

# EFFECT OF COLD ROLLING ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF WORK HARDENED 1020 LOW CARBON STEEL

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**Abstract:** Low carbon steel has a good ductility that is highly considerable for forming process. However, its low strength limited their extensive used for forced structure. The study mechanical properties and microstructure of low carbon steel (1020) in the form of bar with dimension of about 200 x 16mm subjected to cold rolling by 5, 10, 15 and 20% respectively. The “percentage effects of cold rolling on mechanical properties of low carbon steel was estimated by using tensile, charpy and vicker hardness, tests likewise metallographic examination in determining the yield strength, ductility, impact strength and hardness”. Also the microstructure specimens were analyzed. The result of the study shows that “the yield strength, impact strength and hardness property of the steel” decrease as its heat treatment temperature and time increases. The yield strength result shows an initial decrease up to 30 minutes and slightly increases between 30 and 100 minutes of the heat treatment time before finally decreases uniformly between 60minutes and 360mins. The decrease in impact strength and hardness were more pronounced with increasing heat treatment temperature from 500<sup>0</sup>c to 600<sup>0</sup>c. On the other hand, the ductility increases as the heat treatment temperature and time increase with slight increases between 240 and 360 minutes.

**Keywords:** Low carbon steel, mechanical properties, microstructure, heat treatment temperature.

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## 1. INTRODUCTION

### 1.1 BACKGROUND OF THE STUDY

Low carbon steel is an economical and amiable materials used in engineering structure. The widely used of low carbon steel is increasingly becoming fundamental need in our modern day mechanics and material formation. Most metal-forming processes and operations usually have two significant direct consequences on materials. Changes are usually observed to exist in mechanical materials formation processes especially when the shape of materials is considered at their macro and micro scale bases. “On a 'macroscopic scale', the desired shaped change is obtained, and on a 'Microscopic scale', the microstructure of the material is changed”. In most cases, every observed changes in materials' micro-structure is usually related to the chemical and physical properties of metal used; which heavily dependents on external and internal parameters such as temperature, strain, strain rate, deformation mode, lubricants, quality of metal, expertize and many other factors as buttressed below. For instance, “ancient blacksmiths in time past, were mostly concerned with materials' macroscopic shape changes, but modern day metal industries require plastic deformations and thermo-mechanical processes that lead to a product with optimal properties, not only for dimensional precision and appearance but also with respect to mechanical and physical properties”.

Several other instances abound in metal formation processes and engineering. However, “Cold working operations such as cold rolling, cold drawing among others are used to increase the strength of materials by working hardening or strain-hardening”. This is the backdrop upon which this current paper is premised.

## 2. METHODS AND MATERIALS

### 2.1 EXPERIMENTAL METHOD - PROCEDURE

In the course of carrying out this study, required materials sourced and used were mostly “commercially available low carbon steel” 16mm thickness rod with the chemical composition in wt% as tabulated in Table 1 below. This was obtained from Owode market, Lagos.

The steel rod with an initial thickness of 16mm was cut into specific dimensions (150mm long). The steel samples were cold rolled using the laboratory cold rolling machine to the thickness of 12.3mm, 11.2mm, 9.6mm, 8mm and 6.4mm respectively. These deformations represents 5%, 10, 15%, 20% and 25% degree of cold deformation of the low carbon steel rod. A total of 85 samples of the material were prepared for the experiment. 35 out of these cold rolled samples were annealed in muffled furnace at temperature of 500<sup>0</sup>c with varying soaking times (i.e. 5mins, 15mins, 30mins, 60mins, 120mins, 240mins and 360mins respectively).

Similarly, another set of 35 cold-rolled samples were also annealed at 600<sup>0</sup>C for 5 mins, 15mins, 30mins, 60mins, 120mins, 240mins and 360mins.

The samples were withdrawn from the furnace at varying time intervals corresponding to the different holding time for further tests.

One sample which was neither cold-rolled nor annealed was reserved as a control sample while five (5) other samples representing 5%, 10%, 15%, 20% and 25% reductions, but not heated were also set aside for comparison.

### 2.2 HARDNESS TEST

The cold-rolled and annealed samples underwent the hardness at room temperature using the Wolpert Tester 930 Universal Hardness Tester (Serial No: 930-163) scale HVS with Test code ASTM E384-Standard-Test-Method for Knoop and Vicker Hardness of materials. The material hardness test was carried out by ensuring that every specimen used in the test was filed. The process helped in producing flat surface at the pin shank or nailed shank. Moreover, the created flat surface was polished to secure required smooth surface through the use of energy paper in the test process. Thereafter, the obtained hardness results was plotted in graphs in Figures 3 and 4 below.

### 2.3 TENSILE TEST

Test for is commonly known as tensile test. This was carried out or done through the use Montansotensometer. Each specimen used in the tensile test was mounted on Montansotensometer or tensometer one by one. Thereafter, they were subjected to tension test. The test outcome or results obtained were; yield stress (MPa), tensile strength (MPa), Tensile strain (mm/min and ductility are recorded and plotted in graphs in Fig 1 and 2 below.

### 2.4 TEST IMPACT

Test impact otherwise referred to as impact test of the material was achieved through the following process or procedure. Each specimen of the study was made to have a V-notch cut through the use of “Hounsfield notching machine”. The process adopted ensured that the notch screw used was set at an exact depth of 2mm in such a way that the cutter need just a touch on the test piece. The process also ensured that a pendulum was positioned to break every test piece, the experimented material on a “Hounsfield balanced impact machine and the energy absorbed in fracturing is measured”. The test process was performed or conducted on “three different samples” in such a way that each degree of cold-rolled deformation, an average of the measurement was recorded or taken. The results are plotted in Fig. 5 and 6 below.

