American Journal of Materials Science and Engineering, 2019, Vol. 7, No. 1, 7-11
Available online at http://pubs.sciepub.com/ajmse/7/1/2
Published by Science and Education Publishing
DOI:10.12691/ajmse-7-1-2

Microstructural and Mechanical Properties of Bassar Forged Steel

Pali KPELOU[1,*], Ayi Djifa HOUNSI[2], Damgou MANI KONGNINE[1], Tiburce Ahouangbe ABOKI[3], Essowè MOUZOU[2], Gnande DJETELI[1], Kossi NAPO[1]

[1]Department of Physics, Laboratoire sur l'Energie Solaire-Université de Lomé, Lomé, TOGO
[2]Department of Physics, Laboratoire de Physique des Matériaux et des Composants à Semi-conducteurs, Université de Lomé, Togo
[3]Palais de la découverte, Universcience, Avenue Franklin Roosevelt, Paris, France
*Corresponding author: palikpelou@gmail.com

Received January 04, 2019; Revised March 13, 2019; Accepted March 27, 2019

Abstract The Bassar iron industry has produced large quantities of steel ingots exceeding local needs and opening up a vast sub regional iron trade network. Bassar blacksmiths of Bitchabe and those of neighboring peoples such as kabiyè have transformed these ingots into finished products to feed this trade network. The present work studied the microstructural and mechanical properties of traditional Bassar Steel (BS) forged by Kabiyè blacksmiths. The forging process of Kabiyè blacksmiths was described. Optical Microscopy (OM), Scanning electron microscopy (SEM), X-ray diffraction (XRD), Vickers microhardness and tensile tests were used to investigate the microstructural and mechanical properties of the forged samples. Optical micrographs indicate a ferritic matrix containing many non-metallic inclusions. Micro-hardness measurement values ranging from 130 to 185 $Hv_{0.3}$ are measured from the heart to the surface of the Bassar Forged Steel (BFS). This field covers the microhardness values of ferritic steel or very low carbon steel. The tensile strength of the studied forged steel is 148 GPa with a low total strain of 14 %. EDS analysis indicate the presence of Phosphorus in a low proportion.

Keywords: *Bassar forged steel, forging, hardness, microstructure*

Cite This Article: Pali KPELOU, Ayi Djifa HOUNSI, Damgou MANI KONGNINE, Tiburce Ahouangbe ABOKI, Essowè MOUZOU, Gnande DJETELI, and Kossi NAPO, "Microstructural and Mechanical Properties of Bassar Forged Steel." *American Journal of Materials Science and Engineering*, vol. 7, no. 1 (2019): 7-11. doi: 10.12691/ajmse-7-1-2.

1. Introduction

The Bassar iron smelting industry may be one of the most important traditional technic in Africa history [1,2]. Some recent studies have given significant comprehension of the nature and properties of smelted product [3,4]. The Bassar process is an ingenious and controlled know-how for the elaboration of a Wiedmannstätten structure steel containing non-metallic inclusions and bubbles [3,4]. The smelters were able to produce by early 20th century about 200 tons of steel ingots smelted by year [1,5]. This traditional steel production had supplied a vast network of iron trade in West Africa [1].

The BS has an inhomogeneous structure and before using this raw material to forge tools it was required to develop a specific method allowing to overcome the defects it contains [3,6,7]. The Kabiyè blacksmiths had transformed this steel to supply a vast network trade of manufactured tools such as agricultural tools and weapons [1]. Two steps of mechanical and thermomechanical treatments are used by Kabiyè blacksmiths to forge the BS. The raw BS is first cold hammered in order to remove slag off. Some small pieces were then cut off and subjected to repeated series of cold forging and folding before being transformed into relatively thick plate. The plates are then hammered at high temperature to make finished products with a specific form.

Agricultural tools obtained by forging BS were generally preferred by farmers despite their relatively higher cost [2]. These tools had better wear and corrosion resistance than the other forged tools made from imported steel. Despite the reputation of the tools manufactured by forging BS (Bassar steel), very few scientific studies have been conducted on this material. This work aims to make up this gap by investigating microstructural and mechanical properties of Bassar Forged Steel (BFS). Special attention will be given to identifying in its microstructure what may be specifics characteristics of this historical material.

