STM JOURNALS

International Journal of
Mechanical Dynamics and Systems Analysis

Volume 1, Issue 2, 2023
July–December
DOI (Journal): 10.37591/IJMDSA

https://journals.stmjournals.com/ijmdsa

Research IJMDSA

Heat Treatment Research Studies of EN9 Carbon Steel by Quenching Operation in Different Quenching Media

T.R. Vijayaram[1,*], S. Nithish[2], D. Ananthapadmanaban[3]

Abstract

In this experimental research, EN9 type of steels is selected to process the heat treatment by quenching to increase the hardenability of a material. EN9 steel is cut into small work samples with diameter 25mm and length 15mm to analyze. Then they are polished the cut surface in a fine manner. Microstructure and hardness are to be found for EN9 work pieces before heat treatment at different locations like at origin, 2.5 mm, 5 mm, 7.5 mm and 10 mm from origin. The cut work pieces are then placed in muffle furnace and heated at 810º–840º, predetermined temperature range with soaking time 40 minutes. Then once they are heated, immediately they are quenched in different quenching medium with different concentrations in a vessel by using tongs. In this research work, quenching medium chosen are water, oil, brine solution with different concentration and Poly Vinyl Alcohol (PVA), a polymer quenchant with different concentration. Then the microstructure and hardness is compared for EN9 material before heat treatment and after heat treatment with different quenching media to obtain the result. Graphs like location Vs hardness and quenching media Vs average hardness were drawn.

Keywords: EN9, Heat treatment, Water, Oil, Brine solution, Poly Vinyl Alcohol

INTODUCTION

EN9 steel is also known as C55 carbon steel. EN9 is one of the plain carbon steel having 0.5%–0.60% of carbon in its composition. So, it is called as medium carbon steel. Medium carbon steel contains 0.3%–0.6% of carbon content(TABLE: 1). The hardening temperature of this material ranges between 810–840ºC. The standard chemical composition of EN9 material is

***Author for Correspondence**
T.R. Vijayaram
E-mail: vijayaram.mech@bharathuniv.ac.in

[1]Professor, Department of Mechanical Engineering, School of Mechanical Engineering, BIST, BIHER, Selaiyur, Chennai, Tamil Nadu, India
[2]Assistant Professor, Department of Mechanical Engineering, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India
[3]Associate Professor, Department of Mechanical Engineering, Sri SivaSubramaniya Nadar College of Engineering, Kalavakkam, Chennai, Tamil Nadu, India

Received Date: April 01, 2024
Accepted Date: April 13, 2024
Published Date: April 30, 2024

Citation: T.R. Vijayaram, S. Nithish, D. Ananthapadmanaban. Heat Treatment Research Studies of EN9 Carbon Steel by Quenching Operation in Different Quenching Media. International Journal of Mechanical Dynamics and

HEAT TREATMENT PROCESS

Heat treatment is a process in which metal/alloy is heated beyond the critical temperature and cooled at controlled rates to getdifferent microstructuresand hence desired mechanicalproperties.

The properties of metals and alloys can be changed as desired by the heat treatment process. The heat treatment usually provides a simple and low-cost means of achieving desired properties. At the same time, poor or careless heat treatment may result in more harm than good can result. Thus, the understanding of the heat treatment and correlating it with the other manufacturing processes are essential for mechanical engineers in order to obtain optimal results.

Table 1. Chemical composition of EN9 material in %

Material	C	Si	Mn	S	P	Fe
EN9	0.50–0.60	0.05–0.60	0.50–0.80	0.060 max	0.060 max	rest

The theory of heat treatment is since a change takes place in the internal structure of metalbyheatingandcoolingwhichinducesdesiredpropertiesinittherateofcoolingisthecontrolling factor in developing hard or soft structure (Table 1). The variety of metal (such as steel) and various metallurgical processes are depending upon: (*i*) the method and rate of heating and cooling; *(ii)* furnaces used; and *(iii)* quenching medium used.

Purpose of Heat Treatment

- To relieve internal
- To provemachinability.
- To refine grain size.
- To increase hardness.
- Improve mechanical properties (like tensile strength, hardness, ductility shock resistance, etc.).
- To improve magnetic and electricalproperties
- To increase resistance to wear, heat and corrosion.
- To improve ductility and toughness.
- To change the chemical composition.

QUENCHING

Quenching refers to accelerated cooling. Hardening refers to the heat treatment of steel which increases its hardness by quenching. Hardness normally implies heat treating operations which produce microstructures which are entirely or predominantly martensitic.

PURPOSE OF HARDENING

The main purposes of hardening are:

1. To harden the steel toresist wear.
2. To enable it to cut other metals.

INTRODUCTION TO QUENCHANTS

Quenchants are media which dissipate the heat from hot components in a controlled manner. To quantify this principal demand, the relatively simple-to-measure physical value of cooling duration and the resulting cooling rate are used. With this value, it is possible to determine the exact cooling speed required to achieve the required micro-crystalline structure or in other words, the required hardness. The different types of quenching media are Water, Oil, Brine solution and Polymer quenchants.

Water

Water-miscible quenchants are suitable for use in spray and dip-bath applications. In dip-bath lines, the quenchant is in a tank into which the components to be treated are lowered. Normally, the quenchant is kept moving by circulation pumps or propellers. Ideally, this movement should take the form of a flow which accesses the entire component surface.

Oil

Quenching oils are mostly used for dip-bath applications. The oils are in quenching tanks into which the components to be treated are lowered. This can take place automatically or manually in batches on support frames or as loose components off a conveyor belt. As a rule, quenching oils are used at temperatures between 40 and 90°C. Some types of oils can even be heated to 200°C and more. There is always a danger of fire when using quenching oils. In addition and depending on product quality, quenching with oils can create vapors which may be hazardous to health. As opposed to water-miscible quenchants, quenching oils have an almost unlimited service life if they are properly maintained. Bacterial contamination cannot occur because of the absence of water.

Brine solution: It refers to aqueous solutions containing different percentages of salts, such as sodium chloride or calcium chloride (Table 2)

Table 2. Relation of brine density to brine concentration

Salt (%)	Salt concentration (g/L)
4	41.1
6	62.4
8	84.5
10	107.1
12	130.3

POLYMER QUENCHANTS:

Polyvinyl Alcohol (PVA): The use of aqueous solutions of polyvinyl alcohol (PVA) as quenching media was first described in U.S. Patent 2,600,290, issued in 1952. It can be considered as the precursor to modern polymer quenchants. Hydrolyzed forms of PVA also have been used as lubricants for special purposes and as a sizing, coating for glass fiber products.

The concentration of the vinyl resin in the aqueous quench liquid will depend upon the the nature of the vinyl resin utilized, and the desired rate of cooling in the quenching operation. In most cases, the vinyl resin concentration will lie within the range of 0.1 to 10% by weight. By appropriate adjustment of vinyl resin content the cooling characteristics of the quench liquids may be made to substantially duplicate those of the various commonly used quenching oils. Also by increasing the vinyl resin content to 3% or higher, the cooling rate of the quenched liquid may be decreased to alower cooling rate than that of oil. Similarly, by lowering the vinyl resin content within the range of around 0.1 to 1% by weight, the cooling rate of the liquid may be made faster than that of oil.

The process for heat treating steel comprising heating the steel to a quench hardening temperature and therafter quenching steel by immersion in an aqueous liquid containing about 0.5 to 3% by weight of a polyvinyl resin (Table 3).

Table 3. Relation of PVA density to PVA concentration

PVA (%)	PVA Concentration (g/L)
0.1	1
0.2	2
0.5	5
1	10
1.5	15
2	20
3	30

HARDNESS TEST

Hardness test is performed on material to know its resistance against indentation and abrasion. This method of test is suitable for finished or machined parts of simple shapes.

SEM

After completing polishing and etching the samples were taken for micro structure study of the surface characteristics of the metal. After preparation of metallography specimen, the polished samples of both untreated and treated specimens were taken for microstructure determination using Scanning Electrical Microscope. Using SEM the microstructure is seen and captured the grain growth of the above polished samples with a magnification of 100X.

RESEARCH OBJECTIVES

1. To determine the mechanical property like hardness of EN9 material in the as-cast conditions.
2. To subject the steel to suitable heat treatment ie. Heating in muffle furnace with a pre-determined temperature around 810º–840ºC with predetermined time or soaking time 40 minutes.
3. To carry out the quenching process in different quenching media(Water, Oil, Brine solution, Polymer quenchant) with different concentration.
4. To carryout hardness test on as-bought conditions and heat treated conditions.
5. To study the micro constituent phase identification using Optical Microscope (OM) or Scanning Electronic Microscope (SEM) and study the microstructure on heat treated samples and in as-bought condition.
6. To compare the hardness values before heat treatment and after heat treatment.
7. To determine the efficient quenching medium from water, oil, brine solution, polymer quenchant.
8. To check whether the polymer quenching gives uniform results or not.

