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Chemical and Microstructural Evaluation of 16MnCr5 Steel for Enhanced Crankpin Performance in Automotive Applications

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Crankpin is a critical component in internal combustion engines, often fail due to low hardness, high operational temperatures, and inadequate lubrication. Conventional low-carbon steel crankpins are prone to such issues. This study aims to improve crankpin performance by replacing existing materials with 16MnCr5 steel, a low-carbon alloy hardened through case hardening in a sealed quench furnace. The methodology includes material preparation, case hardening, and subsequent evaluation via hardness testing and microstructure analysis. The hardened 16MnCr5 exhibited a surface hardness of 62–63 HRC, core hardness of 40–41 HRC, and an effective case depth of 1.34 mm. Microstructural analysis revealed fine tempered martensite with 2% retained austenite. These findings establish 16MnCr5 as a viable crankpin material and provide a reference for future comparisons with SCM420H and EN1A. Future work will further validate this selection through similar treatment and analysis of the additional materials.

Keywords: Crankpin; low carbon steel; alloy steel; mild steel; crankshaft

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Crankpins play a key role in engines by helping to meet the demands for high performance, lightweight construction, reliable parts, and cost-effective manufacturing. They connect the crankshaft to the connecting rod, which moves up and down during engine operation [1]. The big end of the connecting rod fits onto the crankpin using a bearing. However, crankpins can fail due to several issues such as vibration, poor lubrication, high engines and oil temperatures, or wear caused by low surface hardness [2]. To improve their durability and performance, crankpins are now being made using different types of carbon and alloy steel [3-4]. To make the surface of crankpins stronger, heat treatment methods like case carburizing, nitriding, or induction hardening are used. Among these, carburizing is commonly applied, especially using a sealed quench furnace, which is widely used for hardening crankpins [5].

A detailed review of previous research was carried out to understand earlier studies and gather useful information that could help with the current work. Here are some key takeaways from the reviewed literature Prakash R. (2023) studied microalloyed steels and surface treatments like nitriding and induction hardening. He pointed out that industries are moving from traditional steels to newer, cost-effective materials with better performance. His review supports using 16MnCr5 steel because it has good hardenability and is economical to process. Kriti Srivastava (2020) focused on how heat treatment affects the toughness and hardness of EN8 steel [6-8]. She tested different quenching methods (water, oil, and air) using a muffle furnace. The study showed that oil quenching gave the best results in terms of hardness and toughness.

Pathan S. K. (2024) examined the fatigue life of 16MnCr5 steel under repeated bending, similar to what crankpins face. Samples were heat-treated to different hardness levels (40–55 HRC). The results showed that higher surface hardness improved fatigue resistance, making 16MnCr5 a good choice for such

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applications. Sai Cai (2021) found that surface hardness is a key factor in preventing fractures in 16MnCr5 gear shafts during heat treatment. Fractures occurred when martensite did not form properly, reducing the hardness of the surface. Yoo H.C. (2022), though working with spring steel, showed that shot peening combined with proper heat treatment greatly increases fatigue life. These techniques can also be useful for crankpins because they experience similar stress.

M. Prabhakaran (2021) studied laser-welded joints between austenitic stainless steel and low-carbon steel. The study focused on how post-weld heat treatment affects the joint's microstructure and mechanical properties [9-10]. The results showed a good bond and strong microstructure in both welded and heat-treated conditions. Shaohong Li (2014) researched how different heat treatment settings affect the microstructure and strength of low-carbon steels. Using X-ray, optical, and electron microscopes, the study showed that quenching and tempering increased hardness and strength, though toughness decreased. High-temperature tempering helped convert retained austenite into martensite, improving performance. Gurmeet Singh (2020) explored how heat treatment changes the properties of mild steel. He found that annealing followed by room-temperature cooling gave a larger microstructure, and higher tempering temperatures improved steel's ductility.

Despite extensive research into the mechanical and thermal properties of low-carbon steels and alloy steels used in crankpin applications, there remains a lack of comparative analysis on optimized case hardening parameters across multiple candidate materials processed under identical conditions. Moreover, studies often overlook the practical feasibility of transitioning to new materials, such as cost analysis, ease of processing, and consistent performance across manufacturing batches.