2. Materials and Methods

2.1. Kabiyè Forging Process

Kabiyè blacksmiths were the main customers of Bassar steelmakers. These blacksmiths supplied themselves with iron ingot in Bassar villages and then forged these ingots to elaborate finished products such as agricultural tools, weapons and traditional ceremony objects. In the following paragraphs we will first present the forge workshop and then describe the forging process which is subdivided into two parts: the cold forge and the hot forge.

2.2. Description of the Kabiyè Forge Workshop

The Kabiyè forge workshop is a round hut covered with straw and equipped of two entrances. The essential components of a workshop are: the anvil (a large rock made of granite and implanted in the floor of the workshop), the fireplace, the hammer (granite cut stone weighing about 10 kg with an elliptical shape) and the bellows. Figure 1 presents the schematic horizontal section (Figure 1a) and a recent photo (Figure 1b) of a blacksmith workshop.

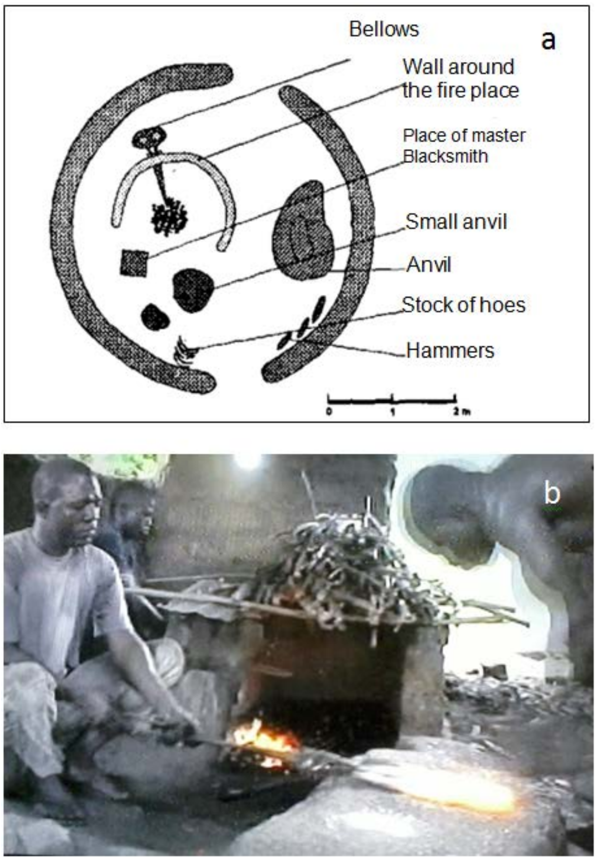

Figure 1. Schematic horizontal section (a) [2] and recent picture of the Kabiyè blacksmith workshop (b)

2.3. Cold Forging of Bassar Steel (BS)

The pieces of ingot are cold hammered strongly. Under the shocks, whole parts, consisting of slag, split off from the ingot. Parts rich in iron, hold together better and deform gradually. The thin pieces of slag are immediately swept and put in piles on the side. Larger pieces are examined for iron content. They are then, cold hammered again to rid them of the slag that still adheres to it. Doing so, at the technical level, blacksmiths take into account the iron's ability to deform. On the other hand, the slag which remains stuck to the pieces of the ingot is very brittle; it breaks up quickly into a particle dust. Pieces of iron with a diameter between 1 and 10 cm are transformed into plate less than 2 cm thick. These steel plates are placed upright, then they are hammered until they become plate again. They break partially during this operation as they still containing slag. The master blacksmith keeps lifting the pieces one after the other; he examines them to determine if the slag remains again. If there is no slag, they are placed in a calabash prepared for this purpose. If not they are hammered again. Most of the pieces of the raw ingot has to be flattened several times, put back upright, flattened again, before joining the pieces already selected as being formed of pure 'iron' [2] The smallest pieces follow another forging process that is not described in the present work.

The master blacksmith observes the color of the piece to determine if it is 'pure' or if it still contains impurities. Pure iron has a matt, light gray color and in some places shines dull. Dark, dim areas are constituted of charcoal inclusion which must be completely removed. The red-brown areas are remnants of the ore that must be removed by hammering.

