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Development of Barrel of Pump Action Gun (PAG)

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ABSTRACT: Firearms have exerted of fascination since medieval times and today weapons are for more effective and accurate than those developed way back in fourteen century. The first firearms developed were simple hand held barrel made of simple iron or brass tube with a fire hole at the top fixed in a stock of wood the end of which was under the arm pit of the shooter, these were used with newly invented gun powder.

It is evident that history and development of firearms is essentially development in manufacturing of Gun barrel. The gun barrel is generally made by EN19 Steel material. However, EN19 steel material has low wear resistance and its service life is shorter. In barrel, particularly bore at muzzle end suffer wear over time to a point where muzzle velocity/accuracy is reduced and gun performance is degraded. Also it necessitates on field replacement which may lead to loss of life under fire in war zone in addition to incursion of extra cost and periodic maintenance under peaceful condition.

In order to maximize performance of Gun Barrel EN 19, this project titled “DEVELOPMENT OF BARREL OF PUMP ACTION GUN (PAG)” has been

envisaged. The project has been divided into three parts, part first outlines currently used methodology under twelve different stages for manufacturing of Gun barrel from EN 19 (cylindrical rod) to finished barrel with its sub assembly. In the second part efforts have been made to improve the performance parameters (hardness, impact test and ultimate tensile strength) of EN 19 barrel by use of different quenchant during heat treatment. The third part focused on use of alternative material EN 24 to replace EN 19. The comparison of performance parameters of both the material has been drawn under different heat treatment condition.

The result of study shows that performance parameter of untreated EN 19 can be improved to attain desirable values by heat treatment in oil. The performance of EN 19 can be further enhanced by use of olive oil as quenchant without changing heat treatment methodology. The study of varying quenchant (water, oil and olive oil) and the comparison drawn on effect of olive oil shows that performance parameter in case of EN 24 are more desirable than EN 19, it can be suggested that EN 24 can be a suitable replacement to existing EN 19 using existing methodology of barrel manufacturing.

I. INTRODUCTION

1. Types of Weapon system

Heavy machine guns, such as light and medium machine guns, are belt driven and designed to shoot at high sustained frequencies. They are supported by a tripod in the center of the body or mounted on vehicles. The main difference between heavy machine guns and others is their size and weight and the penetrating power of their ammunition.

Light cannons generally tend towards the heavier end of the SALW spectrum shape (57 mm 100 mm). Sometimes they shoot single shots and sometimes they can have automatic magazines attached to the back. Like heavy machine guns, they need mechanical support. They often have two wheels.

1. Small Arms

Small arms are, comprehensively, weapons intended for singular utilize. They are for the most part at the lower end of the gauge range (4.6– 40 or 66 mm). Small arms incorporate handguns (self-stacking guns and guns) and shoulder arms (rifles and carbines, sub- assault rifles and light automatic weapons, and explosive launchers).

Handguns are little arms which, in principle, can be shot one-gave. They are generally accessible and can be effortlessly hidden, which makes them one of the weapon writes frequently utilized as a part of wrongdoing, particularly in urban zones. Their military utilize is constrained; however cops are regularly equipped with handguns.

Automatic pistols store the ammunition in the grip, and prepare a new round for firing until the magazine in the grip is empty.

Revolvers, which are likely to be older weapons and have projectile in a revolving cylinder above the trigger, are seen less commonly.

Shoulder arms are designed to be fired with the back end – the butt – held into the shooter’s shoulder for greater stability. They are the most frequently SALW found in South Sudan and other parts of Africa, and are the cause of most arms-related deaths and injuries, both accidental and deliberate. A shoulder arm requires two hands to use effectively [3].

Assault rifles are capable of automatic fire – i.e. squeezing the trigger once releases a burst of bullets. They are the most common shoulder arm today, and are found in almost all areas of civil or military conflict. The most famous are the Kalashnikov family (AK- 47, AKM, AK-74). They tend to be short (up to 70 cm with the butt) and small-weight, and can be recognized by the presence of a large semi-curved (banana-shaped) magazine.

Bolt rifles are long guns that shoot single bullets to a great distance. After each round is fired, the shooter moves a bolt to load the next round for firing.

Semi-automatic rifles use the energy released during the shot to reload another round from a magazine box suspended under the gun. Semi-automatic rifles can be configured to shoot completely automatically

Shotguns and hunting rifles are intended primarily for sport and hunting. They are extremely lethal. As shotguns fire cluster pellets instead of bullets, they are very dangerous to bystanders [4].

Machine-guns are firearms that fire in bursts and are capable of a high rate of sustained fire. Both lights machine-gun and submachine guns are portable and can be fired by one person.

Light machine-guns are usually belt-fed and can fire in rapid bursts to extended ranges. They are sometimes mounted on bipods or tripods for stability. They most often look like large assault rifles [4].

Submachine guns can be conceived of as a hybrid between pistols and assault rifles, with a longer barrel than a pistol and a larger magazine capacity, but a size that is smaller than an assault rifle. Some are very small, light and quick firing, and they are easy to conceal. As they are relatively easy to operate but usually inaccurate, they can inflict a great deal of ‘collateral damage’, as people the shooter was not aiming at get hit as well [5].