In this work, focused on 16MnCr5 steel as a potential replacement for the current crankpin material in connecting rods. This steel is commonly used in automotive parts like gears, shafts, cams, and clutch plates due to its good performance [11-12]. It undergoes case hardening using a sealed quench furnace, following specific process settings. The material was then tested for hardness, microstructure, and cost-effectiveness.

This study addresses that gap by not only investigating 16MnCr5 but also establishing a foundation for comparison with SCM420H and EN1A under identical processing conditions, which will help identify an optimal crankpin material. This will provide clearer insights into which material best mitigates unexpected crankpin failures and offers sustainable performance in automotive applications.

MATERIALS AND METHODS

Material Selection

The 16MnCr5 steel used in this study was sourced from the local market. This type of low-carbon alloy steel is widely applied in automotive and mechanical engineering industries for manufacturing components such as camshafts, levers, piston bolts, and other high-strength parts. After procurement, the material was machined using a lathe to produce cylindrical samples with dimensions of 25 mm in outer diameter and 75 mm in length. The physical properties of the material include a thermal expansion coefficient of 10×10^{-6}/K, thermal conductivity of 25 W/m·K, specific heat capacity of 460 J/kg·K, melting temperature range between 1450°C and 1510°C, density of 7700 kg/m^3, and electrical resistivity of 0.55 Ohm·mm^2/m. Chemically, the steel contains 0.14–0.19% carbon, 0.40% silicon, 1.00–1.30% manganese, 0.025% phosphorus, 0.035% sulfur, and 0.80–1.10% chromium. These properties make 16MnCr5 a suitable material for case hardening applications where both strength and surface wear resistance are required.

The case hardening process for 16MnCr5 steel begins with the procurement of raw material from a local vendor in Chennai, which is then machined into cylindrical samples measuring 25 mm in diameter and 75 mm in length. The procedure involves several sequential steps, such as, the material is cleaned using alkaline demineralized water to remove surface contaminants such as oils and cutting fluids, ensuring effective carburizing. The sample is preheated to 350°C for 30 minutes to reduce the risk of hydrogen-induced cracks, relieve thermal stresses, and improve stress distribution during heat treatment. The material undergoes carburizing in three stages—activation, diffusion, and secondary soaking. Carbon is diffused into the steel at temperatures ranging from 930°C to 860°C, with controlled carbon potential (CP), to enhance surface hardness without quenching at this stage. Carbon-rich gases such as CO_2 and LPG, along with air, are regulated to maintain the appropriate atmosphere for carburizing. After hardening, the part is oil-quenched in Sal Sol Q001 oil at 70°C for 30 minutes. An agitator ensures uniform cooling and prevents thermal distortion. To reduce internal stress and increase toughness, the quenched part is tempered at 150°C for 2 hours. The sequence of Case Hardening Procedure for 16MnCr5 Steel is given in Table 1 and ensures a hardened surface layer with a tough core, making 16MnCr5 ideal for high-stress automotive applications like crankpins.

Table 1. Case Hardening Procedure for 16MnCr5 Steel.

Step	Process	Parameters
Material Info	Source and Size	Sourced locally (Chennai), machined to Ø 25 mm × 75 mm using lathe
Pre-Washing	Cleaning	Alkali Temp: 70°C, Jog Time: 10 min, Spray Time: 10 min
Preheating	Temperature	Temp: 350°C, Time: 30 min
Hardening	Activation	Temp: 930°C, CP: 1.0%, Time: 230 min
	Diffusion	Temp: 930°C, CP: 0.85%, Time: 135 min
	Secondary Soak	Temp: 860°C, CP: 0.7%, Time: 30 min
Atmosphere	Gas Flow Rates	CO_2: 1.0 lpm, LPG: 3.0 lpm, Air Pressure: 6.5 Kg/cm²
Quenching	Oil Quench	Oil Type: Sal Sol Q001, Temp: 70°C, Quenching Time: 30 min, Oil Trip: 15 min, Agitator Speed: 500 rpm
Tempering	Post Treatment	Temp: 150°C, Time: 120 min

RESULTS AND DISCUSSION

Hardness Evaluation

The case hardening of 16MnCr5 steel was successfully completed, and a series of tests were conducted to evaluate its hardness, case depth, and microstructure. The surface hardness reached 62–63 HRC, while the core hardness was measured at 40–41 HRC. The effective case depth was determined to be 1.34 mm. Microstructural analysis revealed fine-tempered martensite with approximately 2% retained austenite on the surface, whereas the core consisted of martensite with lower carbon content. These findings will serve as a benchmark for evaluating the other materials, SCM420H and EN1A, under similar treatment conditions. Figure 1and 2 shows material before hardening and after hardening.