2.4. Hot Forging of Bassar Steel (BS)

The blacksmith introduces the cold forged steel plate into the fire and asks his second apprentice to fan the fire by activating the bellows vigorously. When the sample is heated to red, the blacksmith removes it from the fire using a clamp and holds it on the anvil then with the hammer blows given by the first apprentice, he gives to the plate the progressive form of the final product. For the manufacture of a hoe blade for example, he first shapes the stem of the future hoe blade (Figure 2). After 10 to 12 strokes, the sample is already too cold and must return to fire. Only the part that will be treated during the next phase of work is heated. The movement of the hammer falling on the red-hot sample follows an elliptical trajectory. The apprentice raises the hammer close to his body, then slams it on the anvil, with arms outstretched (Figure 2). This is why, next to the vertical shock effect, there is also a horizontal movement towards the body of the apprentice. This second movement is directed from the center towards the periphery of the forged sample. This movement is very important in the operation of the stone hammer, since, during this phase, the piece stretches.

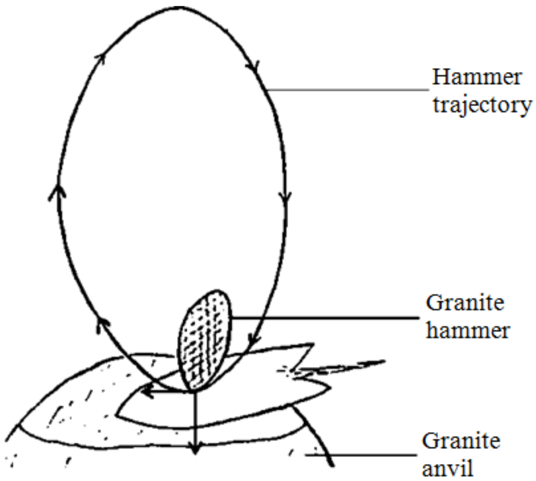

Figure 2. Kabiyè forging technique

The next phase is to forge the finished products such as hoe blades, knives, sword and spears (Figure 3). It is from a spear used for traditional ceremonies that we cut samples for microstructural and mechanical studies.

Figure 3. Photo of Kabiyè spear and a kind of sword

2.5. Description of Samples and Experiments

The samples used in this study were cut from a traditional Kabiyè weapon (spear) provided by the late district chief of Pya-Boudè (Togo) Mr. BOUYO Mathieu. The raw material was forged from Bassar Steel through the application of the traditional Kabiyè's forging process described above.

Small specimens were cut out from this provided sample and mounted and treated following a standard metallographic procedure. The specimens were then etched around 5 seconds using the solution of 3% volumetric nitric acid in balance methanol before being examined under the optical microscope (OM) and the scanning electron microscope (SEM). Diffraction patterns were obtained using X-Ray Diffractometer (XRD, Siemens D5000) Bragg-Brentano type apparatus in reflection mode. The wavelength of copper (Kα= 1.5406 Å) was used in a step scan mode range $20° \leq 2\theta \leq 120°$, with a step of 0.04° 2θ and a step time of 2s. Micro hardness is measured using MHT-200 Series Micro Vickers Hardness Tester with a load charge of 300 g during 5s. Tensile test was conducted on Bassar Forged Steel (BFS) samples at room temperature in an INSTRON 5966 machine at a strain rate of $10^{-3}s^{-1}$. The width and the length of the gage section of the samples were of 5 mm and 50 mm, respectively.

3. Results and Discussion

3.1. Microstructural Characterization

The results of microstructural analysis are presented for the sample of BFS not chemical etched (Figure 4) and for the etched one (Figure 5).

Figure 4 is an optical micrograph of the sample without chemical attack. It contains some larges inclusions and a high number of small precipitates (Figure 4a). In some areas with a high magnificence folds or wrinkles are observed as indicated by white arrows in Figure 4b. These deformations would be due to the forging process.

Figure 5 presents the microstructure of the etched forged sample, consisting of light ferrite grains with many dark precipitates of non-metallic inclusions (Figure 5a). The precipitates are located mostly at the grains boundaries and few are formed inside some grains as it can be observed in the Figure 5b. Such inclusions indicate the bloomery nature of the process leading to the as-obtained BS and the forging technique used to develop the finished products.

