REVERSE ENGINEERING PROJECT

REPORT

The purpose of this project was to learn the Reverse Engineering techniques & to utilize all the techniques used in material's investigation. RE was performed on a finished metal part, and different techniques were performed on this part to identify the grade of the metal used in that part. Different studies of material's properties were also conducted along the identification.

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(Student of TE - Materials Engineering)

Submitted to:
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Chairman, Materials Engineering Department,
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NAME OF THE PART: CRANK SHAFT

REVERSE ENGINEERING PERFORMED BY:

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CLASS: TE – MATERIALS ENGINEERING
ROLL NUMBER: MM – 032
BATCH: 2006 – 2007

DEPARTMENT OF MATERIALS ENGINEERING,
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KARACHI, PAKISTAN
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SUMMARY

GOALS
OBJECTIVES
(AS DIRECTED BY THE CHAIRMAN MMD Dr. ASHRAF ALI MEO)

REVERSE ENGINEERING/TECHNIQUES
PROJECT’S PLAN

Objectives: To provide a learning opportunity by reverse engineering utilising all the techniques used in material’s investigation.

1. Get a metallic “PART” of minimum size =25mm x 25mm or 25mm in diameter [Wrought samples such rods, sheets, squares etc., will not serve the purpose!]
2. Get photograph of the component-take at least five pictures in different directions!
3. Make sketches (in all directions) and mark the position for hardness test, metallography and microscopy in as-received condition
4. Get hardness profile across the sample.
5. Get sample for metallography, microscopy and XRF analysis from all areas of different hardness regions.
6. Prepare the samples for metallography and study the microstructure get at least 6 to 10 micrograph from different region of the samples.
7. Go to the library, compare the microstructure of your sample from Metals Handbook and other books on microstructures and identify it.
8. Get XRF analysis from all the areas of different hardness.
9. Identify the sample material/s from chemical composition
10. Go to the library do literature survey and see “what type of heat treatment is possible” on the sample. A TTT diagram will be helpful.
12. Discuss all your results and data with the project Advisor.
13. Perform heat treatment
14. GO To number 4
15. Make a report of all the work.
The purpose of this report is to explain what we did and learned during Reverse Engineering Project.

The report focuses primarily on the Metallurgical aspects of the Reverse Engineering. The various parts of the report reflect the analytical and theoretical part of reverse engineering, its successes, observations and key processes. The report also gives an efficient overview of all the technical and statistical norms of an unknown sample after being reverse engineered.

It is hoped that this report would serve as a cardinal vehicle to the new students of Materials Engineering.
ACKNOWLEDGEMENTS

I am, grateful to be engaged with such a well coordinated and behaved faculty of Materials Engineering Department.

I have developed a deep respect for Materials Engineering Management & faculty members, especially the entrepreneurial spirit and the passion of Chairman Materials Engineering **Prof. Dr. ASHRAF ALI MEO** for excellence he bring to this Department.

I am very much thankful to all of the concerned people, due to whom my project became possible,

**I like to mention their names with full devotion and respect,**

**Prof. Dr. Ashraf Ali Meo.** (Chairmain, Department of Materials Engineering, NEDUET)

**Engr. Mr. Fayaz Hussain.** (Lecturer and Project Advisor)

**Engr. Mr. Ghufran (PSM)** (Lecturer)

Moreover, i also like to thanks the persons in the laboratories who helped me alot in all the project work.

**Mr. Zahid.** (Metallography lab)

**Mr. Kamran** (Heat treatment Lab)

Equally valuable has been their contribution. Because of the help of all, my experience with this project gives me great confidence.
INTRODUCTION

This report consists of two chapters.

1. Theoretical Aspect
2. Practical work

The first chapter of the report comprises to all the theoretical knowledge about the techniques, processes, and equipments used in this Reverse engineering project. This chapter mainly includes:

- Introduction to Crankshaft
- Some properties of AISI 1045 Plain Carbon Steel
- Literature about the Heat treatment techniques, which applied on Crankshaft specimens
- Some knowledge about the Metallography, Rockwell hardness Tester, XRF technique which were the basis of all the project

The second chapter which is the backbone of this report, includes all the practical performance done during all this project. It starts from selection of a finished part (Crankshaft) to the identification of the steel grade used in that crankshaft and further goes towards the material’s properties investigation techniques that is heat treatments, Metallography, hardness measurements etc. the second chapter mainly includes:

- Photographs in as received condition,
- Different heat treatments techniques performed on different sections of crankshaft,
- Hardness measurements in as received and heat treated form,
- Metallography done in as received and heat treated form in different magnifications,
- Metal composition analysis i.e. Spectroscopy (XRF) done in MMD XRF lab and from PSM,
- Steel grade identification with the help of hardness, microstructures, and composition.