RESEARCH METHODOLOGY

1. Selection of material.
2. Preparation of work samples.
3. Preparation of quenchants.
4. Heat treatment of work samples.
5. Mechanical testing or Hardness testing before heat treatment and after heat treatment.
6. Metallography.

Selection of Material

The EN9 material is chosen for investigation. EN9 is one of the plain carbon steel having 0.50 – 0.60 % of carbon in its composition. So, it is called as Medium Carbon Steel (Table 4). The standard chemical composition of EN9 material is

Table 4. Chemical composition of EN9 material in %

Material	C	Si	Mn	S	P	Fe
EN9	0.50–0.60	0.05–0.60	0.50–0.80	0.060 max	0.060 max	rest

Preparation of Work Samples

The material that we procured from the vendor was of EN9 material in the form of long rod. It is cut into small pieces of following size (Figures 1, 2).

Diameter of each sample = 25 mm
Length of each sample is = 15 mm
Total number of samples = 14 units

Preparation of Quenchants

The quenching medium chosen are Water, Oil, Brine solution and PolyVinyl Alcohol (Figure 3, 4). Water is taken directly. Oil grade 39 is chosen for quenching. Brine solution and polymer quenchant is prepared by selecting the concentrations (Tables 5, 6).

1. Water quenchant-5 litres–1 sample
2. Oil grade 39–5 litres–1 sample
3. Brine solution with different concentrations-5 litres (NaCl + Water)
4. Polymer quenchant with different concentration–5 litres (PVA + Water)

Figure 1. EN9 rod.

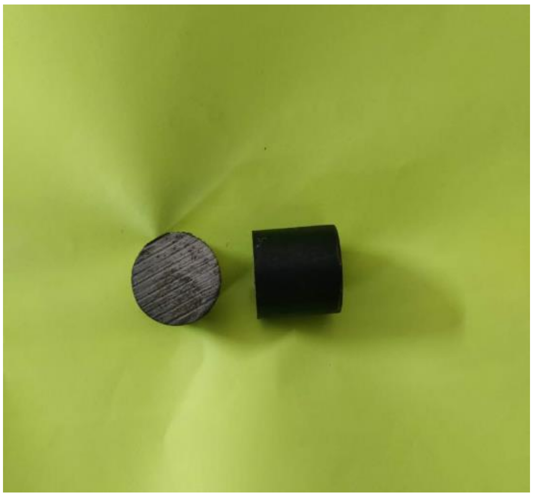

Figure 2. EN9 work samples.

Table 5. Preparation of Brine solution (NaCl + Water)

Sample	Salt (%)	Salt concentration (g/L)	Salt concentration (g/5L)
1	6	62.4	312
2	8	84.5	422.5
3	10	107.1	535.5
4	12	130.3	651.5

Figure 3. NaCl salt.

Table 6. Preparation of polymer quenchant (PVA + Water)

Sample	PVA (%)	PVA concentration (g/L)	PVA concentration (g/5L)
1	0.1	1	5
2	0.2	2	10
3	0.5	5	25
4	1	10	50
5	1.5	15	75
6	2	20	100
7	3	25	150

Figure 4. PVA powder.

Heat Treatment of Work Samples

The cut work pieces or samples are placed in a muffle furnace (Figure 5) for heating at a predetermined temperature of 810ºC–840ºC over a period of predetermined time 40 minutes, which is also known as soaking time. Once the samples reaches maximum temperature of 840ºC with 40 minutes soaking time, they are taken out from the furnace by tongs and then they are quenched immediately in water (Figure 6), oil (Figures 7), brine solution with different concentration (Figures 8,9,10,11) and polymer quenchant with different concentration(Figures 12,13,14,15,16,17,18) in a vessel at room temperature. After quenching, samples are marked (Figure 19).

Figure 5. Muffle furnace.

Figure 6. Water quenching.

Figure 7. Oil quenching.

Figure 8. Brine solution 6%.

Figure 9. Brine solution 8%.

Figure 10. Brine solution 10%.

Figure 11. Brine solution 12%.

Figure 12. PVA 0.1%.

Figure 13. PVA 0.2%.

Figure 14. PVA 0.5%.

Figure 15. PVA 1%.

Figure 16. PVA 1.5%.

Figure 17. PVA 2%.

Figure 18. PVA 3%.

Figure 19. Sample marking.

MECHANICAL TESTING

Initially the hardness test performed for the base material or parent material or untreated material sample. The hardness test performed is Rockwell hardness testing machine (Figure 20). The hardness test is performed on work samples in different locations. The above procedure is followed for all the work samples to determine the hardness at different locations for untreated and heat treated work samples. The hardness test is done on the work samples at location origin ie. Mid point 0,2.5 mm, 5 mm, 7.5 mm, 10 mm from the origin on a circular face of a work samples.

Figure 20. Rockwell hardness testing machine.

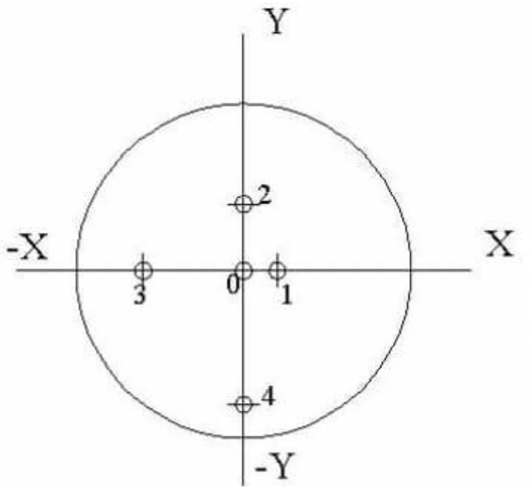

Figure 21. Hardness testing location.

At point 0–0 mm
At pont 1–2.5 mm from 0
At point 2–5 mm from 0
At point 3–7.5 mm from 0
At point 4–10 mm from 0
The hardness test is performed at these locations as shown in the (Figure 21) and values are to be noted.

Metallography

After successful heat treatment operation the heat treated specimens of untreated sample, water quench sample, oil quench sample, brine solution with higher concentration quench sample and polymer quenchanthigher concentration quench sample were taken for the polishing and etching. The polishing is done by 60, 180,240,320,400,600,1200,2000 grid emery polished and 1/0, 1/1,1/2,1/3,1/4,1/5 alumina dry paper polished. After that velvet polishing and water polishing is done by abrassive and alumina polishing machines as shown below (Figure 22). After completing polishing, etching is done for the work samples by combination of Nitric acid and Ethyl alcohol ie. 2% Nitol solution.


Figure 22. Polishing machine.


Figure 23. Polished samples.

After completing polishing and etching the samples were taken for micro structure study of the surface characteristics of the metal. After preparation of metallography specimen, the polished samples as shown in the above (Figure 23) both untreated and treated specimens were taken for microstructure determination using Scanning Electrical Microscopeas shown in the below (Figure 24). Using SEM the microstructure is seen and captured the grain growth of the above polished samples with a magnification of 100x.

Figure 24. SEM.

RESULTS AND DISCUSSION

The mechanical property ie., Hardness is found as a function of different location or points on circular surface of untreated and heat treated samples. Also the hardness is found as a function of quenching media with different concentrations.

Hardness Testing Results for Untreated Sample

The hardness property of untreated sample is measured using Rockwell hardness testing machine at various locations from origin or mid point on the circular surface. The results obtained from testing a specimen is shown in below (Table 7) and (Figure 25).

Table 7. Untreated sample HRC

Point	Location from origin	HRC
0	0	8
1	2.5	8
2	5	9
3	7.5	9
4	10	7

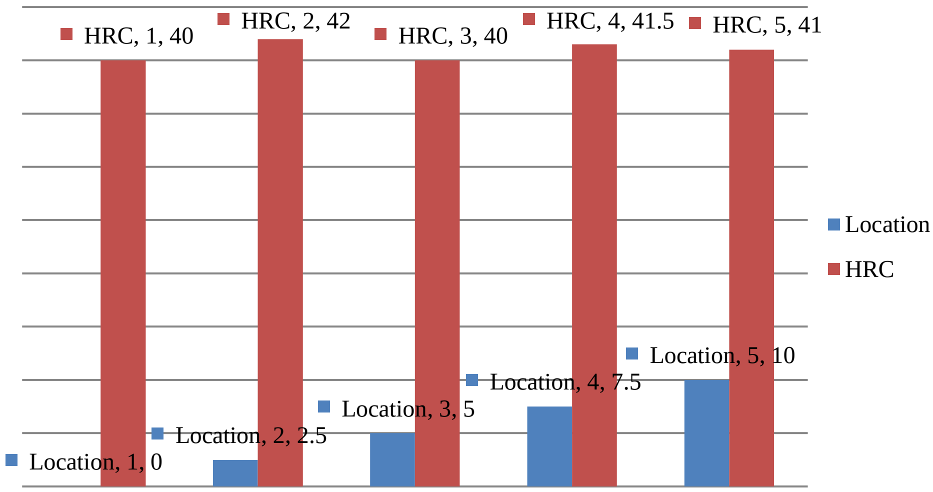

Figure 25. Untreated sample.