The hardness evaluation process was carried out in three key stages: Before Hardening: Initial Rockwell hardness testing showed that the untreated 16MnCr5 sample had a hardness of 12 HRC. After Quenching: Once the hardening process was complete and the sample was post-washed, quench hardness was measured. The results, indicate a sharp increase in hardness to 64–65 HRC. After Tempering: Following tempering, both surface and core hardness were measured using the Rockwell method. The surface was first smoothed with a linishing machine using 120-grit paper. The final surface hardness was 62–63 HRC, and the core hardness was 40–41 HRC. 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.

Figure 1(a) Soft material before hardening.

Figure 1(b) Hardened material after tempering.

Table 2. Pre-washing temperature.

	Set	Actual
Alkali temperature (°C)	70	70
Jog time (min)	10	10
Spray time (min)	10	10

Table 3. Preheating temperature and time.

Temperature	350 °C
Time	30 min

Prewashing

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 2 shows Pre pre-washing temperature of the 16MnCr sample.

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 3 shows Preheating temperature and time of 16MnCr sample.

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 (930°C). After diffusion, cooling starts then diffusion temperature drops from 930°C to 860°C (secondary soak). And also controlling retained austenite by CP drops. Table 4 shows hardening parameters of the 16MnCr sample.

Flow Rate

For flow rate, CO_2, LPG and Air pressure are used for the process. Table 5 shows flow rates used for 16MnCr samples.

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 6 shows quenching parameters of the 16MnCr sample.

Table 4. Hardening parameters.

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

Table 5. Flow Rates.

CO_2 (lpm)	LPG (lpm)	Air pressure (kg/cm^2)
1.0	3.0	6.5

Table 6. Quenching parameters.

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

Table 7. Tempering parameters.

Temperature	150ºC
Time	120 min

Tempering

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

Time for after soaking is 2 hours. Table 7 shows tempering parameters of the 16MnCr sample.

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.

Hardness and Case Depth

Before Hardening

Figure 2 shows soft material before hardening, the raw material or soft material to measure by its hardness in the Rockwell hardness test. Table 8 shows the hardness of the 16MnCrsample before hardening.

Figure 2. Soft material.

Table 8. Hardness of 16MnCr sample before hardening.

Material	Hardness
16MnCr5	12 HRC

Table 9. Quench hardness.

Material	SH
16MnCr5	64,65 HRC

Figure 3. Harden material.

As Quench Hardness

After hardening the material, Post washing was done. As Quench hardness is checked for the tempering. Table 9 shows the hardness of the 16MnCr sample as Quench hardness.

After Tempering

Figure 3 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 grade for surface hardness. Core hardness is checked by a cross section of the material. Table 10 shows the hardness of the 16MnCr sample after tempering.

Case Depth

Micro Hardness Survey

Table 11 shows a micro hardness survey of 16MnCr samples.

Table 10. Hardness of 16MnCr sample after tempering.

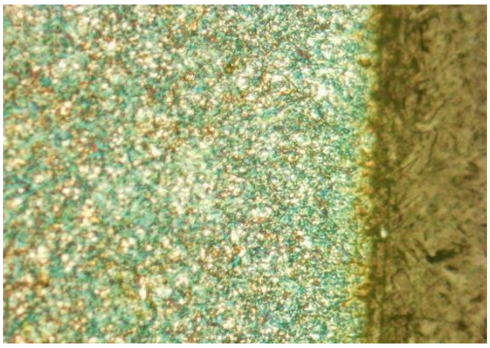
Material	SH	CH
16MnCr5	62,63 HRC	40,41 HRC

Table 11. Micro hardness survey.