### 2.5 ANALYSIS OF MATERIAL METALLOGRAPHY

The metallographic analysis of materials produced was achieved through random selection of samples from rolled out materials or products extracted from central parts or taken from its central parts “in a perpendicular section, parallel with

the rolling direction”. Comparatively, microstructures of both the control sample (i.e. non-cold rolled sample), cold-rolled samples and cold-rolled and annealed samples were examined. The sample preparation undergone all the stages of metallography i.e. sectioning, mounting (where necessary), grinding, polishing, etching and micro- examination. The samples were grounded in order to create flat surfaces. The flat surfaces were equally polished severally or in a continued manner until they become mirror-like in order to eliminate or get rid of possible marks created on the material during the grinding process.

In order to reveal the microstructure, the samples were "etched" in 4% Nital (4% Nitric acid in alcohol solution) for 10 seconds. The etching reagent dissolves the armorphous layer of the metal. After polishing and etching, the samples were examined using the optical (metallurgical) microscope.

The necessary precautions needed or required to achieve desired result of the metallographic process of the experiment was taken to guide against overheating selected samples especially when undergoing the grinding process which could have altered the microstructures of the samples. Moreover, “absolute cleanliness was also ensured at every stage and light pressure was applied at all time during grinding and polishing”.



Fig 1: Lathe Machine



Fig 2: Specimen worked on



Fig 3: Specimen in Furnace before cold rolling



Fig 4: Specimen in Furnace during cold rolling



Fig 5: Finished specimen

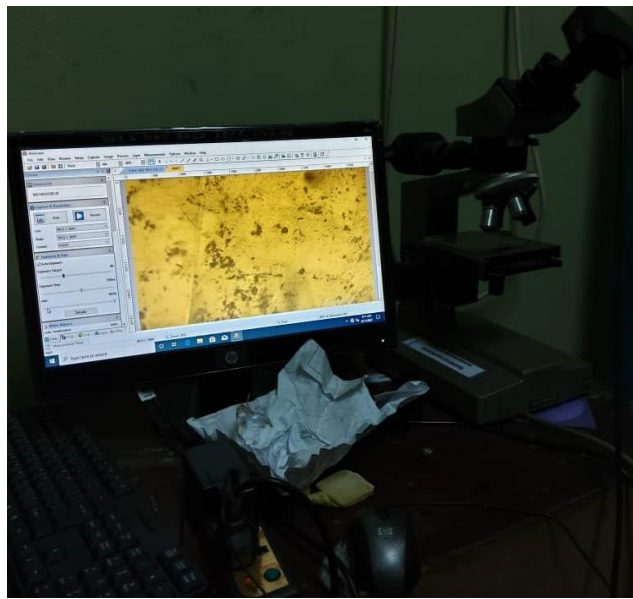


Fig 6: Microscope to determine the micro-Structure of the specimen

### 3. RESULTS AND DISCUSSION

#### 3.1 CHEMICAL COMPOSITION

Table 1: Showing the chemical composition of 1020 Low carbon steel material (wt%)

Element	C	Si	Mn	P	S	Fe	Cr	Ni
%	0.20	0.32	0.51	0.07	0.06	98.04	0.99	0.13

Table 1a: showing the dimension result of cold rolled at % of deformation

Percentage	Initial length	Final length
5%	200mm	210mm
10%	200mm	215mm
15%	200mm	231mm
20%	200mm	263mm
25%	200mm	350mm
Control	200mm	_____

Table 1b: Showing the diameter result of cold rolled at % of deformation

	Initial gauge	Final gauge
Control	12mm	_____
5%	12mm	11.4mm
10%	12mm	10.8mm
15%	12mm	10.2mm
20%	12mm	9.6mm
25%	12mm	9.0mm

Table 1c: Showing hardness result of cold rolled at % of deformation

	1	2	3	HRC
5%	198.8	203.7	191.9	11.9
10%	218.4	248.0	232.3	15.2
15%	233.3	248.2	249.6	18.6
20%	242.0	238.2	223.7	16.4
25%	262.5	241.1	250.0	24.4
Control	167.2	181.7	187.7	8.4