Moreover the report contains a comprehensive knowledge about all the steps and procedures during the entire project. I hope the reader would be quite pleasant to see and read this report.
CHAPTER ONE

THEOROTICAL ASPECT

BASED ON ALL THE THEORY RELATED TO STEP-WISE EXPERIMENTAL WORK/TECHNIQUES PERFORMED ON THE CRANKSHAFT INCLUDING:

- Introduction to Crankshaft
- Some properties of AISI 1045 Plain Carbon Steel
- Literature about the Heat treatment techniques, which applied on Crankshaft specimens
- Some knowledge about the Metallography, Rockwell hardness Tester, XRF technique which were the basis of all the project.
1.1 - CRANKSHAFT

The **crankshaft**, sometimes casually abbreviated to *crank*, is the part of an engine which translates reciprocating linear piston motion into rotation. To convert the reciprocating motion into rotation, the crankshaft has "crank throws" or "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder attach.

It typically connects to a flywheel, to reduce the pulsation characteristic of the four-stroke cycle, and sometimes a torsional or vibrational damper at the opposite end, to reduce the torsion vibrations often caused along the length of the crankshaft by the cylinders farthest from the output end acting on the torsional elasticity of the metal.

1.1.1 - HISTORY

The crank and connecting rod was first used in Roman water mills of late antiquity. The earliest evidence appears on a late 3rd century AD relief of a saw mill from Hierapolis, Asia Minor, in which the mechanism converted the rotary motion of the waterwheel into the linear movement of the saw blades. Two 6th century saw mills excavated at Ephesus respectively Gerasa, now Jordan, working with a very similar mechanism add to the growing body of evidence that the Romans knew and applied the crank and connecting rod as part of a machine.

In literature, crankshafts were described by Al-Jazari (who used it in two of his water-raising machines) in 1206, Konrad Kyeser (d. 1405), Francesco di Giorgio (1439–1502), Leonardo da Vinci (1452–1519), and Taqi al-Din in 1551. A Dutch "farmer" Cornelis Corneliszoon van Uitgeest also described a crankshaft in 1592. His wind-powered sawmill used a crankshaft to convert a windmill's circular motion into a back-and-forward motion powering the saw. Corneliszoon was granted a patent for the crankshaft in 1597.

1.1.2 - BEARINGS

The crankshaft has a linear axis about which it rotates, typically with several bearing journals riding on replaceable bearing (the main bearings) held in the engine block. As the crankshaft undergoes a great deal of sideways load from each cylinder in a multicylinder engine, it must be supported by several such bearings, not just one at each end.

High performance engines often have more main bearings than their lower performance cousins for this reason.
1.1.3 - PISTON STROKE

The distance the axis of the crank throws from the axis of the crankshaft determines the piston stroke measurement, and thus engine displacement. A common way to increase the low-speed torque of an engine is to increase the stroke. This also increases the reciprocating vibration, however, limiting the high speed capability of the engine.

1.1.4 - CONSTRUCTION

Crankshafts can be monolithic (made in a single piece) or assembled from several pieces. Monolithic crankshafts are most common, but some smaller and larger engines use assembled crankshafts.

BY FORGING AND CASTING:

Crankshafts can be forged from a steel bar usually through roll forging or cast in ductile steel. Today more and more manufacturers tend to favor the use of forged crankshafts due to their lighter weight, more compact dimensions and better inherent dampening. With forged crankshafts, vanadium microalloyed steels are mostly used as these steels can be air cooled after reaching high strengths without additional heat treatment, with exception to the surface hardening of the bearing surfaces. The low alloy content also makes the material cheaper than high alloy steels. Carbon steels are also used, but these require additional heat treatment to reach the desired properties. Iron crankshafts are today mostly found in cheaper production engines (such as those found in the Ford Focus diesel engines) where the loads are lower. Some engines also use cast iron crankshafts for low output versions while the more expensive high output version use forged steel.

BY MACHINING:

Crankshafts can also be machined out of a billet, often using a bar of high quality vacuum remelted steel. Even though the fiber flow (local inhomogeneities of the material’s chemical composition generated during casting) doesn’t follow the shape of the crankshaft (which is undesirable), this is usually not a problem since higher quality steels which normally are difficult to forge can be used. These crankshafts tend to be very expensive due to the large amount of material removal which needs to be done by using lathes and milling machines, the high material cost and the additional heat treatment required. However, since no expensive tooling is required, this production method allows small production runs of crankshafts to be made without high costs.

BY FATIGUE STRENGTH:

The fatigue strength of crankshafts is usually increased by using a radius at the ends of each main and crankpin bearing. The radius itself reduces the stress in these critical areas, but since the radii in most cases are rolled, this also leaves some compressive residual stress in the surface which prevents cracks from forming.
BY HARDENING:

Most production crankshafts use induction hardened bearing surfaces since that method gives good results with low costs. It also allows the crankshaft to be reground without having to redo the hardening. But high performance crankshafts, billet crankshafts in particular, tend to use nitridization instead. Nitridization is slower and thereby more costly, and in addition it puts certain demands on the alloying metals in the steel, in order to be able to create stable nitrides. The advantage with nitridization is that it can be done at low temperatures, it produces a very hard surface and the process will leave some compressive residual stress in the surface which is good for the fatigue properties of the crankshaft. The low temperature during treatment is advantageous in that it doesn’t have any negative effects on the steel, such as annealing. With crankshafts that operate on roller bearings, the use of carburization tends to be favored due to the high Hertzian contact stresses in such an application. Like nitriding, carburization also leaves some compressive residual stresses in the surface.

