for the quenching component. Table VII shows quenching parameters of the 16MnCr sample.

Table VII. Quenching parameters

Oil Temperature	Quenching	Oil Trip	Agitator
70C	30 min	15 min	500 rpm

G. Tempering

Tempering is the last step of the process. For low carbon steel, tempering temperatures range from 150^0C to 200^0C.

Table VIII. Tempering parameters.

Temperature	150c
Time	120 min

Time for after soaking is 2 hours. Table VIII shows tempering parameters of the 16MnCr sample.

III. RESULTS AND DISCUSSION

Case hardening process for 16MnCr5 is completed. Surface hardness 62,63 HRC and core hardness 41,42 HRC observed. Effective case depth is 1.34 mm is observed. Microstructure for case is Fine tempered martensite with 2% Retained austenite and for core Low carbon martensite are observed. From this result is considered as a reference for the process of other two materials SCM420H and EN1A.After all processes are completed, hardness, case depth and microstructure to be inspected and observed. Comparing these materials with achieved results and also comparing the economic conditions of the materials.

A. Hardness and Case depth

1) Before Hardening

Fig. 1 Soft material

Fig.1 shows soft material Before hardening, the raw material or soft material to measure by its hardness in Rockwell hardness test. Table IXshows the hardnessof the 16MnCrsample before hardening.

Table IX. Hardness of 16MnCr sample before hardening.

Material	Hardness
16MnCr5	12 HRC

B. As Quench hardness

After hardening the material, Post washing was done. As Quench hardness is checked for the tempering. Table Xshows the hardnessof the 16MnCrsample as Quench hardness.

Table X. Quench hardness

Material	SH
16MnCr5	64,65 HRC

C. After Tempering

Fig 2. Harden material

Fig.2 shows hardened material after tempering, both surface hardness and core hardness checked in the Rockwell hardness tester. Surface of the material is finished by a linting machine with 120 sheet garde for surface hardness. Core hardness is checked by a cross section of the material. Table XIshows the hardnessof the 16MnCr sample after tempering.

Table XI. Hardness of 16MnCr sample after tempering

Material	SH	CH
16MnCr5	62,63 HRC	40,41 HRC

D. Case depth

1) Micro hardness survey

Table XIIshows a micro hardness survey of 16MnCr samples.

Table XII. Micro hardness survey

Depth in mm	**Hardness**
0.1	795
0.2	785
0.3	783
0.4	776
0.5	765
1	620
1.1	568
1.2	549
1.3	520
1.4	502
Core	457
ECD	1.34 MM

E. Calculation for Effective case depth:

HD1 – HB2	HD1 – Hcutoff
D2 – D1	ECD – D1
520 – 502	520 - 513
1.4 – 1.3	ECD – 1.3

ECD = 1.3388 which implies 1.34 mm.

Effective case depth for 16Mncr5 is 134 mm.

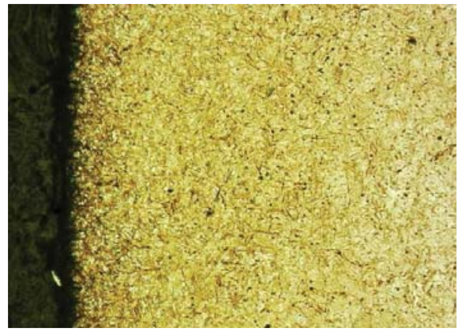
After preparation of mold is done, Micro hardness survey is checked on micro Vickers hardness tester. Load for checking is HV1.0 kg and the cut off value is 513. The below table shows the hardness traversed reading for the effective case depth. Depth is measured by the range of 0.1 mm upto cutoff value. Cut off value is achieved in between 1.3 mm depth to 1.4 mm depth. 1.34 mm is the exact value of Effective case depth.

Fig.3 shows Mold of the specimen is tested with micro hardness survey. After testing is done, the mold sample is etched into the solution. Etching is used after Metallographic Grinding and Polishing Procedures. Etching is prepared from 5% of HNO3 and 95% of Carbofluid. Etching Enhances the Contrast on Surfaces in Order to Visualize the Microstructure.

Fig.3 Specimen mold

F. Microstructures

Fig.4 shows microstructures are observed in Optical microscopy. For case, Fine tempered martensite with 2% Retained austenite observed. Carbides or network carbides or fine carbides are not found.