3.2 TENSILE TEST

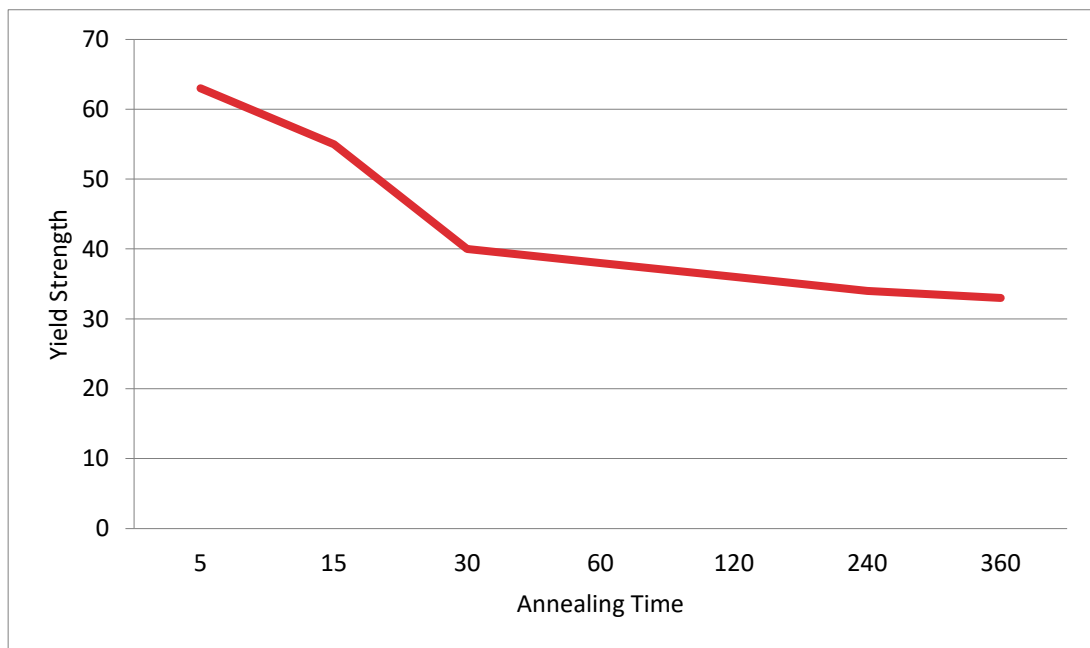


Fig. 1: Effect of soaking time on the yield strength of 10% deformed and annealed at 600<sup>o</sup>c

Figure 1 shows the effect of soaking time on the yield strength of 10% cold-rolled of the steel sample subjected to an annealing temperature of 600°C. It shows an initial decrease of yield strength up to 30 minutes annealing time then suddenly increase between 30 and 60 minutes and finally decreases uniformly between 60 and 360 minutes of annealing time.

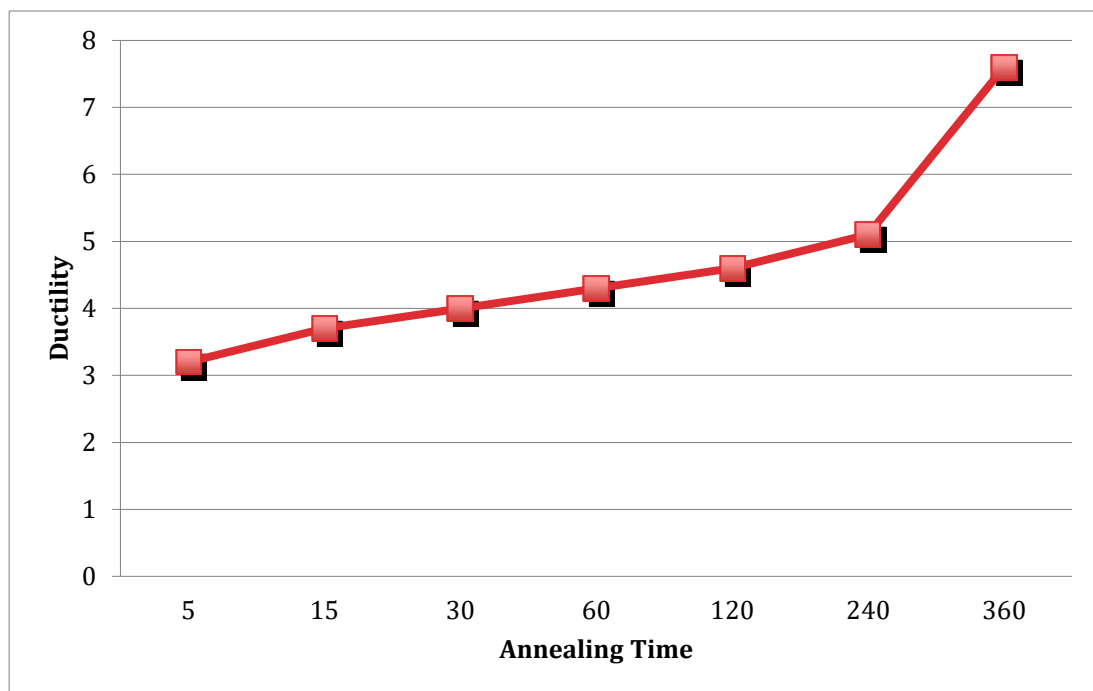


Fig. 2: Effect if soaking time on ductility of 10% deformed and annealed at 600 C

Fig. 2 shows the effect of soaking or annealing time on the ductility of 10% cold-rolled steel sample subjected to an annealing temperature of 600°C. It shows a steady increasing trend of ductility with a sharp increase in ductility between 240 and 360 minutes of annealing times.