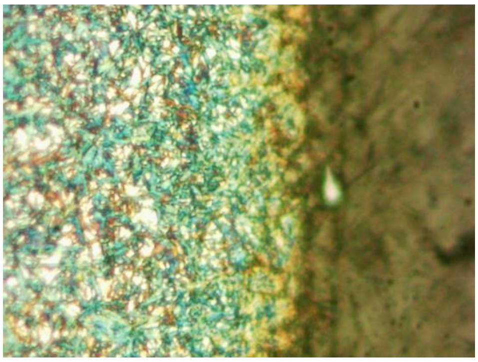
Depth in mm	Hardness
0.1	795
0.2	785
0.3	783
0.4	776
0.5	765
1	620
1.1	568
1.2	549
1.3	520
1.4	502
Core	457
ECD	1.34 MM

Figure 4. Specimen mold.

100X



200X



500X

Figure 5. Case micro structure: Fine tempered martensite with 2% RA with different Magnification range.

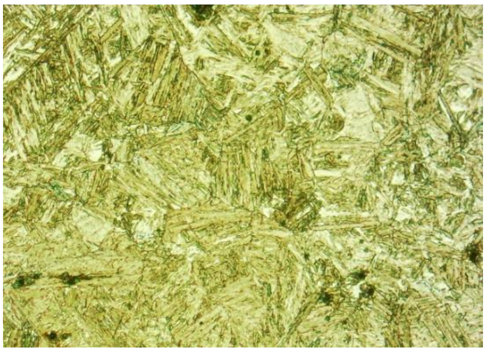
Calculation for Effective Case Depth

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

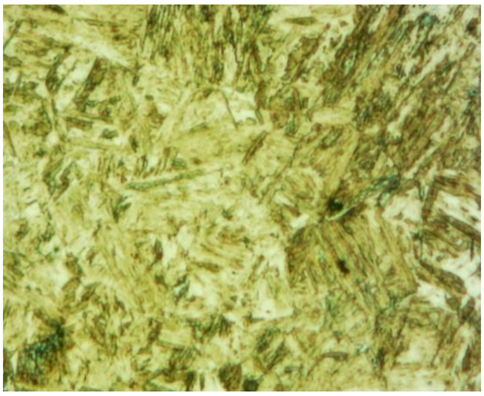
ECD is 1.3388 which implies 1.34 mm. Effective case depth for 16Mncr5 is 134 mm.

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 up to 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.4 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 Carbo-load. Etching Enhances the Contrast on Surfaces in Order to Visualize the Microstructure.

100 X



200 X



500 X

Figure 6. Core microstructure Core: Low tempered martensite with different Magnification range.

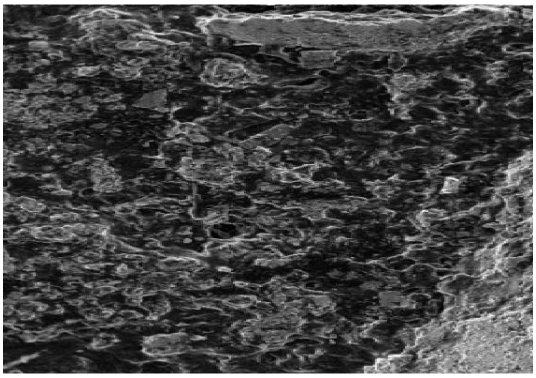


Figure 7. Case micro structure.

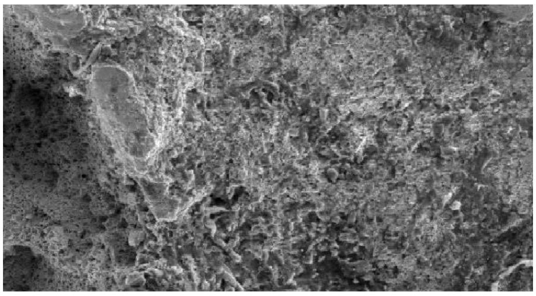


Figure 8. Core microstructure.

Microstructures

Figure 5 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.

From Figure 6 (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.

Surface Morphology

Figure 7 and 8 shows the SEM images obtained for Case microstructure and Core microstructure structure 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.

Table 12. 16MnCr5 sample 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

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 12 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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