BY COUNTERWEIGHTS:

Some expensive, high performance crankshafts also use heavy-metal counterweights to make the crankshaft more compact. The heavy-metal used is most often a tungsten alloy but depleted uranium has also been used. A cheaper option is to use lead, but compared with tungsten its density is much lower.
1.2 - **AISI 1045**

**PLAIN CARBON STEEL**

**AISI 1045**

<table>
<thead>
<tr>
<th>Category</th>
<th>Steel</th>
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<tbody>
<tr>
<td>Class</td>
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<td>Type</td>
<td>Standard</td>
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<td>Designations</td>
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<td><strong>Germany:</strong> DIN 1.1191</td>
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<tr>
<td><strong>Japan:</strong> JIS S 45C , JIS S 48 C</td>
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</tr>
<tr>
<td><strong>Sweden:</strong> SS 1672</td>
<td></td>
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<tr>
<td><strong>United States:</strong> ASTM A29 , ASTM A510 , ASTM A519 , ASTM A576 , ASTM A682 , FED QQ-S-635 (C1045) , FED QQ-S-700 (1045) , SAE J403 , SAE J412 , SAE J414 , UNS G10450</td>
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**Mechanical Properties**

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<thead>
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<th>Properties</th>
<th>Conditions</th>
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<tr>
<td></td>
<td>T (°C)</td>
</tr>
<tr>
<td>Density (×1000 kg/m³)</td>
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<td>Elastic Modulus (GPa)</td>
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<td>Tensile Strength (Mpa)</td>
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<td>Yield Strength (Mpa)</td>
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<td>Elongation (%)</td>
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<td>Reduction in Area (%)</td>
<td>45</td>
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<td>-----------------------</td>
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<td>Hardness (HB)</td>
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**Composition**

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<th>Element</th>
<th>Weight %</th>
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<tr>
<td>C</td>
<td>0.43-0.50</td>
</tr>
<tr>
<td>Mn</td>
<td>0.60-0.90</td>
</tr>
<tr>
<td>P</td>
<td>0.04 (max)</td>
</tr>
<tr>
<td>S</td>
<td>0.05 (max)</td>
</tr>
</tbody>
</table>

**Thermal Properties**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Conditions</th>
</tr>
</thead>
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<tr>
<td>Thermal Expansion (10^-6/°C)</td>
<td>15.1</td>
</tr>
<tr>
<td>T (°C)</td>
<td>0-700</td>
</tr>
<tr>
<td>Treatment</td>
<td>annealed</td>
</tr>
</tbody>
</table>
1.3 - HEAT TREATMENT TECHNIQUES ON AISI 1045

AISI 1045 is a common grade in used in various applications like shafts, crankshafts, forged parts, castings. Numerous heat treatment techniques are employed over this grade to achieve the desired properties required for the service conditions.

Following heat treatments, I performed on AISI 1045 carbon steel crankshaft Sections.

1.3.1 - ANNEALING

ANNEALING is a generic term denoting a treatment that consists of heating to and holding at a suitable temperature followed by cooling at an appropriate rate, primarily for the softening of metallic materials. Generally, in plain carbon steels, annealing produces a ferrite-pearlite microstructure. Steels may be annealed to facilitate cold working or machining, to improve mechanical or electrical properties, or to promote dimensional stability. The choice of an annealing treatment that will provide an adequate combination of such properties at minimum expense often involves a compromise. Terms used to denote specific types of annealing applied to steels are descriptive of the method used, the equipment used, or the condition of the material after treatment.

The iron-carbon binary phase diagram can be used to better understand annealing processes. Although no annealing process ever achieves true equilibrium conditions, it can closely parallel these conditions. In defining the various types of annealing, the transformation temperatures or critical temperatures are usually used.

SUPERCRITICAL OR FULL ANNEALING

A common annealing practice is to heat hypoeutectoid steels above the upper critical temperature ($A_3$) to attain full austenitization. The process is called full annealing. In hypoeutectoid steels (under 0.77% C), supercritical annealing (that is, above the $A_3$ temperature) takes place in the austenite region (the steel is fully austenitic at the annealing temperature). However, in hypereutectoid steels (above 0.77% C), the annealing takes place above the $A_1$ temperature, which is the dual-phase austenite-cementite region. Figure 4 shows the annealing temperature range for full annealing superimposed in the iron-carbon binary phase diagram. In general, an annealing temperature $50 \, ^\circ C (90 \, ^\circ F)$ above the $A_3$ for hypoeutectic steels and $A_1$ for hypereutectoid steels is adequate.