3.3 HARDNESS TEST

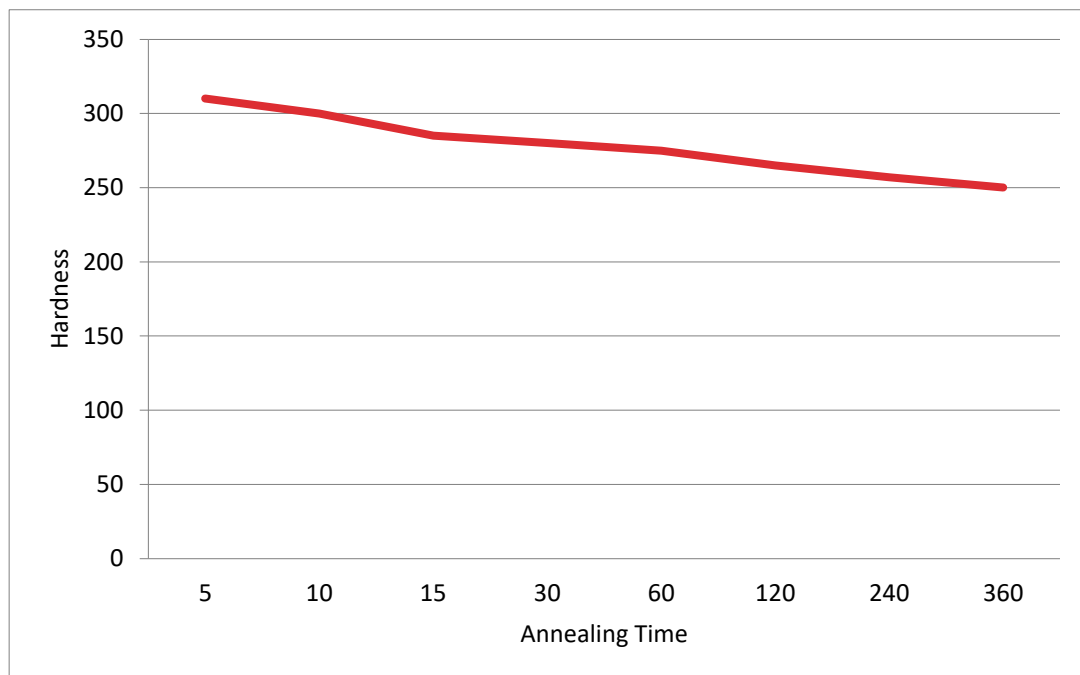


Fig. 3: Effect of soaking time on hardness of the steel deformed at 15% and annealed at 500°C

Fig. 3 shows the effect of annealing time on the hardness of 15% cold-rolled of the steel sample subjected to an annealing temperature of 500°C. It shows a uniform decrease in hardness of the steel as the annealing time increases. This shows that the recrystallization and grain growth taking place in the steel causes the reduction in the hardness of the steel.

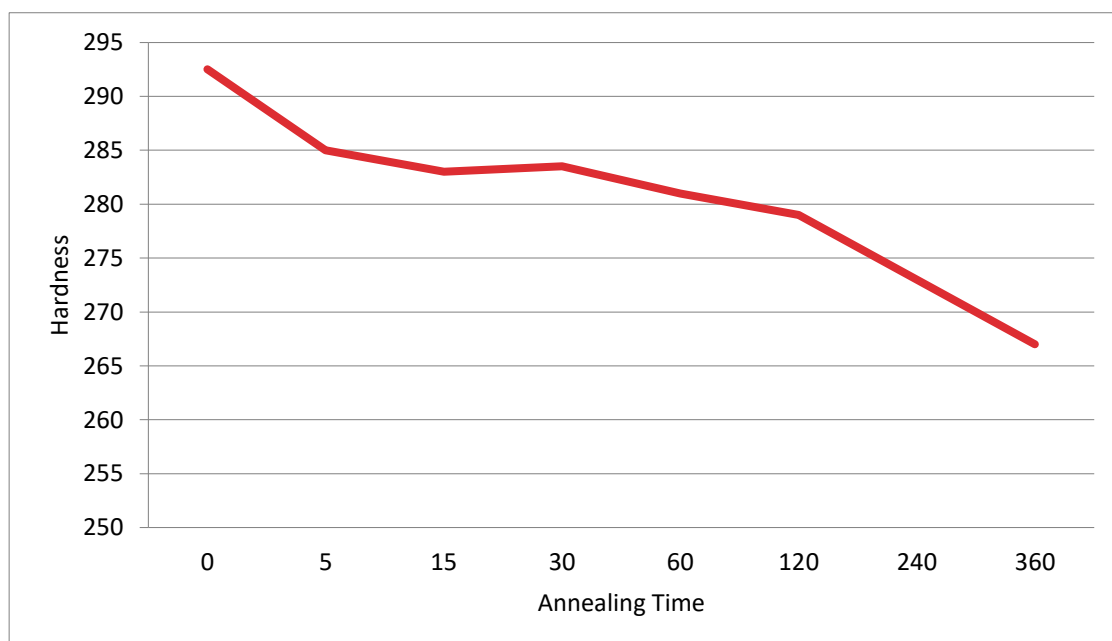
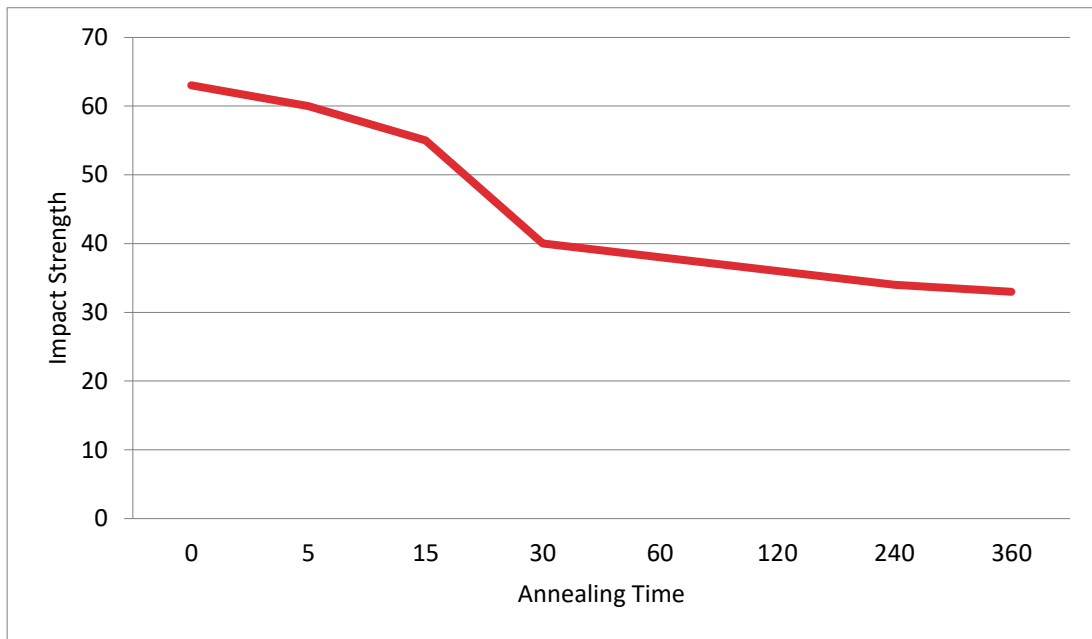