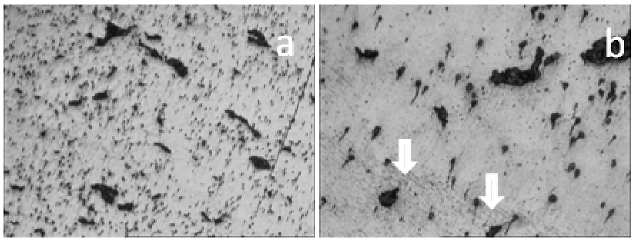

Figure 4. Optical micrographs of not etched sample of BFS

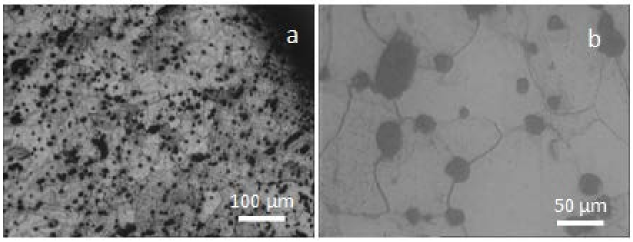

Figure 5. Optical micrographs of forged steel and chemical attacked sample

Figure 6 presents the EDS spectrum of studied traditional Bassar forged steel. It shows the presence of other elements such as O, Mn, Si and P. The presence of phosphorus is known to decrease the mechanical properties of the sample.

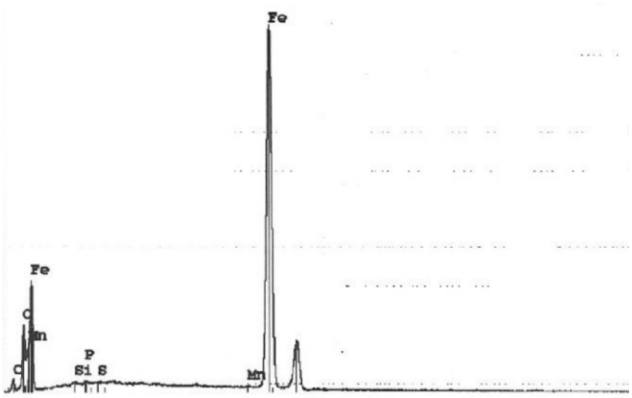

Figure 6. EDS spectrum of Bassar forged steel (BFS)

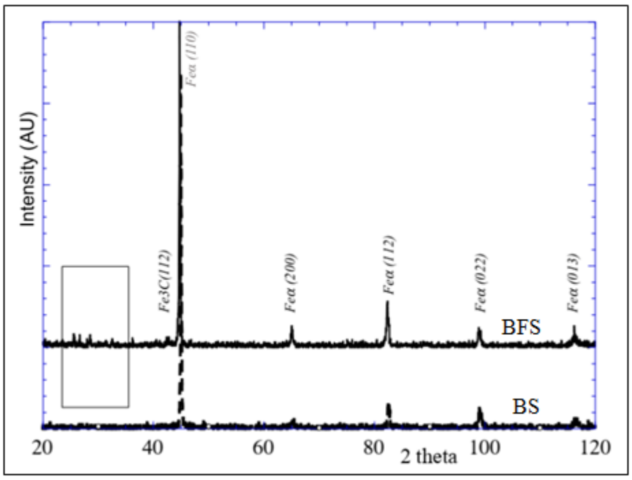

Figure 7. X-rays diffraction patterns of Bassar Forged Steel (BFS) and BS

Figure 7 shows the XRD patterns of BFS sample compared to the Bassar as-smelt steel (BS). The X-rays diffraction patterns indicate the presence of cubic centered ferrite (bcc-Feα) and tetragonal cementite (t-Fe3C). This result confirms the microstructural observations and indicates that BFS is mainly composed of ferrite with a few proportion of cementite.

In low 2-Theta angles (see rectangle of Figure 7), the lines that appear can be attributed to the precipitates and inclusions observed in the optical micrographs of BFS.

3.2. Mechanical Properties

3.2.1. Vickers Hardness

Vickers micro-hardness tests have been performed inwards on the thickness from the surface to the core of the sample. Figure 8 presents this variation as a function of the distance. Vickers micro-hardness value of BFS ranges from 130 $Hv_{0.3}$, to 185 $Hv_{0.3}$. There is a clear decreasing trend from the surface to the core of the studied material. The core of BFS bar is softer than it surface. The value of about 185 $Hv_{0.3}$, a relative high value measured over a thickness range of about 0-50 µm from the surface, suggests surface hardening but is too low to indicate a quenching effect.