Hardness Testing Results for Heat Treated Work Samples

The hardness of heat treated sample is measured using Rockwell hardness testing machine at various locations from origin or mid point on the circular surface.

Water Quench Sample

The hardness of water quenched sample is measured and the values are noted as shown in below (Table 8) and (Figure 26).

Table 8. Water quench sample HRC

Point	Location from origin	HRC
0	0	30
1	2.5	33
2	5	26
3	7.5	27
4	10	30

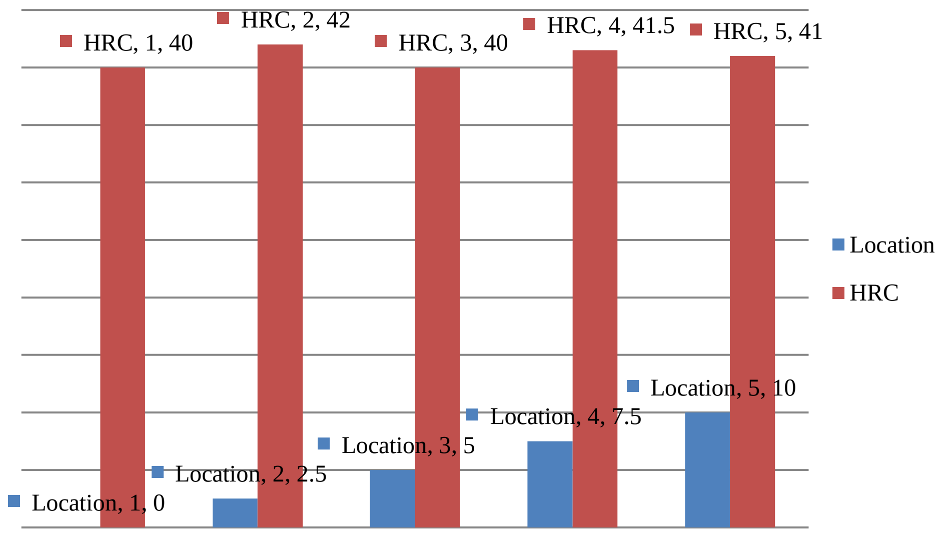

Figure 26. Water quench sample.

From the above table and graph it is observed that the maximum hardness 33HRC occurs at point 2ie. At 2.5mm from origin.

Oil Quench Sample

The hardness of water quenched sample is measured and the values are noted as shown in below (Table 9) and (Figure 27).

From the above table and graph it is observed that the maximum hardness26HRC occurs at point 4ie. At 10 mm from origin.

Table 9. Oil quench sample HRC

Point	Location from origin	HRC
0	0	18
1	2.5	19
2	5	20
3	7.5	23
4	10	26

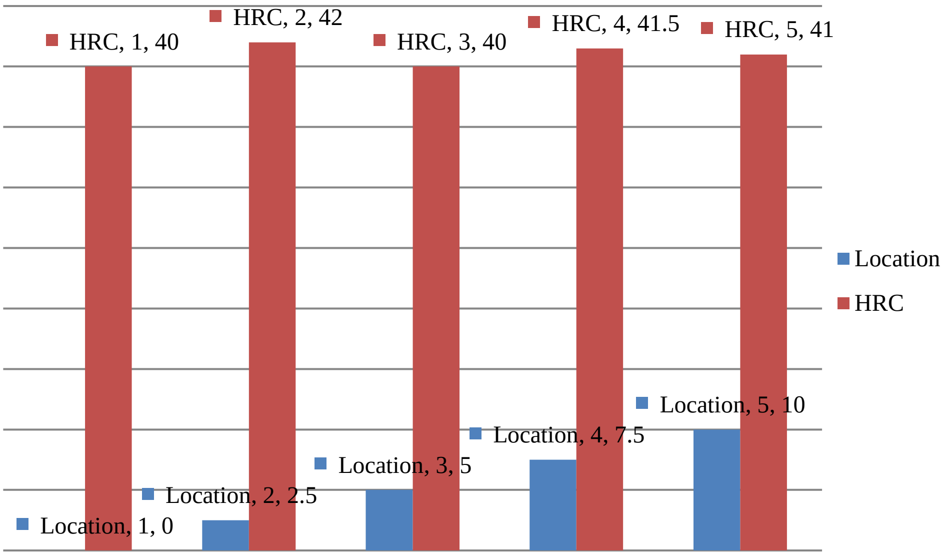

Figure 27. Oil quench sample

Brine Solution 6% Quench Sample

The hardness of Brine solution 6% quenched sample is measured and the values are noted as shown in below (Table 10) and (Figure 28).

Table 10. B S 6% sample HRC.

Point	Location from origin	HRC
0	0	44
1	2.5	45
2	5	53
3	7.5	57
4	10	40

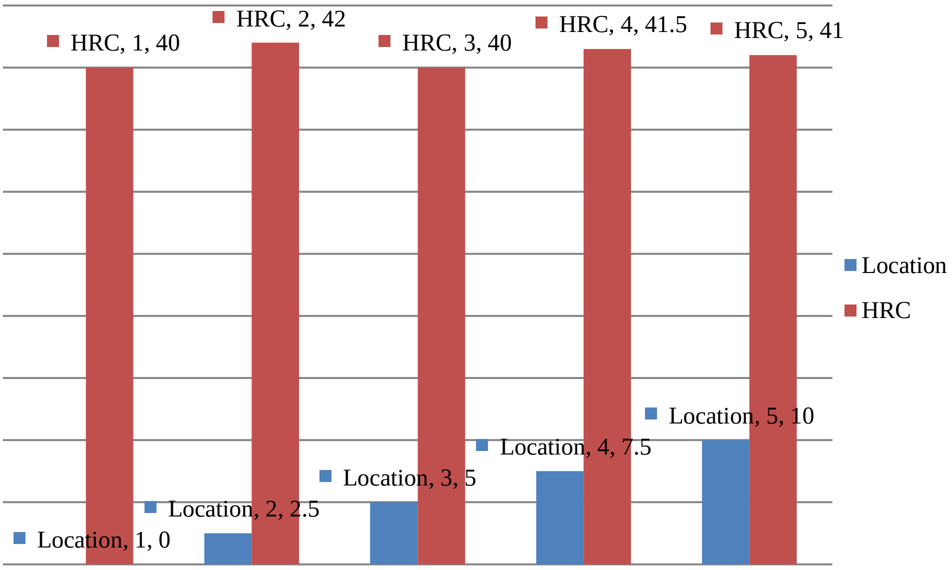

Figure 28. B S 6% sample.

From the above table and graph it is observed that the maximum hardness 57 HRC occurs at point 3 ie. At 7.5mm from origin.

Brine solution 8% quench sample :

The hardness of Brine solution 8% quenched sample is measured and the values are noted as shown in below (Table 11) and (Figure 29).

Table 11. B S 8% sample HRC.

Point	Location from origin	HRC
0	0	48
1	2.5	43
2	5	53
3	7.5	57
4	10	53

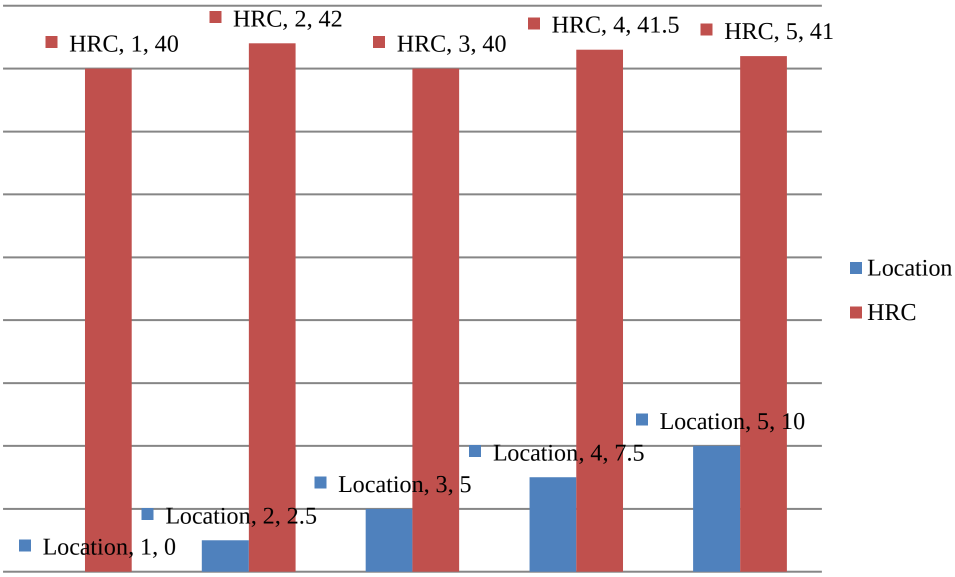

Figure 29. B S 8% sample.