II. LITERATURE REVIEW

Barrel is the most crucial components of Pump Action Gun (PAG). Lot of research work was reported in the literature on the design of barrel, materials and manufacturing of barrel. Due to the excessive pressure developed on the inner surfaces of the barrel, it often gives rise to premature wear of bore and affects the function of Gun. In barrel, particularly bore at muzzle end suffer wear over time to a point where muzzle velocity/accuracy is reduced and gun performance is degraded. The main focus was on determining an alternate material for development of barrel of Pump Action Gun (PAG) and the quenching process used to obtain the required mechanical properties. The heat treatment of steel has a 3500-year history [6]; the main goal of heat treatment of steel is to achieve the desired combination of mechanical properties when subjected to controlled heat treatment. Quenching, as one of the most important processes of heat treatment, can improve the performance of steel greatly, but an important side effect of quenching is the formation of thermal and transformational stresses that cause changes in size and shape that may result in cracks [7]. Therefore, the technical challenge of quenching is to select the quenchant medium that will minimize the various stresses that develop within the barrel to reduce cracking and distortion while at the same time providing heat transfer rates sufficient to yield the desired as-quenched properties such as hardness [6]. This study shows the effects of EN-19 & EN-24 by using different quenching media (water, hard castles, petrofer oil, olive oil etc;) quenching time, quenching temperature and mechanical properties like (Ultimate tensile strength, Impact energy and hardness).

1. Quenching and Its Stages

“Heat Treatment can be defined as an operation or combination of operations involving the controlled heating and cooling of a metal in the solid state for the purpose of obtaining specific properties” [8].

As one of the most important heat treatment processes, quenching of steel refers to the cooling from the solution treating temperature, typically 845-870°C (1550-1600°F), into the hard structure-martensite [9]. Quenching is typically performed to prevent ferrite or pearlite formation and to facilitate bainite or martensite formation [9]. After quenching,



the martensitic steel is tempered to produce the optimum combination of strength, toughness and hardness. For a specific steel composition and heat treatment condition, there is a critical cooling rate for full hardening at which most of the high temperature austenite is transformed into martensite without the formation of either pearlite or bainite [8]. As the steel is heated it absorbs energy that is later dissipated by the quenchant in the quenching process. It is important to understand the mechanisms of quenching..

1. **Mineral oils:-**Mineral oils have been used as quenchant for a long time since a wide range of quenching characteristics can be obtained through careful formulation and blending of the oils and additives. Mineral oils can be any petroleum oil, as contrasted to animal or vegetable oils. Also a highly refined petroleum distillate, or white oil, used medicinally as a laxative. Mineral oils used in quenching are analogous to other petroleum products, including engine oils, spindle oils, and industrial lubricating oils such as gear lubricants [11]. Although petroleum oils are usually refined for specific applications, they remain complex mixture with a variety of possible compositions, which may vary even when produced by a single refinery [10].

2. **Vegetable oils:-**Although mineral oils have traditionally been one of the most commonly used quenching media, unlike water, they are being subjected to ever-increasing controls due to increasingly stringent governmental regulations regarding their use [12]. Routine disposal and inadvertent release into the environment, especially into the soil where they may leach into drinking water aquifers, is being increasingly regulated by governmental agencies. Thus far, the most commonly cited base stocks for the formulation of environmentally friendly quenchants are vegetable oils including olive oil and soybean oil derivatives and so on [13]. Vegetable oils are compounds of carbon, hydrogen, and oxygen, which are found naturally in all plants. Vegetable Oils are defined as liquid glycerides, which is also called ‘salts of organic acids’ and generally consist of three kinds of substances: Saturated fat, polyunsaturated fat, and Monounsaturated fat. Each vegetable oil is characterized by the particular type and concentration [12]. Oil is removed from the vegetable beans (or seed) in an “expelling” process [12]. Expelling can be performed by either pressing the bean (or seed) or, more commonly, by a solvent extraction process. Expulsion by solvent extraction is a three step process: bean preparation, oil extraction and solvent stripping, and reclamation.

1. **Materials and Methods:-**The chemical composition of the EN-19 & EN-24 samples used for this investigation is given in Table 1.

Table.1: Composition (in %) of EN19 and EN24 Alloy steel

	C	Mn	Si	S	P	Cr	Mo	Ni
EN-19	0.35-0.45	0.50-0.80	0.10-0.35	0.040	0.040	0.90-1.40	0.20-0.40	
EN-24	0.35-0.45	0.45-0.70	0.10-0.35	0.040	0.040	0.90-1.40	0.20-0.40	1.30-1.80

2. **Materials:-**Materials used in this study are EN-19 & EN-24, while Hard Castle Petrofer, water and olive oil, as quenching media.

3. Equipment

The equipment used in this work includes: CNC Lathe machine, Pit type furnace, Izod impact machine, Universal Tensile Testing Machine, Affari hardness machine, Electromagnetic Crack Detection Machine, and Optical Emission Spectrometer Microscope.

4. Methods

Samples were machined from the medium carbon steel. One set of the machined test samples (for hardness, tensile and impact) were kept aside to be tested in the as-received condition. The remaining samples were taken into the muffle furnace and austenitized at 880oC and soaked using a muffle furnace for 1hr before being removed and cooled in air. The samples were taken back into the furnace and heated to 880oc again, soaked for 1hr after which a set of test samples for (hardness, tensile, impact) each were removed and quenched in water, engine oil, cotton seed oil, palm



kernel oil, and olive oil respectively. The quenched samples were then removed, cleaned and subjected to hardness, tensile and impact tests respectively.

1. Mechanical Properties

1. **Tensile Properties Test:**-The tensile properties of the quenched steel sample were carried out using “Universal Tensile Testing Machine”. After measuring initial gauge length (l_0) and diameter, the specimen testing was done, the graphs of load versus extension were plotted on a graph paper fixed to the stylus from which yield load, maximum load, were taken for the calculation of yield strength and tensile strength respectively.

$$\text{Yield strength; } \sigma_y = \frac{P_y}{A_0} \quad (1)$$

Where σ_y is the yield strength in N/mm², P_y is the yield load in Newton (N), A_0 is the original cross sectional area in mm².