Fig. 4: Effect of soaking time on hardness of the steel deformed at 15% and annealed at 600°C

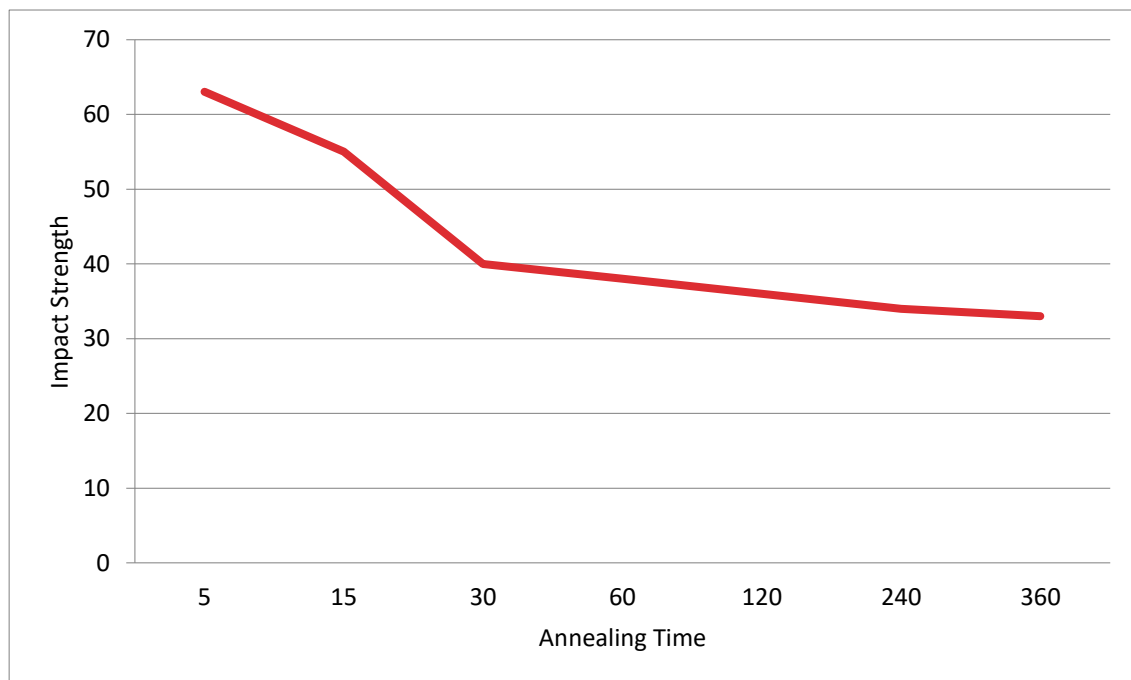
Fig. 4 shows the effect of soaking time on the hardness property of 15% cold-rolled steel subjected to an annealing temperature of 600°C. It shows a decreasing trend of hardness with increasing soaking time. The decrease in hardness is more pronounced here than figure 4.3. This because of the increase in the annealing temperature from 500°C to 600°C.

3.4 IMPACT TEST



**Fig. 5: Effect of soaking time on the impact strength of the deformed at 5% at 500C**

Fig 4.5 shows the effect of soaking time on the impact strength of the 5% cold-rolled steel sample subjected to an annealing temperature of 500°C. It also shows a steady decreasing trend of impact strength up to 30 minutes of annealing time and a sharp decrease in impact strength between 30 and 60 minutes of annealing time and finally decreases uniformly from 60 to 360 minutes of annealing time.



**Fig. 6: Effect of soaking time on the impact strength of the deformed at 5% at 600°C**

Fig. 6 shows the effect of soaking time on the impact strength of 5% cold-rolled steel sample subjected to an annealing temperature of 600°C. It shows a similar decreasing trend of impact strength with figure 4.5. The decrease in the impact strength is more pronounced here because of the increase in the annealing temperature from 500°C to 600°C.

Table 4.2: Showing Vicker’s hardness values for steel annealed at 500°C

%CW	As Received	Steel-500°C 15mins	Steel-500°C 120mins
0	195±15	–	–
5	249±7	220±19	218±5
10	263±9	261±11	213±4
15	271±7	262±6	210±9
20	277±7	269±2	203±4
25	287±9	271±12	200±7

Table 4.3: Showing Vicker’s hardness values for steel annealed at 600°C

%CW	As Received	Steel-600°C 15mins	Steel-600°C 120mins
0	195±15	–	–
5	249±7	218±3	200±11
10	263±9	243±6	206±8
15	271±7	249±9	202±3
20	277±7	250±7	200±4
25	287±9	251±8	196±3

Table 4.4: Stages of annealing

Temp. (degrees C)	Degree of cold work (%)	Annealing Time (minutes)							
		0	5	15	30	60	120	240	360
Room temp (as received)	0	NA							
	5	NA							
	10	NA							
	15	NA							
500	20		–	R	R	R	R	RC	GG
	25		–	R	R/RC	RC	GG	GG	GG
	25		RC	RC	GG	GG	GG	GC	GC
600	5		–	R/RC	RC	GG	GG	GG	GC
	15		RC	RC/GG	GG	GG	GG	GG	GG
	25		RC	RC/GG	GG	GG	GG	GG	GG

3.5 METALLOGRAPHIC EXAMINATION RESULTS

Figure 7 shows the microstructure of the As-received steel sample. The microstructure reveals a ferrite (white constituent) and pearlite (dark constituent) in the As-received condition.

