Effects of hot forging and subsequent carburisation on low-carbon steels.

Sanchit Srivastava¹* and S D Lembhe¹

¹Department of Production Engineering, Bharti Vidyapeeth Deemed University, College of Engineering, Pune, Maharashtra, India. 411030.

*sanchit.8794@gmail.com

Abstract. The research intends to work on the increasing hardness of low carbon steels by a congregation of box carburisation with different combination of low carbon steels that have been initially reduced to a certain volume vis-a-vis hot forging. There has not been ample work that look at a combination of hot forging and carburisation and hence this paper is a comparative study of the increase in surface hardness of three metal surfaces at three different steps- when low carbon steels are just carburised; only forged and when the materials go both carburisation and forging. The research is conducted on three different metals (MS, EN8, SAE8620) and Vicker's Hardness Tester was solicited for hardness testing and conclusions in terms of hardness and case depth rallied with plunge in the volume of the metals.

1. Introduction
The process of carburisation yields a gradual change in carbon content at the surface level, which consequently brings an alteration of mechanical and wear properties. As research by Supriyono[1] mentions it is a process of saturating carbon with the surface layer of steel. The process of heat treatment and carburisation brings a significant change in mechanical properties of low carbon steels. The process of carburising can be defined as an addition of carbon to the surface with low-carbon steels at temperatures usually between 850 to 950°C (1560 and 1740°F), at which austenite, with its high solubility for carbon, is the stable crystal structure. Craig[2] defines carburisation in his work as a ‘diffusion-controlled process’ to produce a highly wear-resistant case which maintains the ductility and toughness of a core with low carbon. A surface hardens when the high-carbon surface layer is suppressed or dampened to form martensite so that a high-carbon martensitic case with reasonable wear and fatigue resistance could be superimposed on a sturdy, low-carbon steel core. Carburising steels for case hardening used today, usually have base-carbon contents of approximately 0.2%[3]. The surface carbon is usually limited to 0.9% because unreasonably high carbon content can result in retained austenite and brittle martensite. Carburising is one of the standard and crucial surface hardening processes. It is used in automobile components such as valve, rocker shafts and axles which is mentioned in the studies of Oyetunji and Anderson[4] and Aramide, et al,[5].

Forging can be defined as “a metal shaping process in which a malleable metal part, known as a billet or workpiece, is worked to a predetermined shape by one or more processes such as hammering, upsetting, pressing and so forth where the workpiece is heated up to about 75% of its melting temperature” The hot forging process is performed at a higher temperature than its recrystallisation point thus avoiding strain hardening. GP Chaudhari mentions grain refinement during this process has a positive effect on microstructure and properties of steel. Chaudhari
found that grain was clearly refined after multidirectional-forging of steel, which induced fine austenite grains because of continuous dynamic recrystallisation and dynamic recovery. The formation of fine grains is essential for enhancing tensile strength and hardness.[6] In order to address the urgent need to enhance the mechanical properties and wear resistance of low carbon and mild steel, this paper works on the aspect of the wear resistance and mechanical properties of mild steel vis-a-vis a low-cost carburisation practice. Herein, the paper determines appropriate relationship between affects of forging and subsequent carburisation on hardness and case depth due to grain refinement. The same practice works on copious kinds of material in the automobile industry, like gears, springs, high wires, and many more.

2. **Experimental Details:** The experiment was carried in multiple steps and hardness of low carbon steels was tested on each step.

2.1. **Materials and Methods**

Low carbon steels of three different chemical composition were purchased in the required dimension from the local market and the test specimens were prepared from it. The chemical composition of low carbon steels is mentioned in Table 1.

| Sr. No. | Material | C   | Si  | Mn  | Cr  | W   | V   | Co  | Mo  |
|---------|----------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1       | MS       | 0.1 | 0.2 | 0.50| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2       | EN8      | 0.35| 0.10| 0.60| -   | -   | -   | -   | -   |
| 3       | SAE 8620 | 0.20| 0.70| 0.40| 0.0 | 0.0 | 0.04| 0.15| 0.40|

The following compounds were used for creating a carbonaceous environment -70% Coal Powder, 5% Graphite Powder, 15% BaCO3 Powder, and 10% CaCO3. Before using this environment for carburisation, this mixture was tested for explosion and blasting at 850°C.