From the above table and graph it is observed that the maximum hardness 57 HRC occurs at point 3 ie. At 7.5mm from origin.

Brine Solution 10% Quench Sample

The hardness of Brine solution 10% quenched sample is measured and the values are noted as shown in below (Table 12) and (Figure 30).

From the above table and graph it is observed that the maximum hardness 50 HRC occurs at point 3 ie. At 7.5mm from origin.

Brine Solution 12% Quench Sample

The hardness of Brine solution 12% quenched sample is measured and the values are noted as shown in below (Table 13) and (Figure 31).

Table 12. B S 10% sample HRC

Point	Location from origin	HRC
0	0	42
1	2.5	42
2	5	50
3	7.5	47
4	10	40

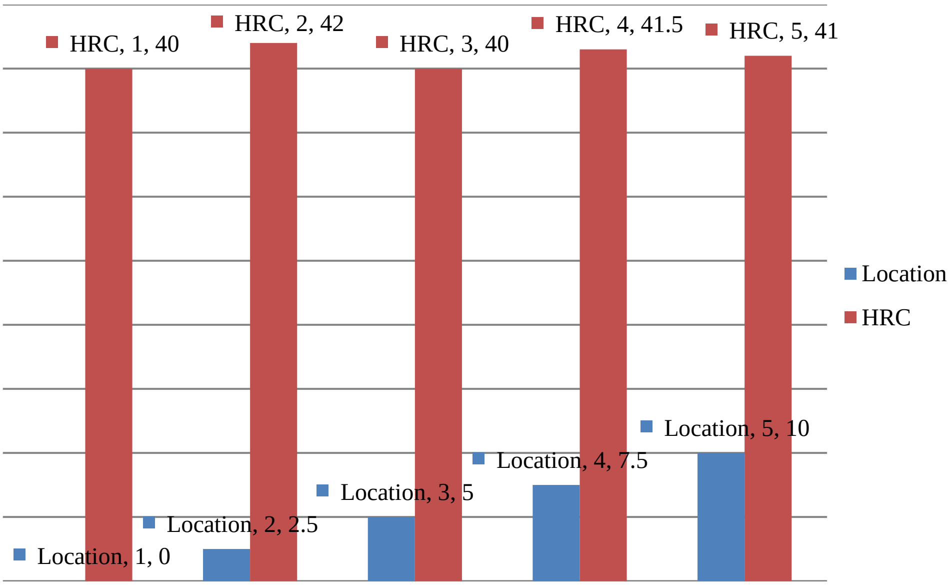

Figure 30. B S 10% sample.

From the above table and graph it is observed that the maximum hardness 60 HRC occurs at point 2 ie. At 5mm from origin.

Table 13. B S 12% sample HRC

Point	Location from origin	HRC
0	0	58
1	2.5	60
2	5	54
3	7.5	56
4	10	57

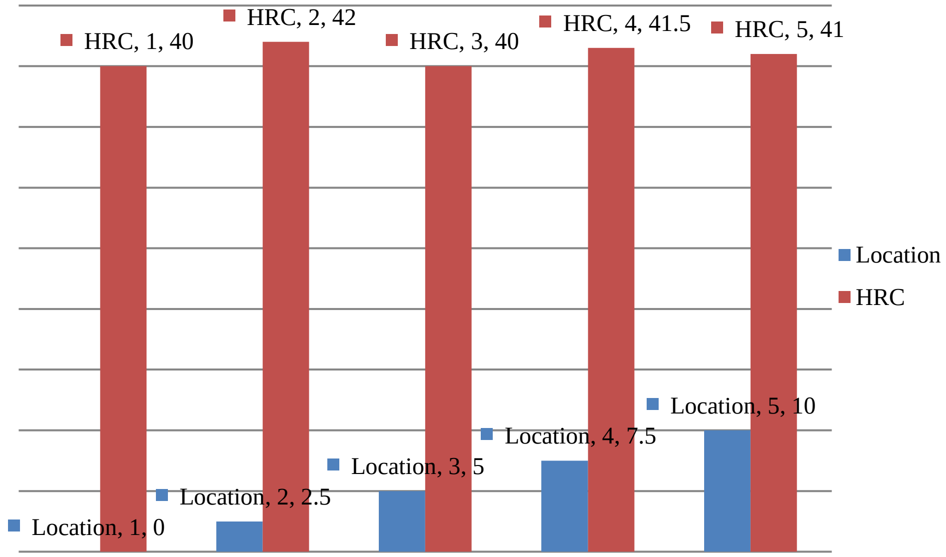

Figure 31. B S 12% sample.

PVA 0.1% Quench Sample

The hardness of PVA 0.1% quenched sample is measured and the values are noted as shown in below (Table 14) and (Figure 32).

Table 14. PVA 0.1% sample HRC.

Point	Location from origin	HRC
0	0	33
1	2.5	38
2	5	42
3	7.5	51
4	10	45

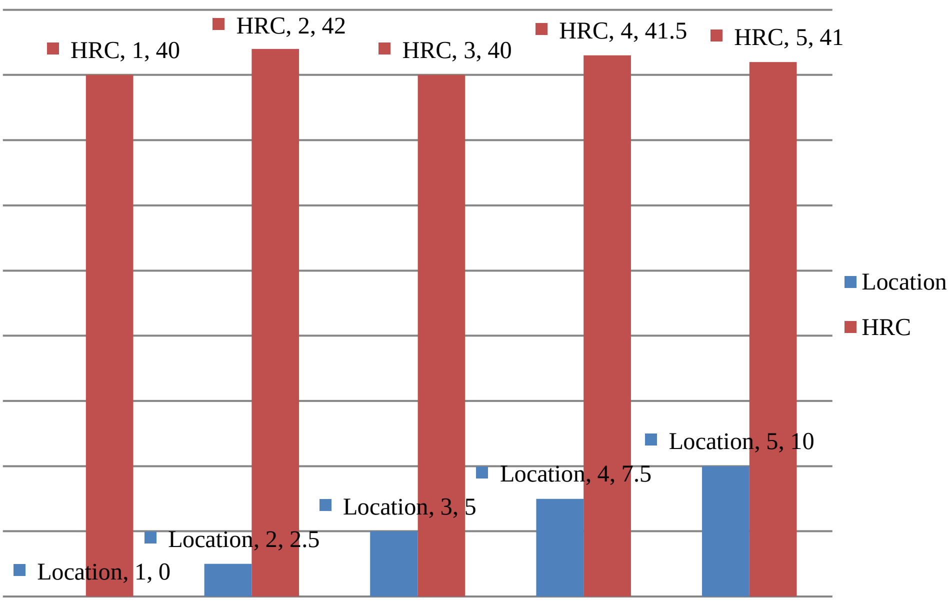

Figure 32. PVA 0.1% sample.

From the above table and graph it is observed that the maximum hardness 51 HRC occurs at point 3 ie. At 7.5 mm from origin.

PVA 0.2% Quench Sample

The hardness of PVA 0.2% quenched sample is measured and the values are noted as shown in below (Table 15) and (Figure 33).

From the above table and graph it is observed that the maximum hardness 44 HRC occurs at point 3 ie. At 7.5 mm from origin.

PVA 0.5% Quench Sample

The hardness of PVA 0.5% quenched sample is measured and the values are noted as shown in below (Table 16) and (Figure 34).

From the above table and graph it is observed that the maximum hardness 52 HRC occurs at point 3 ie. At 7.5 mm from origin.

Table 15. PVA 0.2% sample HRC.