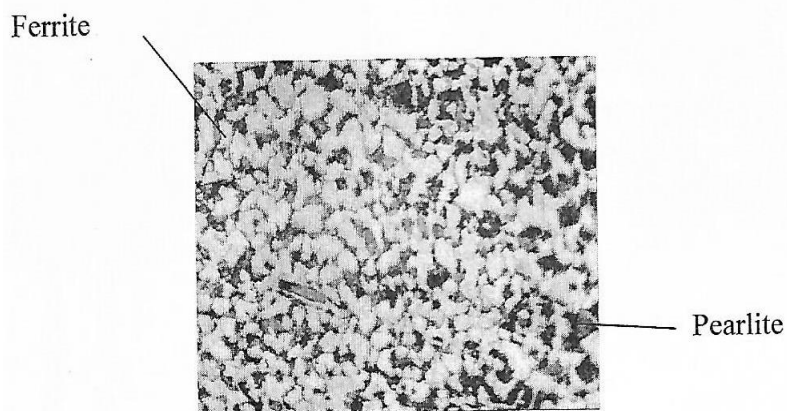


Fig. 4.7: control sample x 100

Figures 8 - 4.12 shows the microstructures of the deformed state of the steel sample in the un-heat treated condition at various percentage reductions i.e. 5%, 10%, 15%, 20% and 25% respectively. These micrographs show an increasing grain elongation in the direction of rolling as the percentage reduction increases.



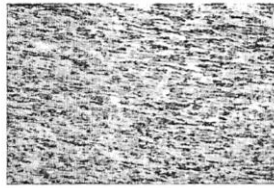


Fig. 4.12: 60% Reduction unheat treated x 100

Fig. 4.13 – 4.16 shows that the microstructure of the steel samples deformed at 20% and annealed at 500°C at various holding times.

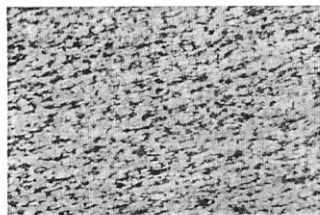


Fig. 4.13: 20% Reduction x 15min x 500°C(x100)

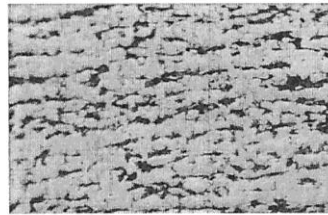


Fig. 4.14: 20% Reduction x 30 min x 500°C(x100)

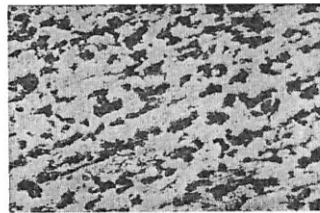


Fig. 4.15: 20% Reduction x 240mins x 500°C (x100)

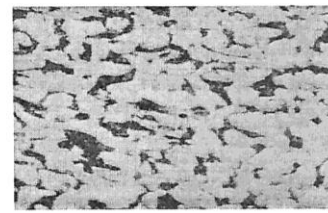


Fig. 4.16: 20% Reduction x 360mins x 500°C (x100)

Fig. 4.17 – 4.20 shows that the microstructure of the steel samples deformed at 40% and annealed at 500°C at various holding times.

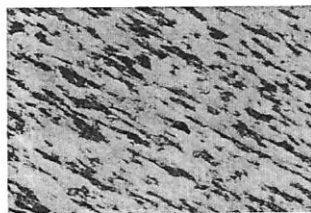


Fig. 4.17: 40% Reduction x 15mins x 500°C(x100)

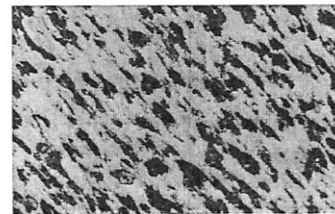


Fig. 4.18: 40% Reduction x 60mins x 500°C (x100)

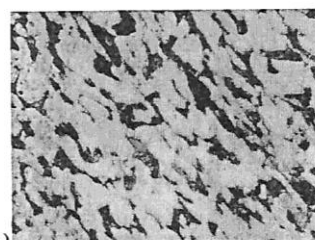


Fig. 4.19: 40% Reduction x 120mins x 500°C (x100)

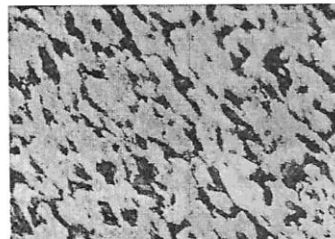


Fig. 4.20: 40% Reduction x 360mins x500°C(x100)

Fig. 4.21 – 4.24 shows that the microstructure of the steel samples deformed at 60% and annealed at 500°C at various holding times.