FULL ANNEALING TEMPERATURE OF AISI 1045

TEMPERATURE: 800 – 850 $^\circ C$

From a practical sense, most annealing practices have been established from experience. For many annealing applications, it is sufficient simply to specify that the steel be cooled in the furnace from a designated annealing (austenitizing) temperature.
1.3.2 - NORMALIZING

NORMALIZING OF STEEL is a heat-treating process that is often considered from both thermal and microstructural standpoints. In the thermal sense, normalizing is an austenitizing heating cycle followed by cooling in still or slightly agitated air. Typically, the work is heated to a temperature about 55 °C (100 °F) above the upper critical line of the iron carbide phase diagram. To be properly classed as a normalizing treatment, the heating portion of the process must produce a homogeneous austenitic phase (face-centered cubic, or fcc, crystal structure) prior to cooling.

NORMALIZING TEMPERATURE OF AISI 1045 = 840 – 880 °C

1.3.3 - HARDENING

It is a treatment consists of heating to hardening temperature, holding at that temperature, followed by drastic cooling in a suitable medium. Cooling rate should be greater than CCR. Hardening treatment gives high wear resistance in tool steels and high yield strength in structural steels.

HARDENING METHODS:

- Hardening by quenching
- Hardening by Mechanical Working
- Hardening by precipitation

FACTORS AFFECTING THE HARDENING PROCESS:

- Composition of metal and alloy
  - Composition determines hardening tempering temperatures.
- Composition is related to retained austenite in case of alloy steel hardening because of austenite stabilizing elements. This retained austenite greatly reduce strength
- Presence of alloy carbides increases wear resistance, machinability because alloy carbides are harder, stable than Fe₃C
- Presence of Fe₃C is desirable in hardened structure to improved wear resistance because Fe₃C is harder than (α´)

HARDENING TEMPERATURE OF AISI 1045:

AISI 1045 is heated to the temperature range of 800 – 850°C i.e. austenitizing temperature. Then soaked properly and quench in some quenching media.
1.3.4 - TEMPERING

- It is simply a reheating process for as hardened parts to optimize the mechanical properties
- It is integral step in conventional hardening by quenching
- Through Tempering transformational stresses can be eliminated

VARIABLES:

Variables associated with tempering, that affect microstructure & mechanical properties of tempered steel include

- Tempering temperature
- Time at temperature
- Cooling rate from the tempering temperature
- Composition of steel, including carbon, alloy and residual elements

MICROSTRUCTURAL CHANGES DURING TEMPERING:

Based on x-ray, dilatometric, & microstructural studies a number of basic phenomenon occurs during decomposition of martensite or tempering.

- Redistribution of carbon atoms in bct lattices of Martensite
- Precipitation of transition carbide (C- carbide) bearing composition as (Fe$_{2.4}$C also called high carbon cementite) and cph structure
- Partial loss of tetragonality of bct lattices of martensite
- Decomposition of retained austenite into (α and Fe$_{3}$C). This structure has often called secondary bainite.
- Conversion of C- carbide into small rod shaped cementite particles
- Spheroidization of rod shaped cementite
- Recovery of ferrite structure
- Recrystallization of ferrite structure

TEMPERING TEMPERATURE FOR AISI 1045:

AISI 1045 is usually tempered at 550c to 650c. Tempered Martensite is obtained after tempering of a hardened (quenched) steel.
1.4 – METALLOGRAPHY

Metallography is the study of the physical structure and components of metals, typically using microscopy.

PREPARING METALLOGRAPHIC SPECIMENS

The surface of a metallographic specimen is prepared by various methods of grinding, polishing, and etching. After preparation, it is often analyzed using optical or electron microscopy. Using only metallographic techniques, a skilled technician can identify alloys and predict material properties.

A systematic preparation method is easiest way to achieve the true structure. Sample preparation must therefore pursue rules which are suitable for most materials. Different materials with similar properties (hardness and ductility) will respond alike and thus require the same consumables during preparation.

Metallographic specimens are typically "mounted" using a hot compression thermosetting resin. In the past, phenolic thermosetting resins have been used, but modern epoxy is becoming more popular because reduced shrinkage during curing results in a better mount with superior edge retention. A typical mounting cycle will compress the specimen and mounting media to 4,000 psi (28 MPa) and heat to a temperature of 350 °F (177 °C). When specimens are very sensitive to temperature, "cold mounts" may be made with a two-part epoxy resin. Mounting a specimen provides a safe, standardized, and ergonomic way by which to hold a sample during the grinding and polishing operations.

After mounting, the specimen is wet ground to reveal the surface of the metal. The specimen is successively ground with finer and finer abrasive media. Silicon carbide sandpaper was the first method of grinding and is still used today. Many metallographers, however, prefer to use a diamond grit suspension which is dosed onto a reusable fabric pad throughout the polishing process. Diamond grit in suspension might start at 9 micrometres and finish at one micrometre.