Point	Location from origin	HRC
0	0	38
1	2.5	39
2	5	40
3	7.5	44
4	10	40.5

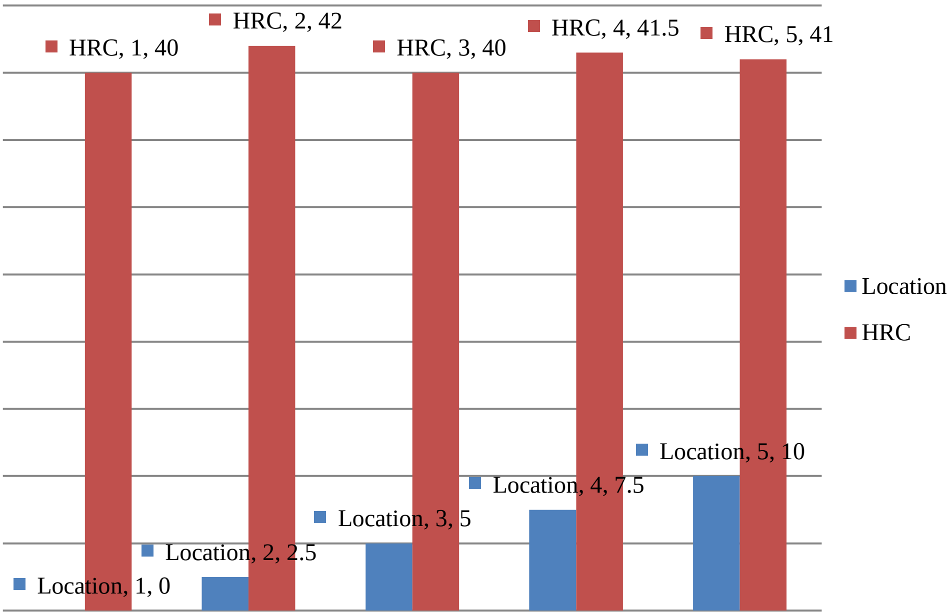

Figure 33. PVA 0.2% sample.

PVA 1% Quench Sample

The hardness of PVA 1% quenched sample is measured and the values are noted as shown in below (Table 17) and (Figure 35).

Table 16. PVA 0.5% sample HRC.

Point	Location from origin	HRC
0	0	40
1	2.5	39
2	5	39.5
3	7.5	52
4	10	40.5

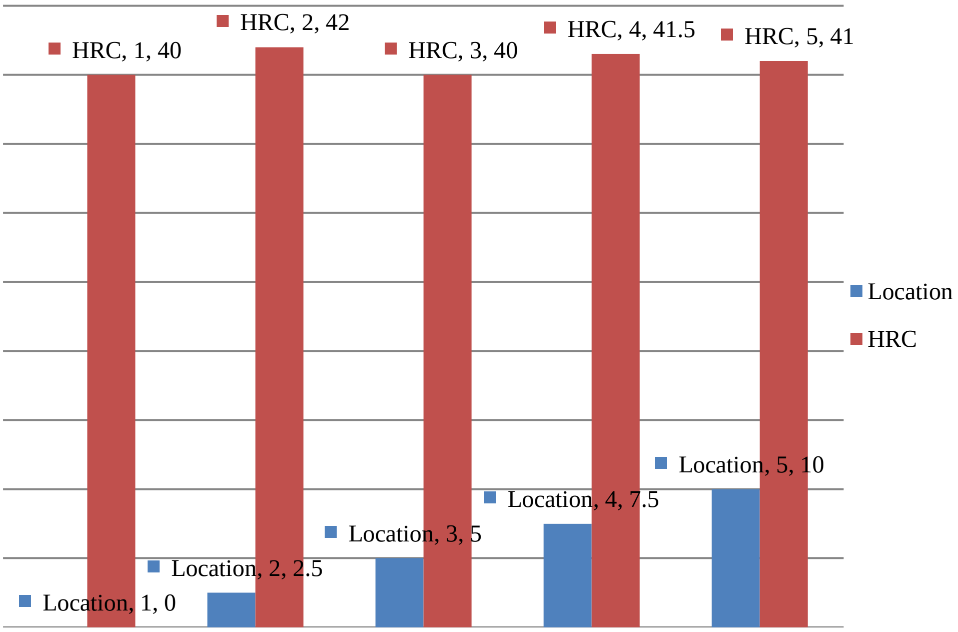

Figure 34. PVA 0.5% sample.

Table 17. PVA 1% sample HRC.

Point	Location from origin	HRC
0	0	39
1	2.5	38
2	5	40
3	7.5	44
4	10	42

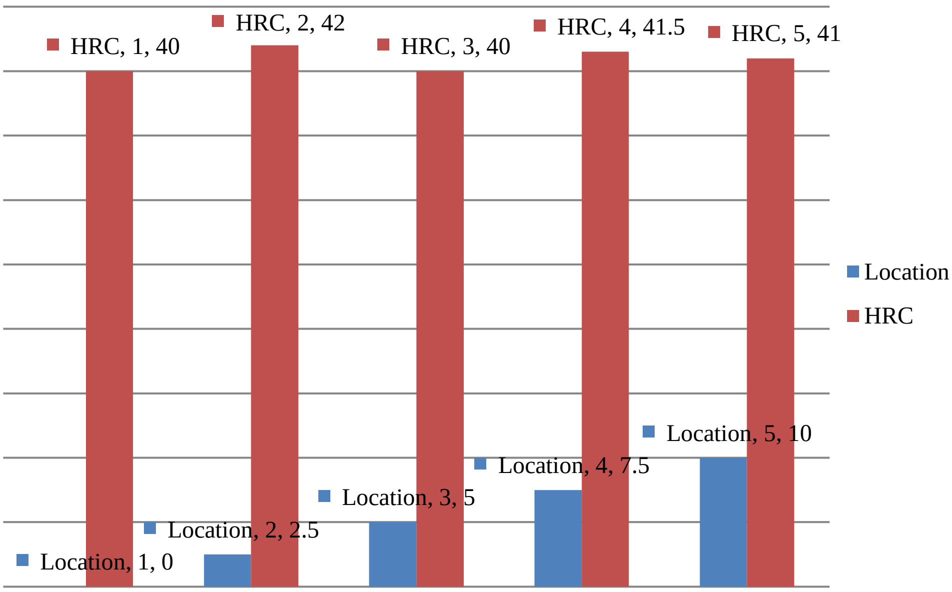

Figure 35. PVA 1% sample.

From the above table and graph it is observed that the maximum hardness 44 HRC occurs at point 3 ie. At 7.5 mm from origin.

PVA 1.5% Quench Sample

The hardness of PVA 1.5% quenched sample is measured and the values are noted as shown in below (Table 18) and (Figure 36).

From the above table and graph it is observed that the maximum hardness 40.5 HRC occurs at point 3 ie. At 7.5 mm from origin.

PVA 2% Quench Sample

The hardness of PVA 2% quenched sample is measured and the values are noted as shown in below (Table 19) and (Figure 37).

From the above table and graph it is observed that the maximum hardness 41.5 HRC occurs at point 3 ie. At 7.5 mm from origin.

Table 18. PVA 1.5% sample HRC.

Point	Location from origin	HRC
0	0	37.5
1	2.5	39
2	5	40
3	7.5	40.5
4	10	40

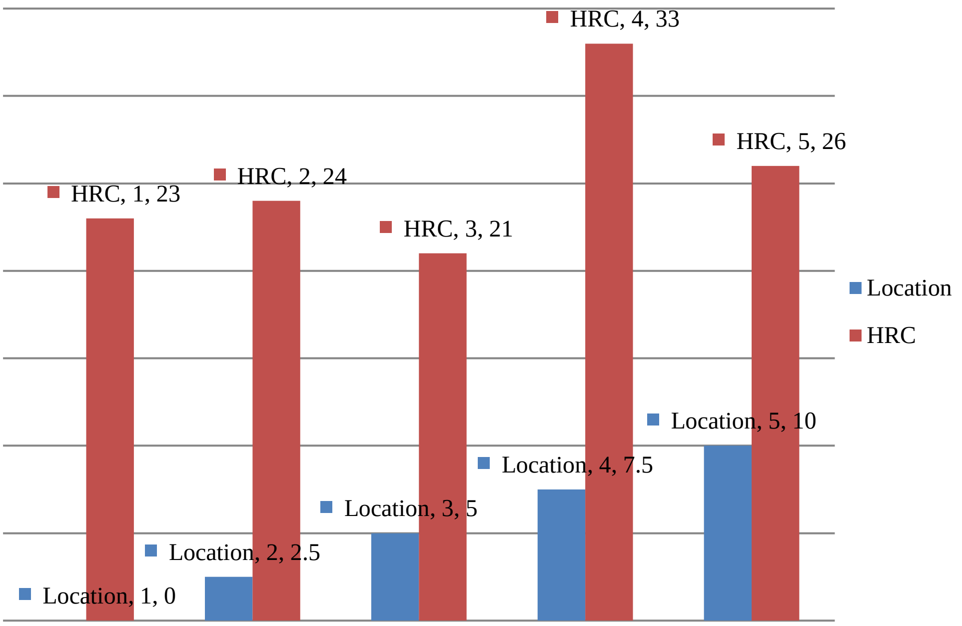

Figure 36. PVA 1.5% sample.