Tensile strength or ultimate tensile strength,

$$\sigma_{\max} = \frac{P_{\max}}{A_0}$$

Where σ_{\max} is the Tensile strength (N/mm²), P_{\max} is the maximum load (N).

The broken ends of the specimen were fitted together after fracture and the measurement of final gauge length (l_f) and the smallest diameter of local neck for the calculation of percentage elongation from the following formula:

Where

$$\% \text{ elongation} = \frac{l_f - l_0}{l_0} \times 100 \quad (3)$$

lo X 100

l_0 is the initial gauge length (mm), l_f is the final gauge length (mm)

1. **Hardness Test Measurement:**- Avery hardness testing machine was used for the hardness measurement. After placing the test specimen on the anvil of the machine, the load was then applied manually which caused a round indentation to be impressed on the sample. The load was then released and the diameter of the impression or indentation was measured with low power microscope and calibrated lens. The Brinell number was calculated according to the formula

$$\text{HBN} = \frac{2P}{\pi(D - \sqrt{D^2 - d^2})} \quad (4)$$

$\pi(D - \sqrt{D^2 - d^2})$

P is the applied force (kgf), D is the diameter of indenter (mm) and d is diameter of indentation (mm)

2. **Charpy Impact Test:**- The charpy impact test of the quenched steel sample was carried on Avery Denson impact testing machine. The specimens were supported horizontally with the V-notch opposite to the strike end. The trigger was released for the pendulum to strike the specimen from an initial potential energy of 0J. The energy absorbed before fracture was then read directly on the gauge of machine.

Conclusion: - The effectiveness of the olive oil as quenching medium in the hardening process of EN-19 & EN-24 has been quantitatively assessed using hardness values, ultimate tensile strength and impact energy in particular. From the results obtained in this study, the following conclusions can be drawn; 1. The Olive oil has hardness values less than that of water and hard castle oil. Hence, Olive oil can be used where cooling severity less than water and hard castle oil is required for hardening of EN-19. 2. Olive oil can be used to improve the toughness and ultimate tensile strength of these samples since it has higher impact energy and ultimate tensile strength values than water and hard castle oil which is the common quenching medium



III. PROPOSED METHODOLOGY AND DISCUSSION

1. Mechanical test

Mechanical test is an essential part of any engineering activity. Mechanical test is applied to the materials, components and assemblies. It consists of measurement of fundamental properties or measurement of responses to particular influences such as load, temperature, etc. Types of mechanical tests carried out in steel Materials are,

- a. Hardness test
- b. Impact test
- c. Tensile Test

These tests are conducted to analyze the hardness, toughness, strength and wear resistance properties of steel. These tests are carried out in different types of testing machines. They are

- a. Rockwell Hardness Testing Machine
- b. Charpy Testing Machine

Test specimen preparation

A set of specimens was prepared for Tensile, Impact and Hardness analyses. The standards used for samples to carry out the various tests are listed below.

Test	Standard used
Hardness Test	ASTM E 18
Tensile Test	ASTM E-8
Charpy Test	ASTM A370

1. Impact test

In this project, the impact test was carried out by CHARPY TEST to find the impact energy. The Charpy test uses a test specimen of size 10mm x 10mm x 55mm (sub size specimen).The impact specimen received with notch at 27.5mm and the depth of the notch is 2mm.

Testing Procedure

The general procedure to conduct an impact test is given below:

- a. The specimen is placed in the vice of the anvil
- b. The pendulum hammer is raised to known standard height depending on the type of specimen to be tested.
- c. When the pendulum is released, its potential energy is converted into kinetic energy just before it strikes the specimen.
- d. Now the pendulum strikes the specimen. It may be noted that the Izod specimen is hit above the V-notch and Charpy specimen will be hit behind the V-notch.
- e. The pendulum, after rupturing the specimen, rises on the other side of the machine.
- f. The energy absorbed by the specimen during breaking is the weight of the pendulum times the difference in two height of the pendulum on the either side of the machine.
- g. Now the energy i.e., the notch impact strength, in foot-pounds or meter-kg, is measured from the scale of the impact testing machine.

1. Rockwell Hardness Test

The hardness test is performed when quick and reading is required and also when the materials have hardness beyond the range of brinell hardness test. It contrasts from the brinell hardness tests that in this test loads for the making indentions are littler and along these lines make little and shallow spaces. Due to these reason, the Rockwell hardness test is widely used in the industry.