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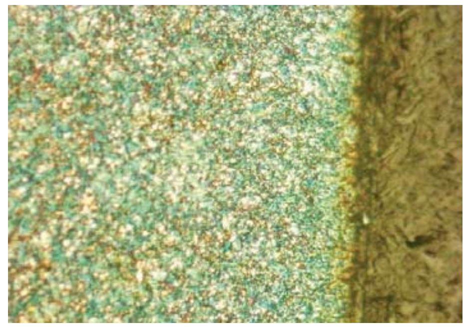

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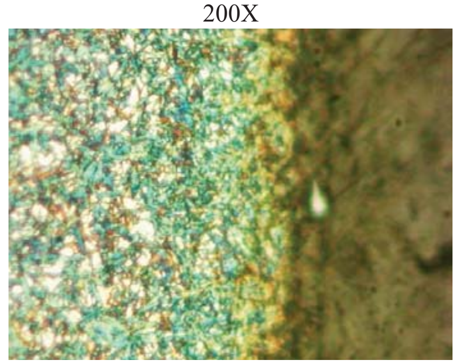

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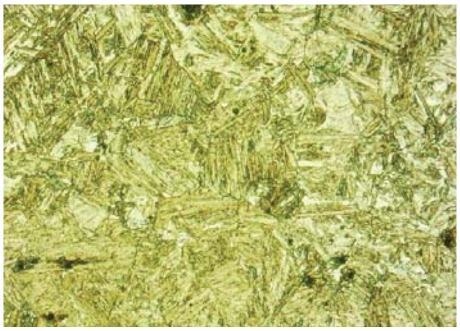
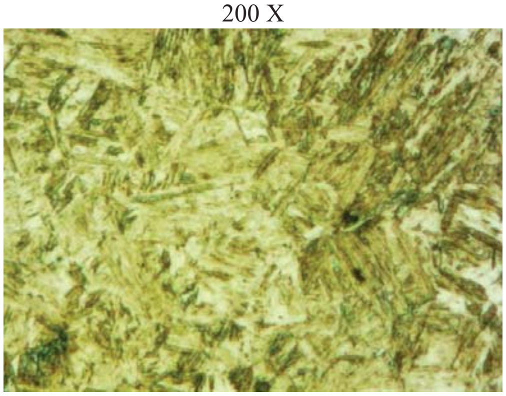
Fig. 4 Case micro structure: Fine tempered martensite with 2% RA with different Magnification range

From figure 5 (ABC) refers to case 16MnCr5 microstructure for case Fine tempered martensite with 2% of Retained austenite are observed with fine grains structure, there are carbides, network carbide, and decarb layer is not found. Oxidation observed below 1mm. From figure 5 (ABC) refers to core 16MnCr5 microstructure for core Low carbon martensite with bainite structure are observed, there is core ferrite and ferrite pitches are not found.

100 X



200 X



500 X

Fig. 5 Core microstructure Core: Low tempered martensite with different Magnification range

G. Surface Morphology

Fig. 6&7 shows the SEM images obtained for Case microstructure and Core microstructurestructure after hardness for the study. The ductile cracked object in the surface morphology images has micro spaces and dimples. As-received specimen, where intergranular fracture and dimples are shown in the Case hardening specimen, but case and core cleavage and dimples are seen in the core hardening specimen.

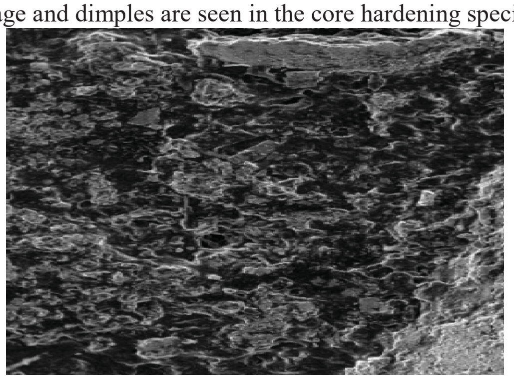


Fig. 6 Case micro structure

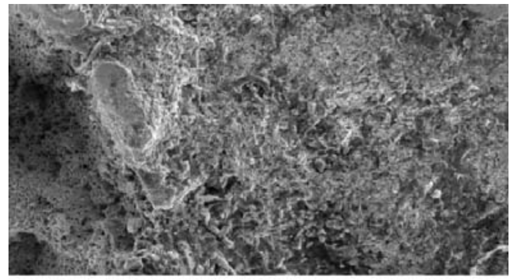


Fig. 7 Core microstructure

IV. CONCLUSION

Selected materials 16MnCr5 is purchased and process parameters, hardened and result analysis were completed. The final results of comparative study of this process are as follows below. Table 12 refers to the Case hardening and core hardening process for 16MnCr5.

Table XIII. 16MnCr5Sample results

MATERIALS	SURFACE HARDNESS	CORE HARDNESS	CASE DEPTH	MICROSTRUCTURE
Case hardening 16MnCr5	62,63 HRC	40,41 HRC	1.34 mm	Case: FTM + 5%RA Core: LCM+BAINITE
Core hardening 16MnCr5	63,64 HRC	38,39 HRC	1.28 mm	Case: FTM + 5%RA Core: LCM+BAINITE

Table XIII shows that results of selected materials 16MnCr5 and the results represents the 16MnCr5 materials achieved similar hardness, case depth and microstructure of presently used SCM420H crank pin material. From the results 16MnCr5 is highly preferred for replacement of current crank pin material. Economic conditions of the material are low compared to old material. 16MnCr5 is of moderate cost than SCM420H. 16MnCr5 has achieved similar hardness, microstructure and economically good for the future production of crankpin.

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