2.1.1. **Specimen Preparation**

Specimen preparation was carried out on raw specimen for initial hardness testing. A metal rod was bought and cut into smaller pieces of optimum length for experiment. The process of metal cutting is represented through Figure 1(a,b,c)
2.1.2. Description

The forging was carried out in furnace of Bharati Vidyapeeth College Of Engineering. The aim of performing forging is to bring reduction in the different specimens at different levels. 6 specimens were heated in furnace for 20 minutes at 1250°C. Then forging was done in two phases. In first and second part of forging one specimen each of the three different materials was used. After the process of forging there was a slight reduction in the volume of the six specimens. The reduction in the samples of Mild Steel, EN8 and SAE8620 are represented as A1, B1, C1 in the table 2. The second phase of reduction is termed as A2, B2, C2 respectively. As one can see there is a slight reduction of volume in the first step of forging and the degree of reduction increases in the second step of forging. The data of reduction is represented in percentage.

Table 2. Reduction in the volume of samples in percentage

| Sr. No. | Material   | Reduction in volume after first forging. (A1,B1,C1) in % | Reduction in volume after second forging (A2,B2,C2) in % |
|---------|------------|---------------------------------------------------------|--------------------------------------------------------|
| 1       | Mild Steel | A1=2.06                                                | A2=4.1                                                |
| 2       | EN8        | B1=2                                                   | B2=13.6                                               |
| 3       | SAE8620    | C1=8.33                                               | C2=15.8                                               |

2.1.3. Surface Preparation

After the forging process, surface preparation was done in all the forged specimen using sand paper with the following grades 80, 150, 200, 400, 600, 800, 1000, 1200 & green paper. Following the surface preparation, hardness testing was done on the forged components. In present experimental work Vickers hardness tester was measured on carburised and tempered mild steel samples which are carburised under different temperature range of 950°C. For each of the sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case. Before the results, the paper will now brief with the Vicker’s hardness testing method.

In the present research micro-hardness was measured using Vickers hardness tester. The Vickers
hardness test method, also referred to as a micro-hardness test method, is mostly used for small parts, thin sections, or case depth work. The Vickers method is based on an optical measurement system. The Micro-hardness test procedure, ASTM E-384, specifies a range of light loads using a diamond indenter to make an indentation which is measured and converted to a hardness value. As Muhammad mentions [7], the diagonals of the indentation left in the surface of the material after the load is removed is measured through a microscope and its surface is calculated. It can be used on a wide type of materials as long as test samples are carefully prepared. A square base pyramid shaped diamond is used for testing in the Vickers scale. Typically loads are very light, ranging from a few grams to one or several kilograms, although "Macro" Vickers loads can range up to 30 kg or more. The Micro-hardness methods are used to test on metals, ceramics, and composites - almost 55 any type of material. Since the test indentation is very small in a Vickers test, it is useful for a variety of applications: testing very thin materials like foils or measuring the surface of a part, small parts or small areas, measuring individual microstructures, or measuring the depth of case hardening by sectioning a part and making a series of indentations to describe a profile of the change in hardness. The Vickers method is more commonly used. Sample preparation is usually necessary with a micro-hardness test in order to provide a small enough specimen that can fit into the tester. Additionally, the sample preparation will need to make the specimen's surface smooth to permit a regular indentation shape and good measurement, and to ensure the sample can be held perpendicular to the indenter. Usually the prepared samples are mounted in a plastic medium to facilitate the preparation and testing. The indentations should be as large as possible to maximise the measurement resolution. (Error is magnified as indentation sizes decrease) The test procedure subject to problems of operator influence on the test results. As already mentioned earlier, the hardness testing has been conducted thrice in this experiment. The six specimens were tested for their hardness and the following results were observed as shown in Table 3.

| Serial Number | Material | Original Hardness (S1,S2,S3) | Hardness after first Forging (A1, B1, C1) | Hardness after second Forging (A2, B2, C2) |
|---------------|----------|------------------------------|------------------------------------------|------------------------------------------|
| 1             | MS       | S1=137                       | A1=155                                   | A2=163                                   |
| 2             | EN8      | S2=193                       | B1=307                                   | B2=426                                   |
| 1             | MS       | S3=142                       | C1=385                                   | C2=250                                   |

2.2 Carburisation of mild steel samples:

The different test specimen samples made up of mild steel for mechanical and wear properties testing were subjected to pack carburisation treatments. Huang [8] mentions different kinds of carburising technology including Pack carburising, Gaseous carburising etc in his study. In this process the low carbon steel samples were placed on the thick bed of carburiser kept in a stainless steel container and fully covered from all sides, the top of the container was covered with a steel plate. The container was then introduced into the muffle furnace and then maintained at the required carburisation temperatures of 950°C for 6 hours with the soak time of
20 mins, by this way the low carbon steel samples got carburised and then they were quenched in water which is the way hardness was effected immediately after carburisation by formation of martensite state. With this carburisation process the mechanical and wear properties of mild steel samples increased considerably. The carburised steel samples were then tempered for a particular temperature and time and then it processed for the hardness test again. The images below mentioned as Figure 2(a,b) show the process described above.