Generally, polishing with diamond suspension gives finer results than using silicon carbide papers (SiC papers), especially with revealing porosity, which silicon carbide paper sometimes "smear" over. After grinding the specimen, polishing is performed. Typically, a specimen is polished with a slurry of alumina, silica, or diamond on a napless cloth to
produce a scratch-free mirror finish, free from smear, drag, or pull-outs and with minimal deformation remaining from the preparation process.

After polishing, certain microstructural constituents can be seen with the microscope, e.g., inclusions and nitrides. If the crystal structure is non-cubic (e.g., a metal with a hexagonal-closed packed crystal structure, such as Ti or Zr) the microstructure can be revealed without etching using crossed polarized light (light microscopy). Otherwise, the microstructural constituents of the specimen are revealed by using a suitable chemical or electrolytic etchant. A great many etchants have been developed to reveal the structure of metals and alloys, ceramics, carbides, nitrides, and so forth. While a number of etchants may work for a given metal or alloy, they generally produce different results, in that some etchants may reveal the general structure, while others may be selective to certain phases or constituents.

1.5 – ROCKWELL HARDNESS TESTER

The Rockwell scale is a hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, which are denoted by a single letter, that use different loads or indenters. The result, which is a dimensionless number, is noted by HRX where X is the scale letter.

When testing metals, indentation hardness correlates linearly with tensile strength. This important relation permits economically important nondestructive testing of bulk metal deliveries with lightweight, even portable equipment, such as hand-held Rockwell hardness testers

OPERATION

The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load, and then noting the depth of penetration, hardness value directly from a dial, in which a harder material gives a higher number. The chief advantage of Rockwell hardness is its ability to display hardness values directly, thus obviating tedious calculations involved in other hardness measurement techniques.

It is typically used in engineering and metallurgy. Its commercial popularity arises from its speed, reliability, robustness, resolution and small area of indentation.

In order to get a reliable reading the thickness of the test-piece should be at least 10 times the depth of the indentation. Also, readings should be taken from a flat perpendicular surface,
because round surfaces give lower readings. A correction factor can be used if the hardness must be measured on a round surface.

**SCALES AND VALUES**

There are several alternative scales, the most commonly used being the "B" and "C" scales. Both express hardness as an arbitrary dimensionless number.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Abbreviation</th>
<th>Load</th>
<th>Indenter</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>HRA</td>
<td>60 kgf</td>
<td>120° diamond cone†</td>
<td>Tungsten carbide</td>
</tr>
<tr>
<td>B</td>
<td>HRB</td>
<td>100 kgf</td>
<td>1/16 in diameter steel sphere</td>
<td>Aluminium, brass, and soft steels</td>
</tr>
<tr>
<td>C</td>
<td>HRC</td>
<td>150 kgf</td>
<td>120° diamond cone</td>
<td>Harder steels</td>
</tr>
<tr>
<td>D</td>
<td>HRD</td>
<td>100 kgf</td>
<td>120° diamond cone</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>HRE</td>
<td>100 kgf</td>
<td>1/8 in diameter steel sphere</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>HRF</td>
<td>60 kgf</td>
<td>1/16 in diameter steel sphere</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>HRG</td>
<td>150 kgf</td>
<td>1/16 in diameter steel sphere</td>
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</tr>
</tbody>
</table>

† Also called a *brale indenter*

The *superficial* Rockwell scales use lower loads and shallower impressions on brittle and very thin materials. The 45N scale employs a 45-kgf load on a diamond cone-shaped Brale indenter, and can be used on dense ceramics. The 15T scale employs a 15-kgf load on a 1/16-inch diameter hardened steel ball, and can be used on sheet metal.

Readings below HRC 20 are generally considered unreliable, as are readings much above HRB 100.

**TYPICAL VALUES**

- Very hard steel (e.g. a good knife blade): HRC 55 - HRC 62 (a typical 1095 carbon steel)† Axes, chisels, etc.: HRC 40 – 45 - about 1045 carbon steel
Several other scales, including the extensive A-scale, are used for specialized applications. There are special scales for measuring case-hardened specimens.

1.6 - X-RAY FLUORESCENCE (XRF)

X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is widely used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials, and for research in geochemistry, forensic science and archaeology.

When materials are exposed to short-wavelength x-rays or to gamma rays, ionisation of their component atoms may take place. Ionisation consists of the ejection of one or more electrons from the atom, and may take place if the atom is exposed to radiation with an energy greater than its ionisation potential. X-rays and gamma rays can be energetic enough to expel tightly held electrons from the inner orbitals of the atom. The removal of an electron in this way renders the electronic structure of the atom unstable, and electrons in higher orbitals "fall" into the lower orbital to fill the hole left behind. In falling, energy is released in the form of a photon, the energy of which is equal to the energy difference of the two orbitals involved. Thus, the material emits radiation, which has energy characteristic of the atoms present. The term fluorescence is applied to phenomena in which the absorption of higher-energy radiation results in the re-emission of lower-energy radiation.