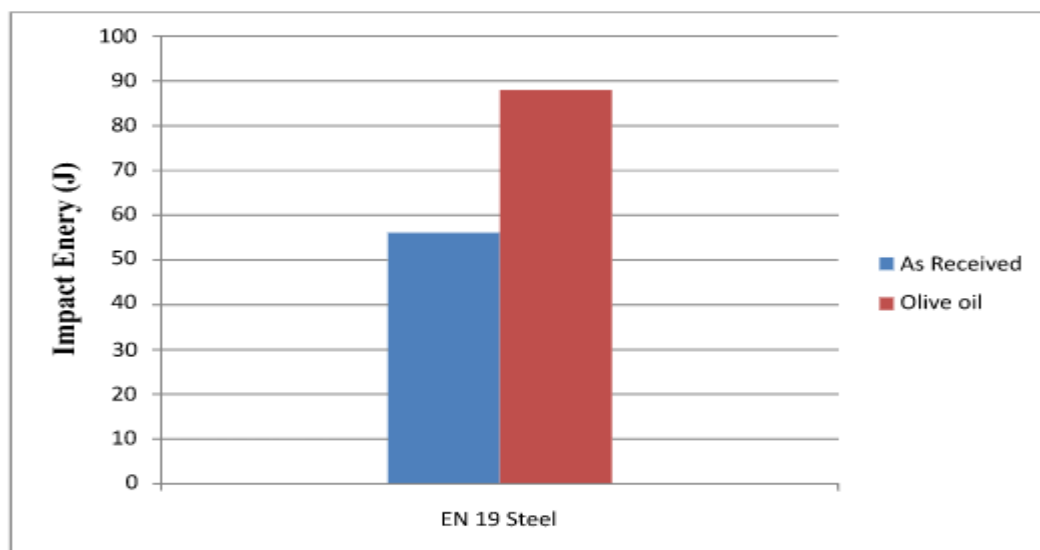
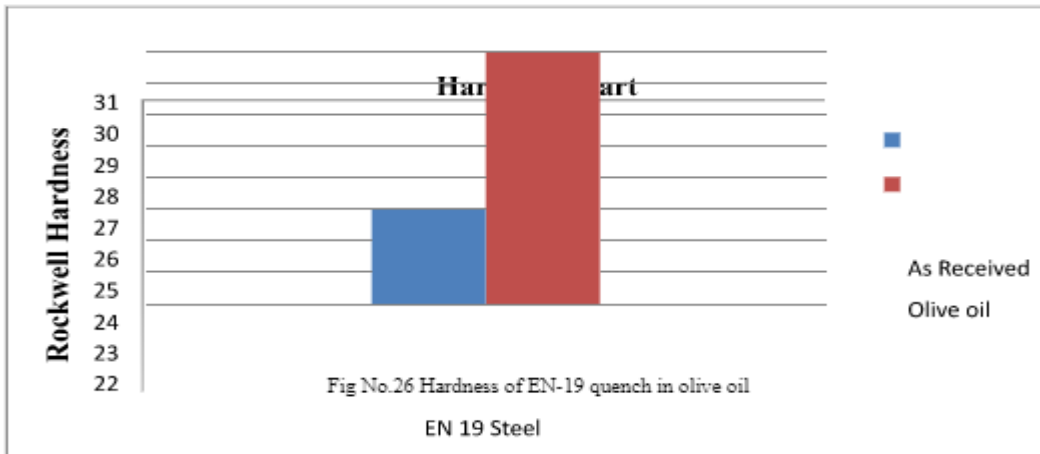
The Advantages of the Rockwell hardness Test is given below

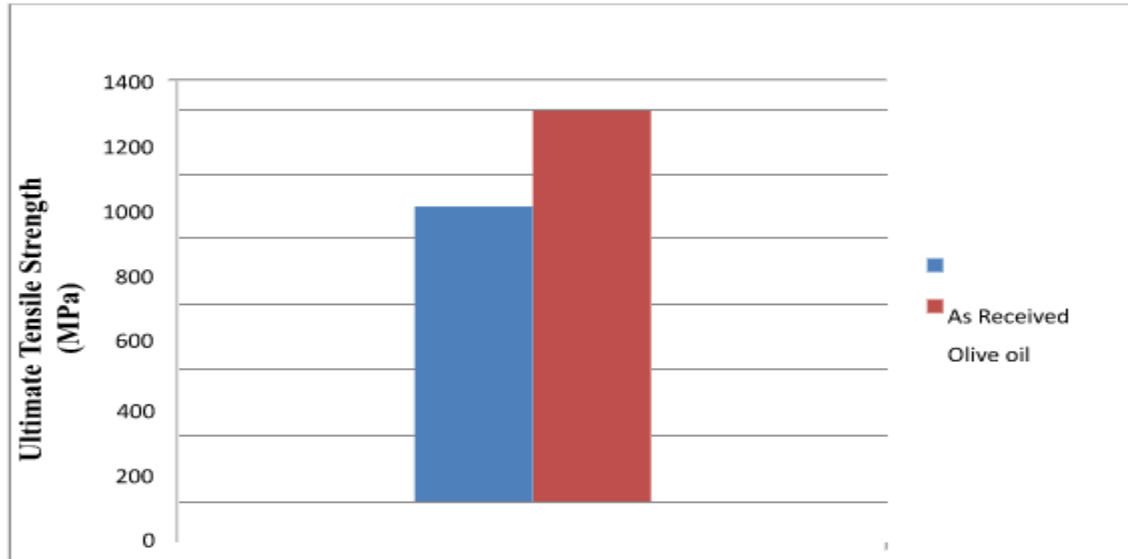


1. The testing is relatively fast.
2. The hardness is directly read on the scale.
3. There is no impairment for the testing material since a small indentation is left on the objects.
4. Utilization of the underlying minor load evades the blunders emerging out of the uneven surface of the material and other instrumental mistakes

2. **Tensile testing** – Tensile testing is most common methods for determining materials properties. It is also recognized as tension testing, is a basic materials science test, in which, a specimen is subjected to a controlled tension until failure. The tensile test has been carried out on computerized Universal Testing Machine (UTM) of 100 KN capacity [41].