Figure 2 (a,b). 2(a) shows box carburisation and 2(b) shows furnace test.

After the carburisation process, the steel is often harder than needed and is too brittle for most practical uses. Also, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, we should temper the steel after it is hardened. So in this tempering process the carburised steel samples were heated at the temperature of 600°C for duration of 2 hours and then cooling it usually in the still air. The carburised and tempered mild steel specimens are then subjected to hardness test. The image of carburised and tempered low carbon steel samples is shown in Figure 3. The samples received from carburising and tempering was subjected to surface preparation using sand paper of grades 80, 100, 200, 400, 600, 800, 1000, 1200, green paper for hardness testing and case depth.

Figure 3. Carburised and tempered specimen
measurement. Then the specimens were proceeded to lapping process. Then each specimen was dipped in a solution of alcohol (90%) and nitric acid (10%).

2.3 Forging and Carburisation

Now, one of the main aims of the paper is to strike an optimum combined effect of forging and carburisation in order to yield a significant increment in hardness. Therefore, the forged specimens both A1, B1, C1 and A2, B2, C2, are taken and carburised respectively to analyse the maximum results produced. The test for hardness was carried out on Micro-Hardness Tester and 1000Kg load was applied for 20 seconds by the indenter and the hardness was measured after measuring the dimensions of the rhombus. The results produced were as follows: Table 4.0 presents an overview of the entire experiment and portrays a comparative analysis of the results produced when the specimens undergo various experiments of forging, carburising and an optimum combination of both. Table 4 displays a chart mentioning various specimens and the VPN hardness number. In table 5, CS1, CS2, CS3 represent carburisation of uncompressed sample of MS, EN8 and SAE8620 respectively. CA1, CB1, CC1 represent carburisation of A1, B1, C1 samples respectively. CA2, CB2, CC2, represent forged carburised specimen.

Table 4: Representation of VPN at different levels of different materials.

| Sr. No. | Material | VPN Hardness Number |
|---------|----------|---------------------|
|         | Original Specimen | Carburised original specimen | Forged specimen First Reduction | Carburised forged specimen First Reduction | Forged specimen Second Reduction | Carburised forged specimen Second Reduction |
| 1       | MS       | S1=137             | CS1=140                  | A1=155                         | CA1=163                      | A2=159                         | CA2=168                      |
| 2       | EN8      | S2=193             | CS2=256                  | B1=307                         | CB1=426                      | B2=331                         | CB2=436                      |
| 3       | SAE 8620 | S3=142             | CS3=146                  | C1=185                         | CC1=250                      | C2=198                         | CC2=262                      |

As mentioned in Table 4, it can be observed in case of MS, SAE8620, and EN8, the hardness increases after forging. Increase in hardness on forging and subsequent carburisation in all the samples has been noticed. In case of MS, initial surface hardness was 137 and when it was forged and compressed to 2.06%, it got increased by 18 VPN. On further carburisation, there was an increment of 8 VPN when compared to the hardness of compressed sample (A1) of MS. When sample A2 was carburised its initial hardness increased from 159 to 168. This suggests that there exists a margin for carbon penetration for forging. When sample CA2 with surface hardness of 168 after carburisation and 4.1% reduction is compared to CS1 (carburised, original, uncompressed specimen), there is deviation of 38 VPN which owes its additional hardness to forging and carburisation. Similar patterns can be seen with EN8 and SAE 8620.

In case EN8, hardness of uncompressed carburised EN8 sample (CS2) is 256 VPN and it gets boosted to 436 VPN after forging and carburisation. This surplus increment can be accounted to forging till 331; and from 331 to 436 VPN it owes its increment to the combined effect of
forging and carburisation. So, it can be said that a combined process of forging and carburisation led to an increment of 66.4% in comparison to uncompressed carburised EN8 sample. Such deductions can be made for remaining samples of metals too.

Figure 4. Graphical Representation of Hardness in VPN
3. **Microstructure and case depth analysis**

Microstructures of carburised specimen to measure the case depth of all samples. In the following images [figure 5,6,7], on moving, left to right a dark green portion in contrast to the core of the sample can be seen. This portion shows the carbon penetration and its dimensions were calculated to measure the case depth.