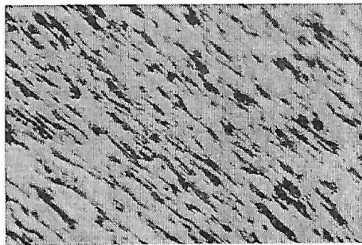


Fig. 4. 21: 60% Reduction x 15mins x500°C ( x 100)

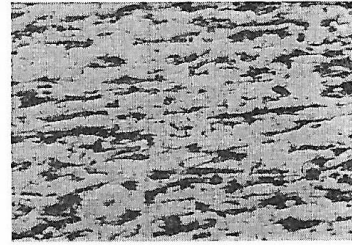


Fig. 4.22: 60% Reduction x 30mins x500°C ( x 100)

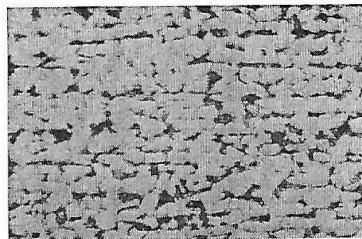


Fig. 4.23: 60% Reduction x 120mins x500°C (x100)

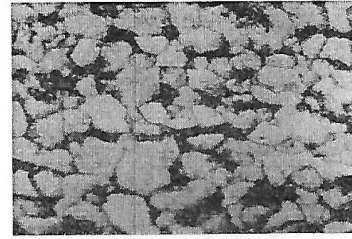


Fig. 4. 24: 60% Reduction x 360mins x 500°C(x 100)

Fig. 4.25 – 4.28 shows that the microstructure of the steel samples deformed at 20% and annealed at 600°C at various holding times.

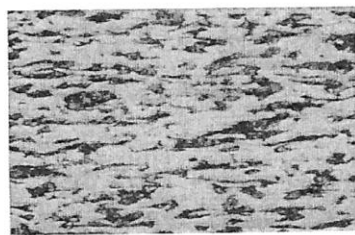


Fig. 4.25: 20% Reduction x 15mins x 600°C ( x 100)

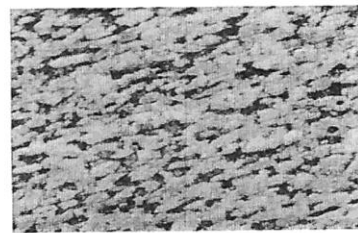


Fig. 4.26: 20% Reduction x 60mins x 600°C(x 100)

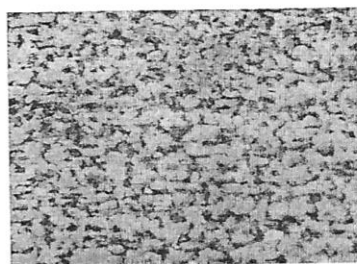


Fig. 4.27: 20% Reduction x 240mins x600°C( x 100)

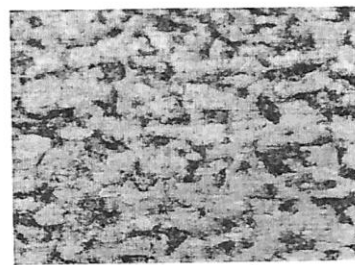


Fig. 4.28: 20% Reduction x 360mins x600°C( x 100)



Fig. 4.29 – 4.32 shows that the microstructure of the steel samples deformed at 40% and annealed at 600°C at various holding times.

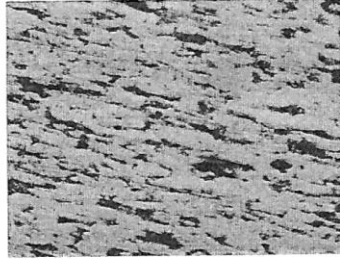


Fig 4.29: 40% Reduction x 15mins x600°C (x 100)

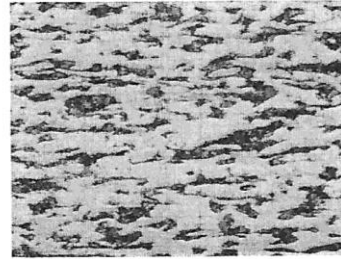


Fig 4.30: 40% Reduction x 60mins x600°C (x 100)

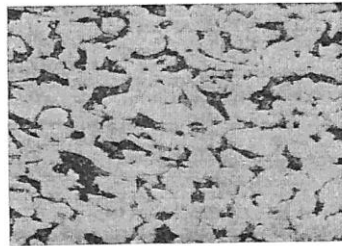


Fig. 4.31: 40% Reduction x 240mins x 600°C (x 100)

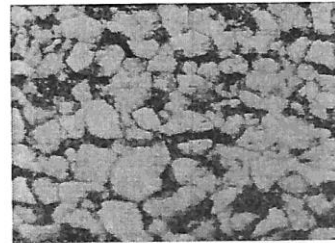


Fig. 4.32: 40% Reduction x 360mins x600°C (100x)

Fig. 4.33 – 4.36 shows that the microstructure of the steel samples deformed at 60% and annealed at 600°C at various holding times.