RESULTS of EN 19 WHEN QUENCHED IN OLIVE OIL:-The mechanical testing results of EN 19 when quenching medium olive oil is used are represented in graph form appended below:





EN 19 Steel
Figure No.28 Ultimate tensile strength of EN-19 quench in olive oil

Observation

Existing EN 19 material has properties like hardness 25 HRC, Impact energy 56J and ultimate tensile strength 900 MPa after heat treatment process using olive oil as quenchant the properties show increase in hardness 30 HRC, impact energy 89J & ultimate tensile strength 1200 MPa .

It is observed that Hardness is just within the range of the required standard values while the increase in ultimate tensile strength increase by 33.33% and increase in impact energy by 58.92 % .

1. Suggestion of Alternative Material EN24

As it is evident from the results of EN19 that change of quenching medium has a significant impact on the properties of the material but there is no significant change in the hardness.

The scope of work has been extended to use of EN24 as the alternative material to replace EN19 and analyzed for its performance.

EN 24 Steel chemical Composition

Table 19 Chemical Composition of EN24 Steel

Chemical	Composition
C	0.35- 0.45 %
Mn	0.45-.070 %
Si	0.10-0.35 %
S	0.040 %
P	0.040 %
Cr	0.90- 1.40 %
Mo	0.20-0.40 %
Ni	1.30-1.80 %



Reason for choosing EN24: The presence of Nickel, which is an austenite stabilizer, promotes the formation of needle like fine grain martensite phase and its effect on hardness is significant under Heat treatment process.

Application of EN 24 Steel:-

- Aircraft and heavy vehicle crank shafts
- Connecting rods
- Propeller shafts
- Punches & dies
- Drill bushings
- Retaining rings
- Gears
- High strength shafts

IV. EXPERIMENTAL DETAILS

1. Analysis of Mechanical Properties En24 Steel Used In Gun Barrel

Barrel is one of the key parts or components in the Gun. Due to the excessive pressure developed on the inner surfaces of the barrel, it often gives rise to premature wear of bore and affects the function of Gun. The objective of this work is to study experimentally hardening with different quenchants (water, oil and olive oil) for EN24 were carried out in pit type furnace.

RESULTS

Mechanical Testing:

Hardness test – The resistance to indentation value of specimens and materials is shown in Figure 7. Rockwell hardness machine test results before heat treatment and after heat treatment of EN 24 steel is tabulated in Table.

Specimen	HARDNESS			
	As Received	Sample quenching in water	Sample quenching in oil	Sample quenching in Olive oil
EN 24	29HRC	39 HRC	37HRC	33HRC

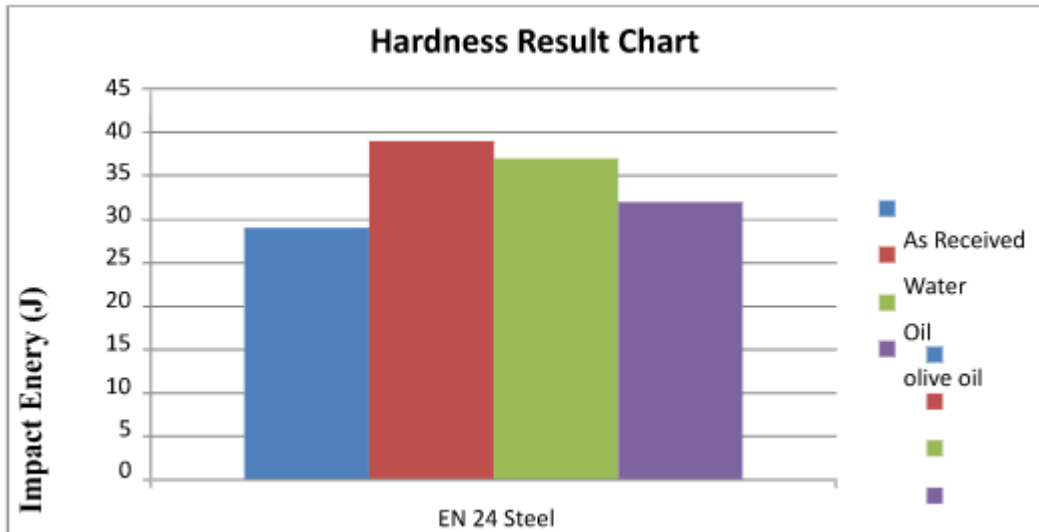


Fig No. 29 Variation of HRC of EN 24 Steel with as received, quench in water, oil and olive oil

Impact Test –The resistance of material to resist an impact or sudden load applied is impact strength. The results measured in terms of energy (joules) are shown in Table. The graph in Figure 8 shows Charpy values of Table;-

Table No.20 Impact Test Result

Specimen	IMPACT ENERGY IN (J)			
	As received	Sample quenching in water	Sample quenching in oil	Sample quenching in Olive oil
EN24 Steel	55	60	75	100