![Figure 8 - Characteristics Intensities of elements present](image)

![Figure 7 - Flowchart of Mechanism](image)
CHAPTER TWO

EXPERIMENTAL WORK

BASED ON ALL THE STEP-WISE EXPERIMENTAL WORK/TECHNIQUES PERFORMED ON THE CRANKSHAFT INCLUDING:

- Photographs in as received condition,
- Different heat treatments techniques performed on different sections of crankshaft,
- Hardness measurements in as received and heat treated form,
- Metallography done in as received and heat treated form in different magnifications,
- Metal composition analysis i.e. Spectroscopy (XRF) done in MMD XRF lab and from PSM,
- Steel grade identification with the help of hardness, microstructures, and composition.
2.1 - PHOTOGRAPHS
IN AS RECEIVED CONDITION
Crankshaft was cut in five sections AS NAMED ABOVE by using abrasive cut off machine and manual hacksaw at MMD workshop.

**NOTE:** THE NAMED ASSIGNED TO THE CRANKSHAFT SECTIONS WILL BE USED AS STANDARD NAMES THROUGHOUT THE CHAPTER
NAMES OF THE SECTIONS
2.3 - HARDNESS PROFILE IN AS RECEIVED CONDITION

EQUIPMENT: ROCKWELL HARDNESS TESTER (MMD)

More than two hardness readings were taken on serial points on all the sections (Section-1 to Section-5). These readings are given below:

SECTION – 1  71 HRB, 72 HRB, 72 HRB
SECTION – 2  68 HRB, 69 HRB
SECTION – 3  63 HRB, 60 HRB, 68 HRB
SECTION – 4  70.5 HRB, 72 HRB
SECTION – 5  60 HRB, 70 HRB, 67 HRB, 69 HRB, 64 HRB, 65 HRB, 63 HRB

Then, Hardness profile is drawn according to the order of the points from Section-1 towards Section-5.
2.4 - MICROSTRUCTURES IN AS RECEIVED CONDITION

For steel grade identification purposes the micrograph of crankshaft material was taken in longitudinal & lateral direction and then matched with ASM Metal Handbook for steel microstructures.

2.4.1 - IN LATERAL DIRECTION OF CRANKSHAFT:

Lateral micrographs of Section-1 was taken in three different magnifications i.e. 100x, 200x, and 400x using 2% Nital solution. This was done in Metallography lab MMD.

MICROGRAPHS AT 100x – 2% NITAL

(a)  
(b)
MICROGRAPHS AT 200x – 2% NITAL

(a)  
(b)

MICROGRAPHS AT 400x – 2% NITAL

(a)  
(b)
2.4.2 - IN LONGITUDENAL DIRECTION OF CRANKSHAFT:

Longitudenal micrographs of Section-4 was taken in three different magnifications i.e. 100x, 200x, and 400x using 2% Nital solution. This was done in Metallography lab MMD. For this purpose, a corner of the Section-4 was cut longitudinally (as shown in figures above) and mounted by using Bakelite in Universal Mounting Press in MMD Metallography lab.
MICROGRAPHS AT 100x – 2% NITAL

(a)

(b)
MICROGRAPHS AT 200x – 2% NITAL

(a)

(b)
MICROGRAPHS AT 400x – 2% NITAL

(a)

(b)
2.5 - **XRF ANALYSIS IN MMD XRF LAB**

XRF analysis on two sections i.e. Section-2 and Section-3 was performed by MMD XRF. The technique was done on each section three times for purpose of removing error. And then the concurrent reading of each element was taken as final composition of each element.

The elemental composition determined by MMD XRF equipment is as under:

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>SECTION-2</th>
<th>SECTION-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td>0.16%</td>
<td>0.14%</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.69%</td>
<td>0.68%</td>
</tr>
<tr>
<td>Iron</td>
<td>99.05%</td>
<td>99.17%</td>
</tr>
<tr>
<td>Copper</td>
<td>0.10%</td>
<td>0.12%</td>
</tr>
</tbody>
</table>

**RESULT:** No grade was identified from XRF system library.

FROM ALL THE ABOVE INFORMATION i.e. HARDNESS VALUES, AS RECEIVED MICROSTRUCTURE, THE XRF ANALYSIS ANALYSIS FROM MMD XRF LAB, IT WAS CONFIRMED THAT THE CRANKSHAFT IS MADE OF PLAIN CARBON STEEL WHICH MAY BE HAVING MEDIUM CARBON STEEL.