PVA 3% Quench Sample

The hardness of PVA3% quenched sample is measured and the values are noted as shown in below (Table 20) and (Figure 38).

Table 19. PVA 2% sample HRC.

Point	Location from origin	HRC
0	0	40
1	2.5	42
2	5	40
3	7.5	41.5
4	10	41

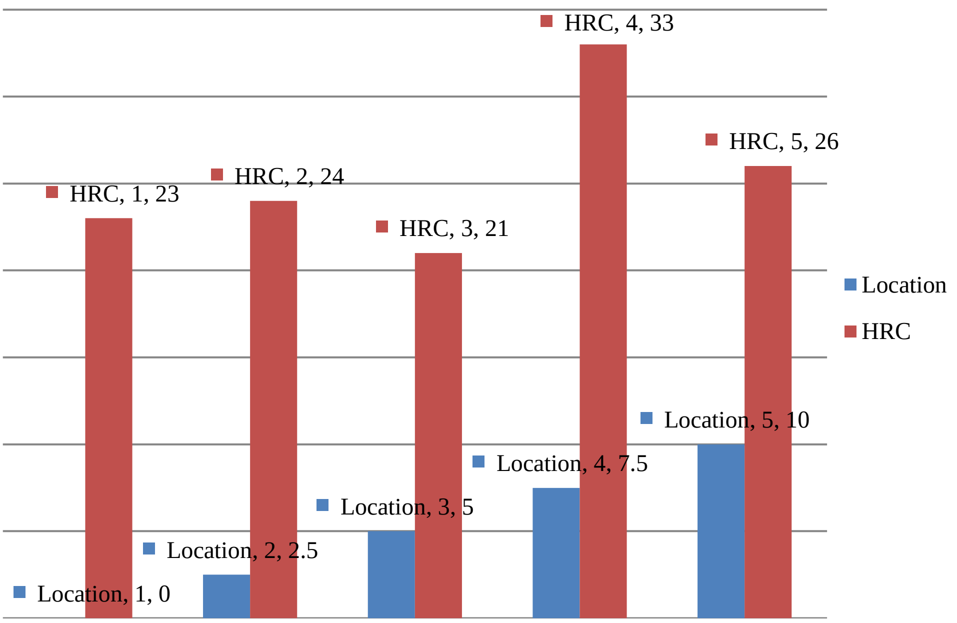

Figure 37. PVA 2% sample.

Table 20. PVA 3% sample HRC.

Point	Location from origin	HRC
0	0	23
1	2.5	24
2	5	21
3	7.5	33
4	10	26

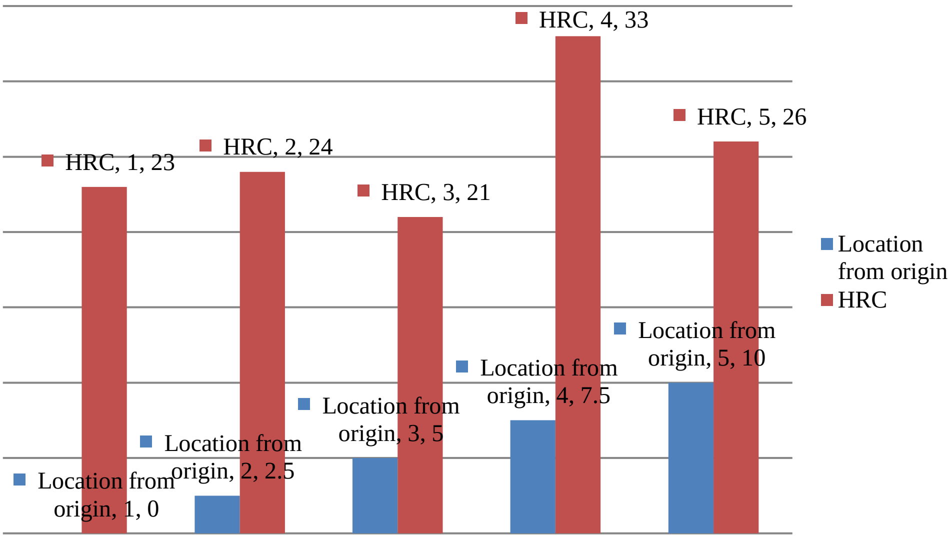

Figure 38. PVA 3% sample.

From the above table and graph it is observed that the maximum hardness 33 HRC occurs at point 3 ie. At 7.5 mm from origin.

It is observed that an uniform quenching has taken place in polymer quenching by looking at the highest hardness values at point 3 of different concentrations.

Comparision of EN9 Before and After Heat Treatment

The average hardness is found and tabulated for all the work samples with irrespective of locations with different quenching media. The comparison graph is drawn between quenching media and hardness before and after heat treatment.

X-Axis ---- Quenchant media

Y-Axis ---- Average HRC

From the above Figure 39 and Table 21 we can say that an uniform quenching has taken place in polymer quenching by observing average hardness values from the table and graph progression.

Metallography Results

Scanning Electronic Microscope (SEM) is used to scatter the different phases present in the surface of EN9 material for both before and after heat treated conditions.The microstructure is seen at different locations of work samples and the images are scattered with range 100X magnification. The different locations are the location where the hardness test is performed ie.

At point 0–0 mm

At pont 1–2.5 mm from 0

At point 2–5 mm from 0

At point 3–7.5 mm from 0

At point 4–10 mm from 0

Table 21. Average HRC values for various quenching media.

S.N.	Quenchant	Average HRC
1	Untreated	8.2
2	Water	29.2
3	Oil	21.2
4	BS 6%	47.8
5	BS 8%	50.8
6	BS 10%	44.2
7	BS 12%	57
8	PVA 0.1%	41.8
9	PVA 0.2%	40.3
10	PVA 0.5%	42.2
11	PVA 1%	40.6
12	PVA 1.5%	39.4
13	PVA 2%	40.9
14	PVA 3%	25.4

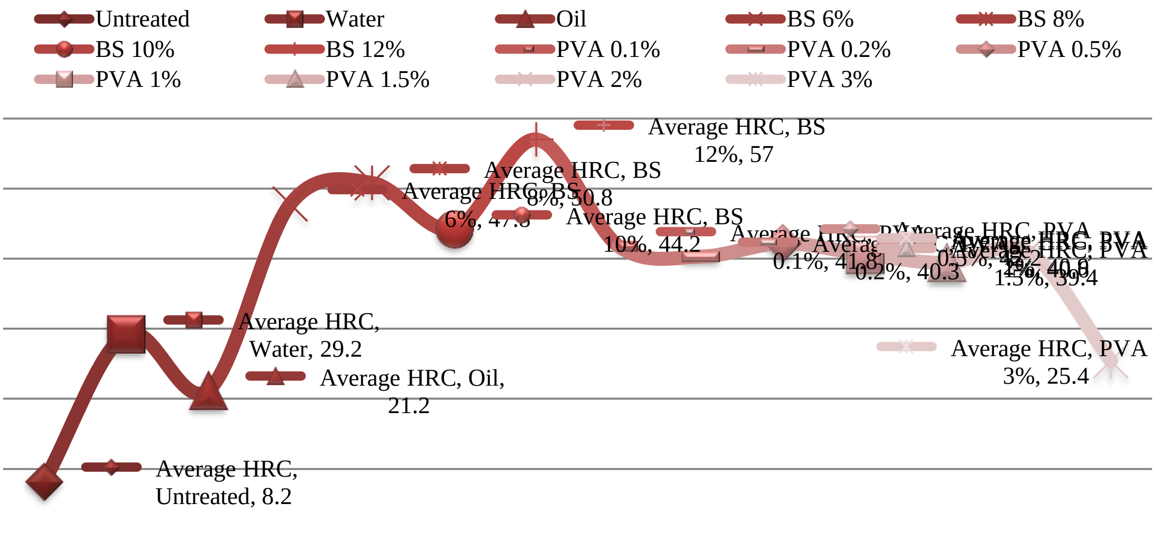

Figure 39. Quenching media vs Average HRC.

Untreated Sample or Base material:

The images shows in Figure 40 (a,b,c,d,e) the microstructure present in EN9 material before heat treatment.

Figure 40. (a) BM at point 0.

Figure 40. (b) BM at point 1.

Figure 40. (c) BM at point 2.