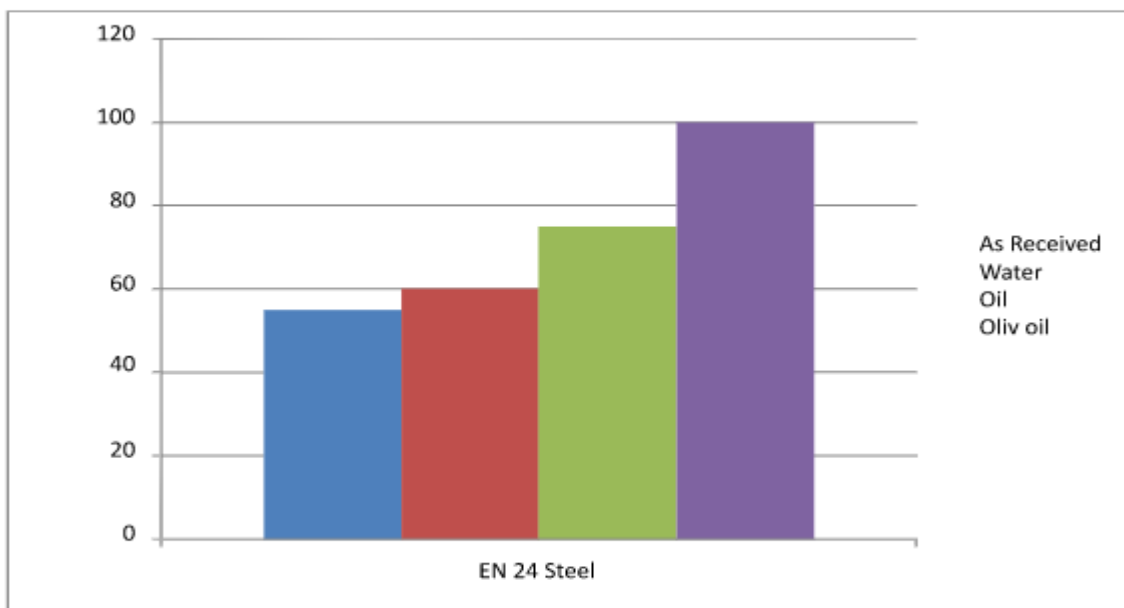


Fig No.30 Variation of Impact Energy of EN 24 Steel with as received, quench in water, oil and olive oil



Tensile test –Table shows the results of tensile test of specimens done on UTM machine. Figure 12 is representing table result in graph form.

Table No.21 Variation of UTS of EN 24 Steel with as received, quench in water, oil and olive oil

Specimen	Tensile Strength (MPa)			
	As received	Sample quenching in water	Sample quenching in oil	Sample quenching in Olive oil
EN24 Steel	920	1220	1060	1250

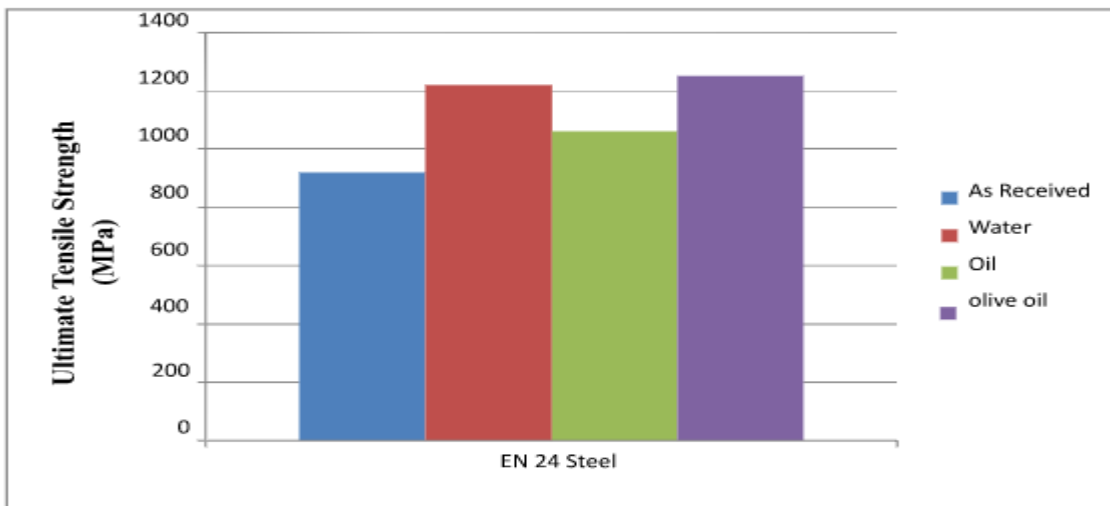


Fig No. 31 Variation of UTS of EN 24 Steel with as received, quench in water, oil and olive oil

Observation

- i Hardness :
 - a) there is increase of 34.48% when water is used as quenching
 - b) there is increase of 27.58% when oil is used as quenching
 - c) there is increase of 6.89% when olive oil is used as quenching
- ii Impact energy
 - a) there is increase of 9.09% when water is used as quenching
 - b) there is increase of 36.36% when oil is used as quenching



c) there is increase of 81.81% when olive oil is used as quenching

1. Existing EN24 material has properties like Hardness 29 HRC, Impact energy 55J and ultimate tensile strength 920 Mpa. Results of Heat treatment on EN 24 in different quenching media like water, oil and olive oil has significant effect on different mechanical properties which are as below;