**Figure 5 (a,b).** Represent microstructures of MS : CA1, CA2

**Figure 6 (a,b).** Represent microstructures of EN8 CB1,CB2

**Figure 7(a,b).** Represent microstructures of SAE8620: CC1,CC2
3.1. Case Depth Results.

Case depth was also measured for all the carburised and forged and forged and carburised specimen. Case Depth determines the shift in the formation of martensite due to the drifting of electrons at the time of quenching. Microstructures were observed under the microscope and case depth was measured Vicker’s microscope. The Table 5 mentions the results of case depth in the three categories of specimen.

Table 5. Case Depth of the three categories of Specimen.

| Sr. No. | Material | Carburized Original Specimen | Carburized forged Specimen after first Reduction | Carburized forged Specimen after second Reduction |
|---------|----------|-----------------------------|------------------------------------------------|-------------------------------------------------|
| 1       | MS       | CS1=0.12                    | CA1=0.22                                      | CA2=0.34                                       |
| 2       | EN8      | CS2=0.2                     | CB1=0.42                                      | CB2=0.56                                       |
| 3       | SAE8620  | CS3=0.2                     | CC1=0.36                                      | CC2=0.52                                       |

Figure 8. Case Depth plotted against Specimen
When we analyse the case depth of samples of MS, EN8, SAE8620, it can be observed that carburised and compressed samples had greater case depth than uncompressed samples. The sample that was compressed to a greater level has more case depth than the sample that was only compressed once. So it can be deducted, with increase in compression levels the case depth also increases and it can be seen in the graph that that plots case depth against specimens.

4. Conclusion

The surface properties of low carbon steels were found to be strongly influenced by the process of forging and subsequent carburisation. With forging, there is an increase in level of penetration into the low carbon steels. With increase in percentage deformation of the material, the level of carbon penetration increases. Case Depth and hardness are directly proportional to the magnitude of deformation before carburisation.

The process of carburisation holds a significant value in today’s day and context. India’s economy depends mostly on agricultural produce. Ploughs, harrows, peddlers, furrow opener, are readily available low carbon and mild steels farm tools that are affordable for every farmer. However, these implements undergo much abrasion and need replacements often due to wear and tear. In order to work on the failures of agro-based industries to introduce resistant low-carbon steel implements, this research intends to engage with this process of carburisation through this paper. In order to address the urgent need to enhance the mechanical properties and wear resistance of low carbon and mild steel, this paper works on the aspect of the wear resistance and mechanical properties of mild steel vis-a-vis a low-cost carburisation practice. This work lays its focus on the agro-based industrial products but does not confine itself to it. The same practice works on copious kinds of material in the automobile industry, like gears, springs, high wires, and many more.

5. References

[1] Supriyono S. The effects of Pack carburizing using charcoal on properties of mild steel. MEDMEs. [Internet]. 2018 [cited 15 June 2020];19(1):38-42. Available from: https://www.semanticscholar.org/paper/THE-EFFECTS-OF-PACK-CARBURIZING-USING-CHARCOAL-ON-Supriyono/bc0021de165fd108320670af8a2e605aa84aded2

[2] Fitzgerald C. Case Hardening in a Home Garage [Internet]. Hemmings.com. 2020 [cited 23 July 2020]. Available from: https://www.hemmings.com/stories/article/case-hardening-in-a-home-garage

[3] Ahmad J. Carburizing of Steel. Int. J. Mater. Sci. Appl. 2015;4(2):11-14.

[4] Oyetunji A, Adeuson S. Effects of Carburizing Process Variables on Mechanical and Chemical Properties of Carburized Mild Steel. J.Basic. Appl. [Internet]. 2012;8(2):319-324. Available from: http://www.lifescienceglobal.com/images/Journal_articles/JBASV8N2A11-Oyetunji.pdf

[5] Rajan T, Sharma C, Sharma A. Heat treatment. 2nd ed. New Delhi: PHI Learning; 2012.

[6] Padap A, Chaudhari G, Pancholi V, Nath S. Warm multiaxial forging of AISI 1016 steel. Mater. Des. 2010;31(8):3816-3824.
[7] Muhammad N. EFFECTS OF CARBURIZATION PROCESS ON THE MECHANICAL PROPERTIES OF CARBURIZED MILD STEEL [Undergraduate]. University Malaysia Pahang; 2013.

[8] Huang Z, Xu S. Research on carburizing technology and developments. 3rd Int., Conference., on Energy, Environment and Materials Science [Internet]. IOP Conference Series: Earth and Environmental Science; 2017 [cited 23 July 2020]. p. 1-4. Available from: https://iopscience.iop.org/article/10.1088/1755-1315/94/1/012068