Figure 40. (d) BM at point 3.

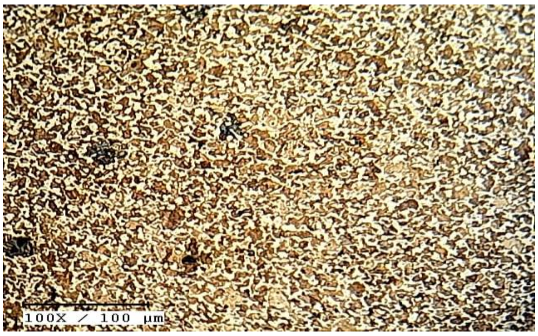

Figure 40. (e) BM at point 4.

At point 0: 50% Pearlite + 50% Ferrite
At point 1: 50% Pearlite + 50% Ferrite
At point 2: 75% Pearlite + 25% Ferrite
At point 3: 75% Pearlite + 25% Ferrite
At point 4: 40% Pearlite + 60% Ferrite

Water Quench Sample

The images shows in Figure 41 (a,b,c,d,e) is Water quench sample

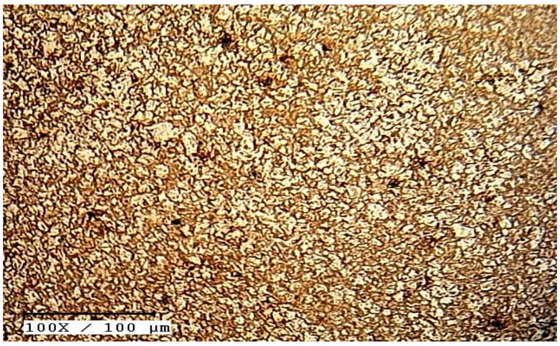

Figure 41. (a) Water quench at point 0.

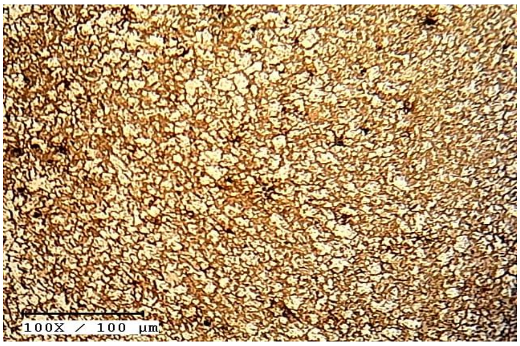

Figure 41. (b) Water quench at point 1.

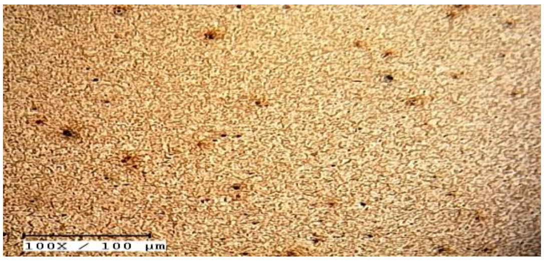

Figure 41. (c) Water quench at point 2

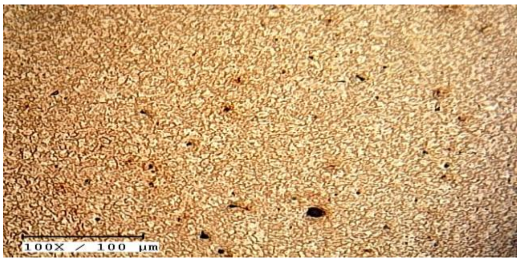

Figure 41. (d) Water quench at point 3.

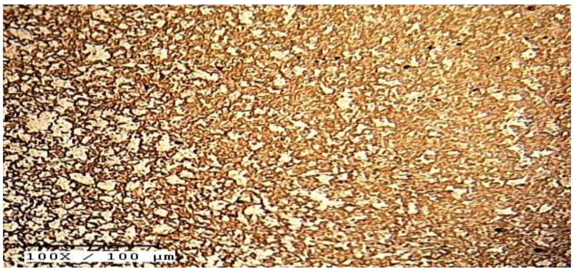

Figure 41. (e) Water quench at point 4.

At point 0: 70% Martensite + 50% Pearlite
At point 1: 75% Martensite + 25% Pearlite
At point 2: 65% Martensite + 35% Pearlite
At point 3: 65% Martensite + 35% Pearlite
At point 4: 40% Martensite + 60% Pearlite

Oil Quench Sample

The images shows in Figure 42 (a,b,c,d,e) is Oil quench sample

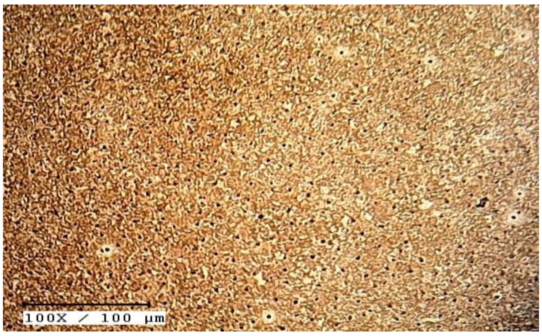

Figure 42. (a) Oil quench at point 0.

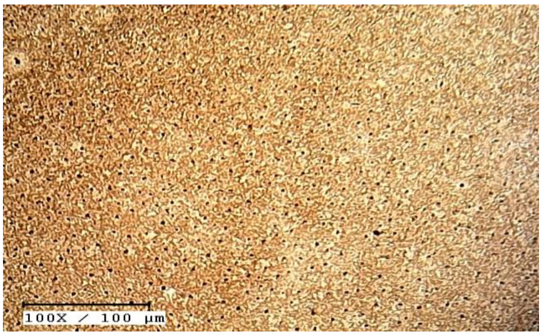

Figure 42. (b) Oil quench at point 1.

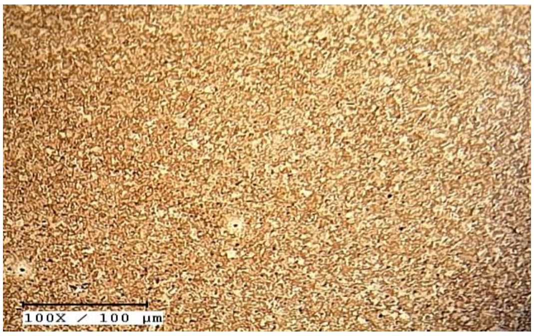

Figure 42. (c) Oil quench at point 2.

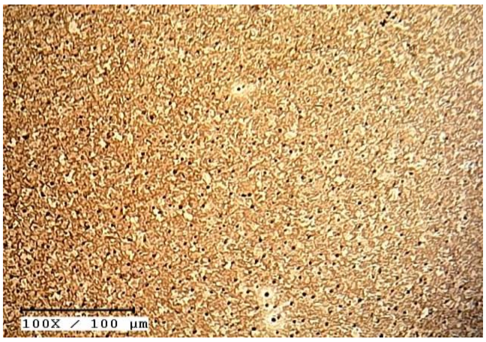

Figure 42. (d) Oil quench at point 3.

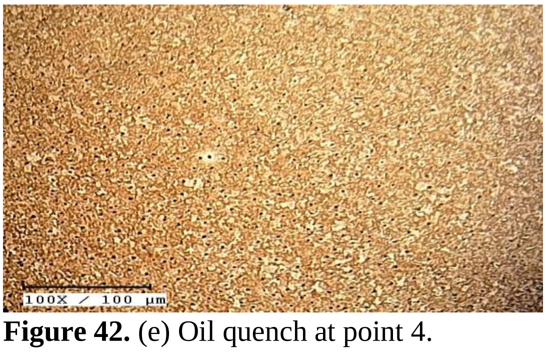

Figure 42. (e) Oil quench at point 4.

At point 0: 75% Pearlite + 25% Martensite
At point 1: 75% Pearlite + 25% Martensite
At point 2: 80%Pearlite + 20% Martensite
At point 3: 85% Pearlite + 15% Martensite
At point 4: 90% Pearlite + 10% Martensite

Brine Solution 12% Quench Sample

The images shows in Figure 43 (a,b,c,d,e) is Brine solution 12% quench sample

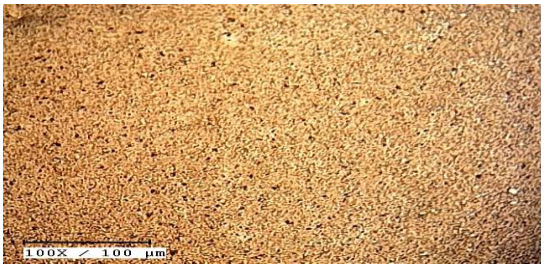

Figure 43. (a) Brine solution 12% at point 0.