iii Ultimate tensile strength

a. here is increase of 32.60% when water is used as quenching

b. there is increase of 15.21% when oil is used as quenching

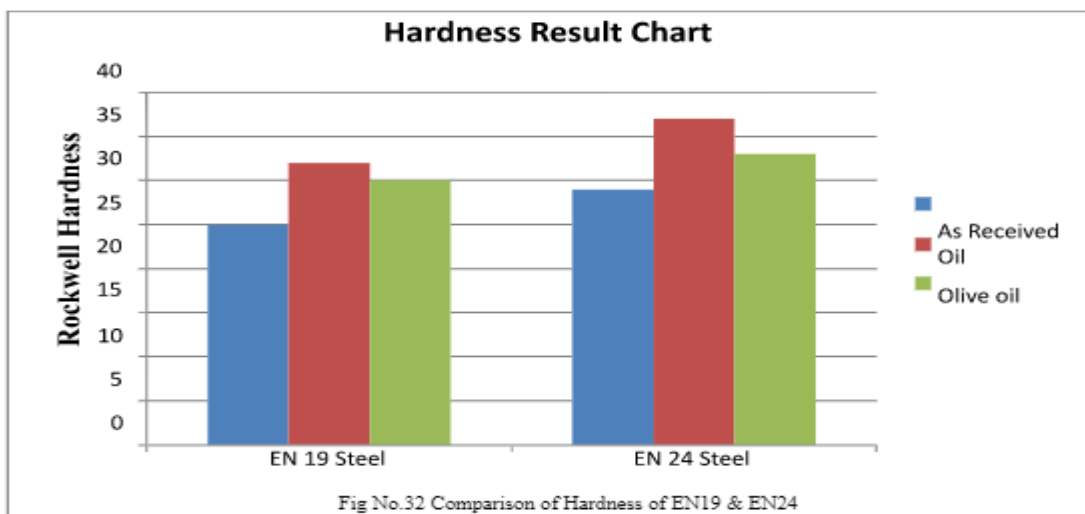
c. there is increase of 35.87% when olive oil is used as quenching

2. Comparative study of EN19 & EN24

The study of both EN19 and EN24 for changes in performance parameters have been suitably depicted in the graphs in previous section. In this section the focus is to (i) study the comparative performance parameters of both the materials (ii) deliberate upon the effects of heat treatment on both (iii) Suggested choice of material for use (iv) Utility for Mass production.

Comparison of Hardness for EN19 & EN24:

Specimen	As received Sample	Sample quenching in oil	Sample quenching in olive oil
EN19 Steel	25HRC	33HRC	30HRC
EN24 Steel	29HRC	37HRC	33HRC





Specimen	IMPACT ENERGY IN (J)		
	As received	Sample quenching in oil	Sample quenching in olive oil
EN19 Steel	56	55	88
EN24 Steel	55	75	100

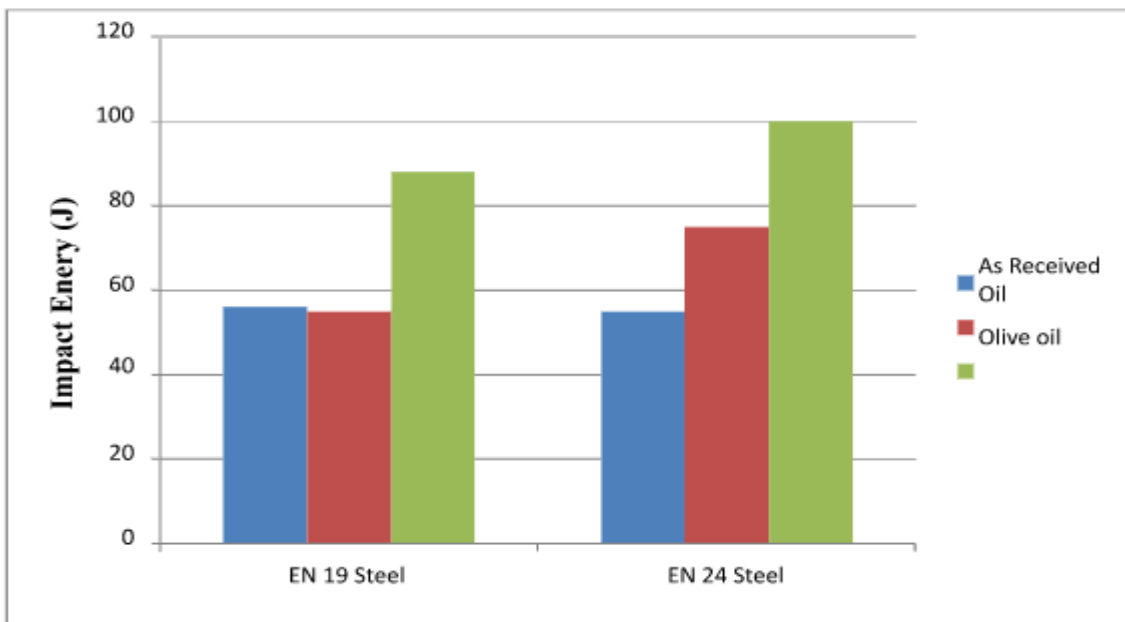


Fig No. 33 Comparison of Impact Energy of EN19 & EN24

Comparison of Tensile test for EN19 & EN24–Table 8 shows the results of tensile test of specimens done on UTM machine.

Specimen	Ultimate Tensile Strength (MPa)		
	As received	Sample quenching in oil	Sample quenching in olive oil
EN19 Steel	900	1150	1200
EN24 Steel	920	1060	1250