FOR FURTHER CONFIRMATION OF THE STEEL GRADE, I SENT MY SPECIMEN TO PSM (PEOPLES STEEL MILLS) FOR OPTICAL EMISSIIN SPECTROSCOPY FOR FOR COMPLETE COMPOSITION OF SPECIMEN INCLUDING CARBON CONTENT.
2.6 – LIGHT EMISSION SPECTROSCOPY  
DONE IN PSM (PEOPLES STEEL MILL)

The complete composition of the specimen including carbon content is as follows:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.463 %</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.183 %</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.798 %</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.0139 %</td>
</tr>
<tr>
<td>Sulpher</td>
<td>0.0137 %</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.162 %</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.001 %</td>
</tr>
<tr>
<td>Molybenium</td>
<td>0.012 %</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.035 %</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.001 %</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.005 %</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.021 %</td>
</tr>
<tr>
<td>Copper</td>
<td>0.096 %</td>
</tr>
<tr>
<td>Lead</td>
<td>0.001 %</td>
</tr>
<tr>
<td>Strontium</td>
<td>0.0058 %</td>
</tr>
<tr>
<td>Antimony</td>
<td>0.001 %</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.0029 %</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.004 %</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.0001 %</td>
</tr>
<tr>
<td>Niobium</td>
<td>0.0007 %</td>
</tr>
<tr>
<td>Boron</td>
<td>0.00035</td>
</tr>
<tr>
<td>Iron</td>
<td>98.18 %</td>
</tr>
</tbody>
</table>

2.7 – IDENTIFICATION

2.7.1 – GRADE

FROM ALL THE ABOVE INFORMATION, THE STEEL GRADE OF THE CRANKSHAFT WAS IDENTIFIED AS:

AISI 1045

WHICH IS A MEDIUM CARBON STEEL IN THE CATEGORY OF PLAIN CARBON STEEL WITH ZERO REPRESENTING NO ALLOYING ELEMENTS.
2.7.2 – MANUFACTURING PROCESS

There was a slight difference between the lateral and longitudinal microstructure of the crankshaft in as received form. But these microstructures did not show any forging patterns.

This crankshaft is made of ductile steel AISI 1045, when we see the hardness values in as received form, it varies between 60 to 72 HRB at different positions. It shows that the crankshaft material is soft (not hard) in as received form. Forging whether done in hot or cold conditions, induce sufficient hardness & strength in the material. But here in this crankshaft the hardness values in as received form are very low.

Therefore:

- ✔ This crankshaft was not produced by forging because of no signs & low hardness.
- ✔ This crankshaft is made of AISI 1045, which is ductile steel and can be cast easily.
- ✔ Therefore, most probably, this crankshaft was first cast to retain a specific shape.
- ✔ Then the obtained shape was heat treated to remove the undesirable as cast structure which contains dendrites. The heat treatment applied would be annealing because annealing removes the as cast structure. Also makes it machineable.
- ✔ The final shape of this crankshaft is obtained by machining process (i.e. Lathe and Milling machines) as we can see the Section-1, Section-3 & Section-5 of this crankshaft, they are containing the machining lines, groove(taper), and threads.
2.8 - HEAT TREATMENTS PERFORMED IN MMD HEAT TREATMENT LAB

Then the steel grade AISI 1045 was searched for heat treatment cycles and following heat treatment techniques were performed for material’s properties investigation.

For this purpose, the Section-1 of the Crankshaft was cut into four quarters as shown below:

Then four parts of Section-1 was named as under:

HEAT TREATMENT TECHNIQUES ON THE ABOVE SUB-SECTIONS WERE PERFORMED AS:

- Full annealing was performed on Section-1a
- Normalizing was performed in Section-1b
- And conventional hardening & tempering was performed on Section-1c
2.8.1 – ANNEALING:

The specimen was treated as heat treatment cycle shown.

Specimen was charged in muffle furnace and heated with a rise up rate of 70°C/hr to the temperature 800 – 850°C, at this temperature, the sample was soaked for 45 mins and then furnace was switched off. Furnace cooling was done.

After cooling, the Rockwell hardness readings and microstructures of the specimen were taken for properties investigation.

2.8.1.1 – ANNEALED HARDNESS:

The hardness values of the annealed specimen reduced than the as received form. The hardness values after annealing are:

1. 55 HRB
2. 53 HRB
3. 56 HRB

2.8.1.2 – ANNEALED MICROSTRUCTURES:

In as received microstructures, the grains were not coarse but after annealing the grains have become coarser.

Annealed microstructures are taken in magnification 200x and 400x using 2% natal solution.

Microstructures are as under:
AT 200x, USING 2% NITAL SOLUTION
AT 400x, USING 2% NITAL SOLUTION
2.8.2 – NORMALIZING:

The specimen was treated as heat treatment cycle shown.

![Diagram of heat treatment cycle]

Specimen was charged in muffle furnace and heated with a rise up rate of 70c/hr to the temperature 840 – 880c, at this temperature, the sample was soaked for 45 mins and then removed from the furnace. Air cooling was done.

After cooling, the Rockwell hardness readings and microstructures of the specimen were taken for properties investigation.