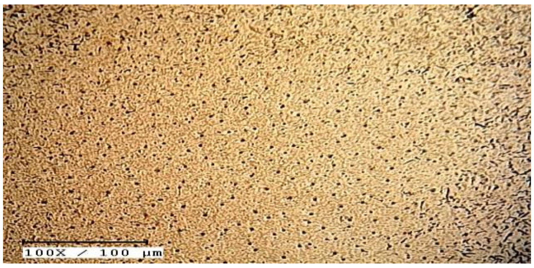

Figure 43. (b) Brine solution 12% at point 0.

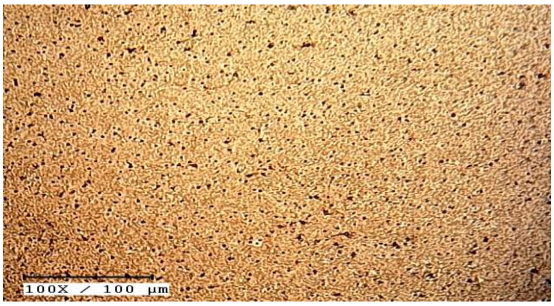

Figure 43. (c) Brine solution 12% at point 2

Figure 43. (d) Brine solution 12% at point 3.

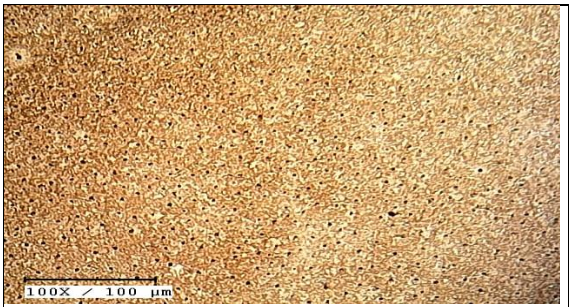

Figure 43. (e) Brine solution 12% at point 4.

At point 0: 50% Martensite + 50% Pearlite
At point 1: 70% Martensite + 30% Pearlite
At point 2: 40% Martensite + 60% Pearlite
At point 3: 45% Martensite + 55% Pearlite
At point 4: 50% Martensite + 50% Pearlite

PVA 3% Quench Sample

At point 0: 70% Martensite + 30% Pearlite
At point 1: 75% Martensite + 25% Pearlite
At point 2: 65% Martensite + 40% Pearlite
At point 3: 80% Martensite + 20% Pearlite
At point 4: 75% Martensite + 25% Pearlite

By analyzing the microstucture and hardness at same points, it can be stated that hardness is increased with increase in martensite phase, hardness is moderate with increase in pearlite phase and hardness is decreased with increase in ferrite phase (Figure 44 a,b,c,d,e).

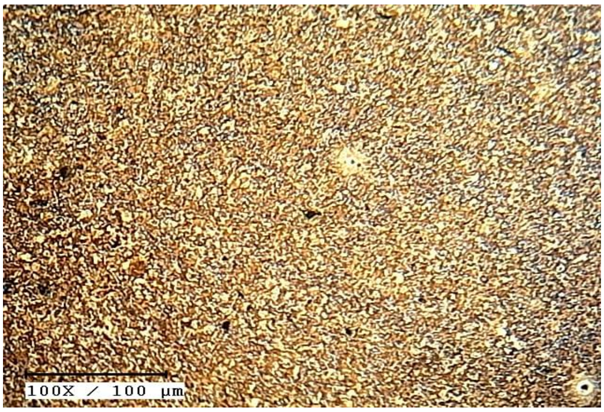

Figure 44. (a) PVA 3% at point 0.

Figure 44. (b) PVA 3% at point 1.

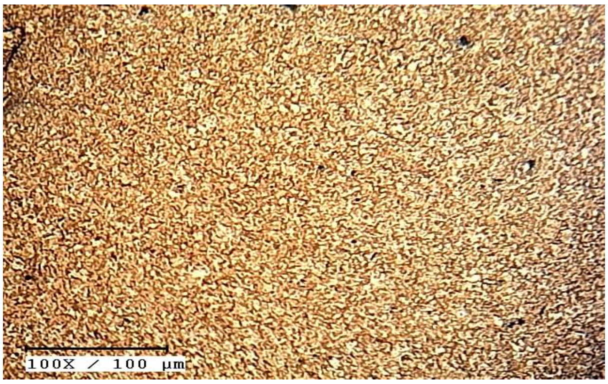

Figure 44. (c) PVA 3% at point 2.

Figure 44. (d) PVA 3% at point 3.

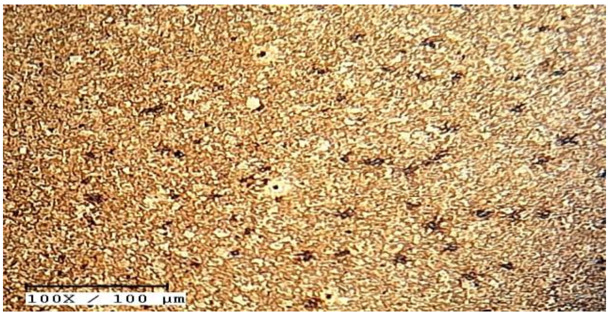

Figure 44. (e) PVA 3% at point 4.

CONCLUSION

The study has shown that using of Water, Oil, Brine solution and polymer quenchants as quenching medium improves the mechanical properties when compared to the untreated steels. In polymer quenching no visible cracks are found, micro and macro cracks are also not found on the surface of quenched sample. Where as in water quenched sample the drag is formed on the surface of a quenching. Cost effective is high for polymer quenching where as other mediums are low. Oil quenching is riskier than other quenching mediums as it catches fire due to high flash point. This study shows that polymer quenching takes place uniformly in all the polymer quenched samples even though the concentration is changed. Therefore uniform quenching reduces time. So, it can be used in industrial applications for heat treatment in hardening and tempering.

REFERENCES

1. Dossett, J., & Totten, G. E. (2013). ASM handbook. volume 4A, Steel Heat Treating Fundamentals and Processes, ASM.
2. Dziubek, M., & Grygier, D. (2022). Comparative analysis of construction materials used for fastening elements of six-point safety belts in rally cars. Combustion Engines, 61.
3. Munk, S. A., Lai, R. K., Burke, J. E., Arasasingham, P. N., Kharlamb, A. B., Manlapaz, C. A., ... & Garst, M. E. (1996). Synthesis and pharmacologic evaluation of 2-endo-amino-3-exo-isopropylbicyclo [2.2. 1] heptane: a potent imidazoline1 receptor specific agent. Journal of medicinal chemistry, 39(6), 1193-1195.
4. Miracle, D. B., Donaldson, S. L., Henry, S. D., Moosbrugger, C., Anton, G. J., Sanders, B. R., ... & Scott Jr, W. W. (2001). ASM handbook (Vol. 21, pp. 107-119). Materials Park, OH: ASM international.
5. Tuna, B. A., Tinar, E., & Rockwell, D. (2013). Shallow flow past a cavity: globally coupled oscillations as a function of depth. Experiments in fluids, 54, 1-20.
6. Application of Polymeric Quenchants in Heat treatment of Steel.M.Eshraghi-kakhi, M.A.Soltani, K.Amini, et.al, International journal of ISSI, Vol.6 (2009) , No.1 , pp. 34-38
7. Gopalkrishna, G., Gurumurthy, R. B., & Davanageri, M. (2019, March). Heat treatment and mechanical characterization of En8 steel. In AIP Conference Proceedings (Vol. 2080, No. 1). AIP Publishing
8. Zainulabdeen, A. A., Mahmood, N. Y., & Mohmmed, J. H. (2018, December). The effect of polymeric quenching media on mechanical properties of medium carbon steel. In IOP Conference Series: Materials Science and Engineering (Vol. 454, No. 1, p. 012053). IOP Publishing.
9. Chandan, B. R., & Ramesha, C. M. (2017). Evaluation of mechanical properties of medium carbon low alloy forged steels quenched in water, oil and polymer. J. Mater. Sci. Eng, 6(2), 1-5.
10. Effects of Heat Treatment on the Properties of Mild Steel Using Different Quenchants. Ahaneku I. E.1,*, A. R. Kamal2, O. A. Ogunjirin2 **.**Frontiers in Science 2012, 2(6): 153-158 DOI: 10.5923/j.fs.20120206.04
11. Aronov, A., Kobasko, N., Powell, J., Andreski, B., & O'Rourke, B. (2014, May). Intensive quenching processes: Basic principles, applications, and commercialization. In Proc. of European Conference on Heat Treatment and 21st IFHTSE Congress. Germany, Munich (pp. 267-274).