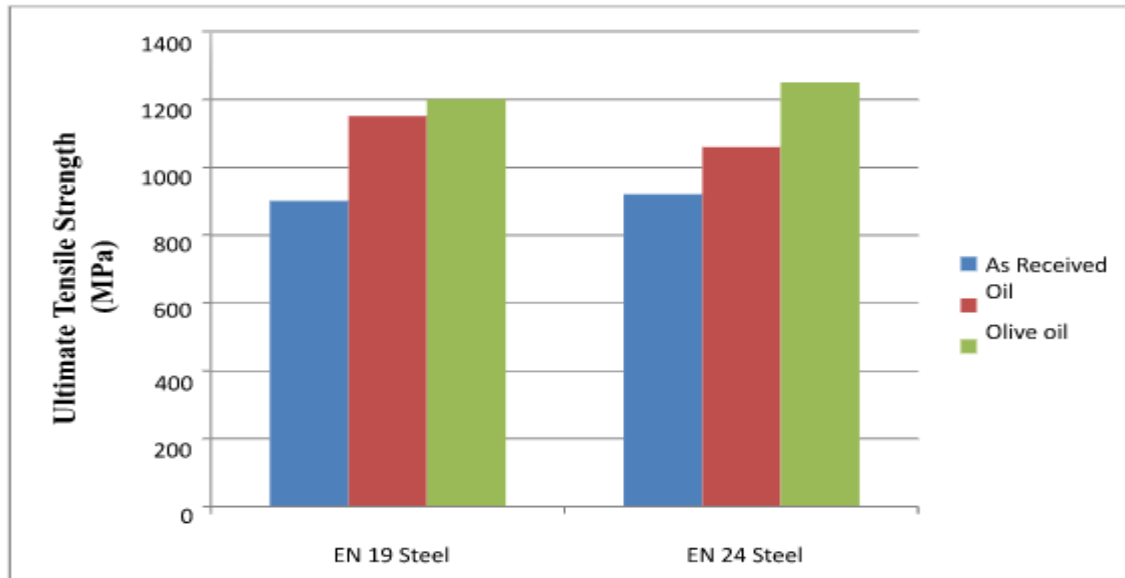


Fig No. 34 Comparison of UTS of EN19 & EN24

V. DISCUSSION

1. It is observed that hardness of EN 19 in quenching oil and olive oil is 33 HRC and 30 HRC respectively and hardness of EN 24 in quenching oil and olive oil is 37 HRC and 33 HRC respectively. The found hardness of EN 24 in quenching oil i.e. 37 HRC exceed the required range of hardness.
2. It is observed that hardness is just within the range of the required standard values while the increase in ultimate tensile strength increase by 27.77% which shows increase in ease of manufacturing and decrease in impact energy by 1.78 % of EN 19 shows decrease in toughness when oil is used as quenching media.
3. It is observed that hardness of EN 24 in oil is exceed the required standard values while the increase in ultimate tensile strength increase by 15.21% and increase in impact energy by 36.36%.The increase in hardness will lead to increase in brittleness thereby rapid formation of crack in barrel.
4. It is observed that hardness is just within the range of the required standard values while the increase in ultimate tensile strength increase by 33.33.% which shows to withstand more pressure of cartridge and increase in impact energy by 58.92 % which increase limit of plastic deformation of EN 19 when olive oil is used as quenching media.
5. It is observed that hardness of EN 24 in olive oil is just within the range of the required standard values while the increase in ultimate tensile strength increase by 35.87% and increase in impact energy by 81.81%. The effect of ultimate tensile strength is lead to withstand more pressure during firing and impact energy enhances to absorbed more energy before fracture.

VI. CONCLUSION

1. The study of EN 19 raw material shows that required properties of hardness (25 HRC) as shown in Fig no. 20 below requirement (30-33 HRC), ultimate tensile strength (900 MPa) as shown in Fig no. 22 below requirement (1150 MPa) and impact strength (56J) as shown in Fig no. 21 close to required value (55J).
2. Heat treatment of EN 19 in oil is done as per methodology explained under Stage 2 of 6.1.2. The process is done for hardening of 855°C for soaking time 180 min. The results are shown in Fig no. 20 in which hardness is 32 HRC within requirement, Fig no. 22 shows ultimate tensile strength 1150 MPa acquire required ultimate tensile strength, Fig no. 21 shows impact strength (55J) equal to required value (55J) which suggest that heat treatment of EN 19 raw material is essential requirement to attain required value of performance parameters.
3. Heat treatment of EN 19 in olive oil is done as per methodology explained under Stage 2 of 6.1.2. The process is done for hardening of 855°C for soaking time 180 min. The results are shown in Fig no. 26 in which hardness 30



HRC is more than untreated EN 19 but less than oil quenched EN 19 which shows olive oil quenching provides standard hardness without increasing the brittleness of the material to extent as in case of oil, Fig no. 28 shows ultimate tensile strength 1200 MPa is more than untreated EN 19 & oil quenched EN 19 and Fig no. 27 shows impact strength (88J) is more than untreated EN 19 & oil quenched EN 19. The decrease in hardness and increase in impact strength & ultimate tensile strength are both desirable effects to enhance life of barrel. Therefore it can be suggested that performance of existing oil quenched EN 19 can be improved by incorporating olive oil as quenchant without changing the process methodology and parameters (temperature and soaking time).

4. Heat treatment of EN 24 in olive oil is done as per methodology explained under Stage 2 of 6.1.2. The process is done for hardening of 855°C for soaking time 180 min. The results are shown in Fig no. 29 in which hardness 32 HRC is more than treated EN 19 in olive oil, Fig no. 31 shows ultimate tensile strength 1250 MPa is more than treated EN 19 olive oil and Fig no. 30 shows impact strength (100J) is more than treated EN 19 in olive oil. The desirable effects of heat treatment in olive oil of EN 24 are more prominent than effect on EN 19. The material EN 24 treated in olive oil can be considered as replacement for existing oil quenched EN 19.

5. The investigation has demonstrated that utilizing of water, oil and olive oil as quenchants enhances the mechanical properties when contrasted with the untreated steels. Olive oil quenching improves the impact energy and ultimate tensile strength of the steel because of its lower and uniform cooling rate compared with water and oil; also there is lesser risk of cracking and distortion in the parts. The uniform low cooling rates also result in better mechanical properties for the olive oil quenched steels.

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