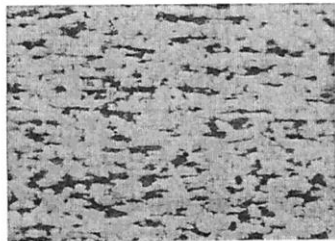


Fig 33: 60% Reduction x 15mins x600°C (x 100)

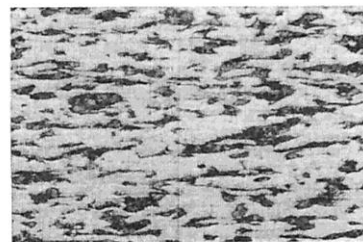


Fig 34: 60% Reduction x 30mins x600°C (x 100)

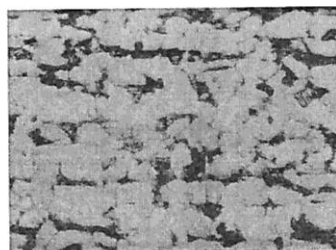


Fig 35: 60% Red x 240mins x600°C (x 100)

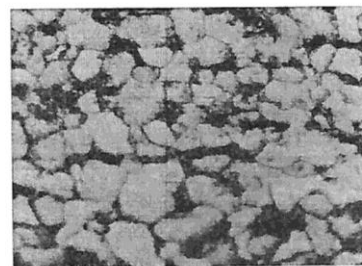


Fig 36: 60% Reduction x 360mins x600°C (x 100)

#### 4. DISCUSSION OF RESULTS

From the foregoing, it can therefore be inferred from the results generated through its various tables presented and graphical plot that; “the yield strength and the tensile strength reduces with increase in soaking time”. It implies that “increase in soaking time brings about relief of internal stresses (residual stresses) that are capable of causing a lowering in the strength of the steel material. Obviously, it could be observed that at every soaking time of 5 minutes to 30 minutes, the yield strength reduces slowly, and relatively increases slightly between 30 and 60 minutes then reduces rapidly between 120 and 240 minutes of annealing time and finally reduces uniformly between 240 and 360 minutes annealing time. This is as a result of recovery, recrystallization and grain growth processes taking place in the steel.

Soaking time effects on the material ductility of the 30% cold-rolled steel sample is presented in Figure 2. It is noted that, there is a uniform increase in ductility of the steel up to 240 minutes and a pronounced increase ductility between 240 and 360 minutes annealing time. The observed rapid increase in ductility of the steel is as a result of recrystallization and grain growth taking simultaneously in the steel. Similarly, the annealing time effect on the hardness of the steel deformed at 40% and annealed at 500°C is presented in Figure 4.3. It is observed that there is “a slight reduction in the hardness of the steel within **“the first 15 minutes of the soaking time”**”. The observed changes observed could have resulted from the recovery process that occurred in the process often characterized by insignificant or relatively very small reduction of the steel hardness. There is a uniform reduction in the hardness of the steel between 15 and 360 minutes of soaking time. This could be as a result recrystallization and grain growth taking place in the steel sample.

Figure 4 shows a similar reduction in the hardness of the steel as the annealing time increases. Here, the reduction in the hardness of the steel is more pronounced than in figure 4.3 due to increase in the annealing temperature from 500°C to 600°C.

Figure 5 shows that the impact strength of the steel reduces slightly from 5 minutes to 30 minutes, decreases sharply between 30 and 60 minutes annealing time and finally reduces uniformly between 60 and 360 minutes annealing time. The slow changes within the time frame reported could have resulted from the stress-relief and formation of several new strain-free grains, as well as the probable growth of the observed new strain-free grains in the steel sample.

Figure 6 shows a reduction in the impact strength of the steel similar to figure 5. Here, the reduction is more pronounced due to the increase in the annealing temperature from 500°C to 600°C.

Table 2 shows the Vicker's hardness values of the steel sample in the as-received condition and when it is annealed at 500°C and soaked at 15 minutes and 120 minutes respectively. It is observed from the Table that as the annealing time increases, there is a corresponding reduction in the hardness values.

Table 3 shows the Vicker's hardness values of the steel sample in the as received condition and when it is annealed at 600°C and soaked at 15 and 120 minutes of annealing time. It is observed from the table that there is a slight increase in the rate of reduction in the hardness values compared with Table 2. The slight increase in the rate of reduction in hardness is as a result of increase in annealing temperature from 500°C to 600°C.

Table 4 shows the various stages of annealing of the steel sample. It is observed from this table: “as the annealing time/temperature and deformation degree increases, the various stages of annealing processes (i.e. recovery, recrystallization and grain growth) occurs”.

#### Interpretation of Micrographs

Figure 7 shows the micrograph of the as-received steel structure. The micrograph reveals a ferrite (white constituent) and pearlite (dark constituent), the micrograph also shows uniform distribution grains in an orderly manner.

Figures 4.8 – 4.12 shows the microstructures of the deformed the steel sample of the various degree of percentages of reduction i.e. 20%, 30%, 40%, 50%, and 60% respectively. These micrographs shows an increasing grain elongation as the degree percentage reduction increases.

Figures 4.13 – 4.36 shows the microstructures of the deformed (cold rolled) steel structure annealed at 500°C and 600°C, hold at various holding times. It is observed that as the annealing temperature and times increases, there was a corresponding coarsening of the grain (i.e. the grain become more bigger) due to recrystallization and grain growth taking place.

## 5. CONCLUSION

### 5.1 CONCLUSION

The effect of annealing temperature and time on mechanical properties and microstructure of a cold-rolled low carbon steel were investigated. From the studies, it can be concluded that “the yield strength, impact strength and hardness” of the cold-rolled steel especially 10%, 15% and 25% reduction decreases as the annealing temperature and time increases as shown in Fig. 4.1 above. The yield strength shows an initial decrease up to 30 minutes of annealing time and slightly increases between 30 and 60 minutes annealing and finally decreases uniformly between 60 minutes and 360 minutes. These changes are also shown in microstructure as seen in Fig. 4.13 - 4.36, where the grains get bigger and bigger (grain coarseness) as annealing temperature increases. Ductility, on the other hand, increases with a sharp increase between 240 and 360 minutes of annealing time. It was concluded that these changes in mechanical properties of the steel were as a result of recovery, recrystallization and grain growth processes that takes place in the steel as the annealing temperature and time increases.

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