2.8.2.1 – NORMALIZED HARDNESS:

The hardness values of the Normalized specimen increased than the as received form. The hardness values after normalizing are:

1. 91 HRB
2. 94 HRB
3. 95.5 HRB

2.8.2.2 – NORMALIZED MICROSTRUCTURES:

In as received microstructures, the grains are dispersed but after normalizing the grains became relatively fine and arranged.

Normalized microstructures are taken in magnification 200x and 400x using 2% Nital.

Microstructures are as under:
AT 200x, USING 2% NITAL SOLUTION
AT 400x, USING 2% NITAL SOLUTION
2.8.3 – HARDENING:

The specimen was treated as heat treatment cycle shown.

Specimen was charged in muffle furnace and heated with a rise up rate of 70c/hr to the temperature 800 – 850c, at this temperature, the sample was soaked for 45 mins and then removed from the furnace. Water quenching was done.

After cooling, the Rockwell hardness readings and microstructures of the specimen were taken for properties investigation.

2.8.3.1 – QUENCHED HARDNESS:

The hardness values of the quenched specimen highly increased than the as received form. Hardness values after quenching are:

1. 60 HRC
2. 56 HRC
3. 56.5 HRC

2.8.3.2 – QUENCHED MICROSTRUCTURES:

In as received microstructures, the grains are coarse but after quenching, very fine martensite was obtained in microstructure.

Quenched microstructures are taken in magnification 200x and 400x using 2% Nital.

Microstructures are as under:
AT 200x, USING 2% NITAL SOLUTION
AT 400x, USING 2% NITAL SOLUTION
2.8.4 – TEMPERING:

The specimen was treated as heat treatment cycle shown.

![Diagram showing heat treatment cycle](image)

Specimen was charged in muffle furnace and heated with a rise up rate of 70°C/hr to the temperature 550 – 650°C, at this temperature, the sample was soaked for 45 mins and then removed from the furnace. Air cooling was done.

After cooling, the Rockwell hardness readings and microstructures of the specimen were taken for properties investigation.

2.8.4.1 – TEMPERED HARDNESS:

The hardness values of the tempered specimen reduced than the quenched condition. The hardness values after tempering are:

1. 41 HRB
2. 44 HRB
3. 45.5 HRB

2.8.4.2 – TEMPERED MICROSTRUCTURES:

In quenched microstructures, there was very fine martensite, but after tempering length of martensite needles was reduced & tempered martensite was obtained.

Tempered microstructures are taken in magnification 200x and 400x using 2% Nital.

Microstructures are as under:
AT 200x, USING 2% NITAL SOLUTION
AT 400x, USING 2% NITAL SOLUTION
2.9 – HARDNESS PROFILES AFTER HEAT TREATMENTS

2.9.1 - ANNEALED TO NORMALLIZED - HRB PROFILE

Annealed hardness 55 HRB, 53 HRB, 56 HRB
Normalized hardness 91 HRB, 94 HRB, 95.5 HRB

2.9.2 – QUENCHED TO TEMPERED – HRC PROFILE

Quenched hardness 60 HRC, 56 HRC, 56.5 HRC
Tempered hardness 41 HRC, 44 HRC, 45.5 HRC
SUMMARY

This report consists of two chapters.

3. Theoretical Aspect
4. Practical work

The first chapter of the report comprises all the theoretical knowledge about the techniques, processes, and equipments used in this Reverse engineering project. This chapter mainly includes:

- Introduction to Crankshaft
- Some properties of AISI 1045 Plain Carbon Steel
- Literature about the Heat treatment techniques, which applied on Crankshaft specimens
- Some knowledge about the Metallography, Rockwell hardness Tester, XRF technique which were the basis of all the project

The second chapter which is the back bone of this report, includes all the practical performance done during all this project. It starts from selection of a finished part (Crankshaft) to the identification of the steel grade used in that crankshaft and further goes towards the material’s properties investigation techniques that is heat treatments, Metallography, hardness measurements etc. the second chapter mainly includes:

- Photographs in as received condition,
- Different heat treatments techniques performed on different sections of crankshaft,
- Hardness measurements in as received and heat treated form,
- Metallography done in as received and heat treated form in different magnifications,
- Metal composition analysis i.e. Spectroscopy (XRF) done in MMD XRF lab and from PSM,
- Steel grade identification with the help of hardness, microstructures, and composition.

Moreover the report contains a comprehensive knowledge about all the steps and procedures during the entire project. I hope the reader would be quite pleasant to see and read this report.
GOALS ACHIEVED

I found a lot of improvement in my knowledge and experience while working in this Reverse Engineering Project. Mainly following goals were achieved:

✓ Learnt the use of XRF equipment.
✓ Learnt the proper use of Rockwell Hardness Tester.
✓ Improved skills in Metallography and microscopy due to the extensive use of the equipments.
✓ Learnt, how to work practically on heat treatment cycles and perform heat treatment techniques.
✓ Gained an experience for undertaking and individual project.
✓ Improved my skills in report making of engineering projects.