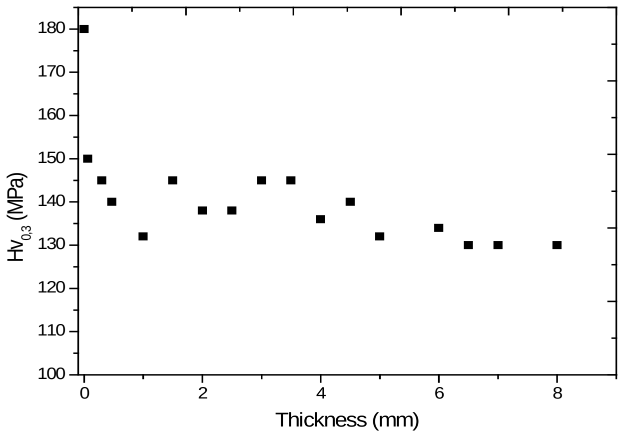

Figure 8. Vickers micro-hardness of BFS in function of its thickness

Figure 9 is the SEM micrographs of BFS. The inclusions are thin at the edge and have a larger size towards the center of the sample (Figure 9a). In some cases, larger inclusions pass through some grains (Figure 9b). The hardness profile would be in agreement with the evolution of the microstructure observed on the SEM micrograph (Figure 9), and could be due to the size and distribution of the precipitates.

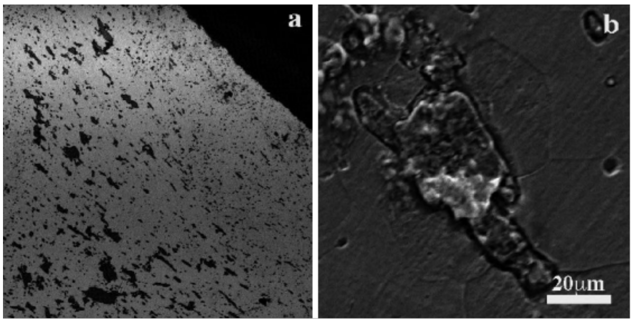

Figure 9. SEM micrographs of BFS, overview of the edge towards the inside (a), detail of a precipitate (b)

The location of fine precipitates on the surface would have induced a slight hardening effect which may explain the better mechanical properties of forged tools. The presence of many inclusions could explain the chemical resistance of forged steel with a process close to that of New Delhi iron pillar [8].

3.2.2. Tensile Test

Figure 10 show the stress-strain curve of BFS presenting an elasticity domain with a short Lüders deformation area.

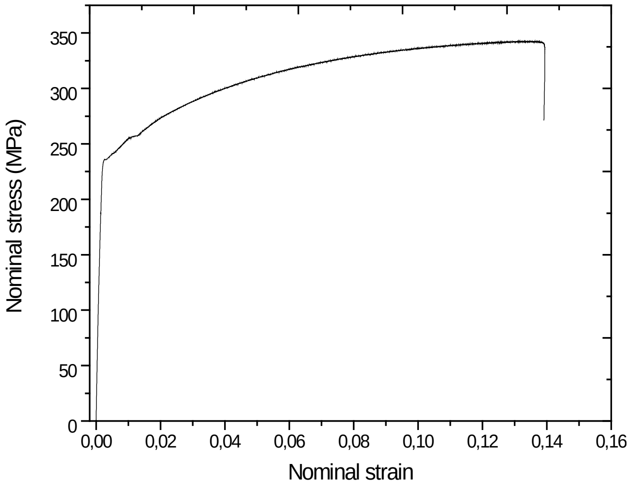

Figure 10. Nominal stress-strain curve of BFS

Table 1 presents the mechanical characteristics such us yield strength (YS), tensile strength (TS), ultimate tensile strength (UTS) and total elongation (TE) determined from the deformation at specimen rupture.

Table 1. Font Sizes for Papers

Mechanical parameters			
TS (GPa)	YS (MPa)	UTS (MPa)	TE (%)
148	233	342	14

The tensile strength of Bassar forged steel (BFS) is 148 GPa. This low value is in the range of ferritic steel [9]

The total strain of BFS is 14 %. The BFS total elongation (TE) is lower than those of ferritic steel [10]. This would be due to the presence of many precipitates or second phase such as Fe_3P or Fe_3C which are mainly located at grains boundaries [11,12]. Some of these precipitates which appear at the surface of the sample could induced an early break. In addition, the EDS analysis revealed the presence of phosphorus which would have induced a fracture by grain boundaries embrittlement [9,11]. A combined action of the two previous causes could better explain the early breaking of BFS.

4. Conclusion

In this paper the microstructural and mechanical properties of the Bassar Forged Steel have been investigated. The results obtained can be summarized as follows:

(1) The BFS has a ferritic microstructure comprising of many nonmetallic inclusions and precipices.

(2) The finer precipitates on the surface of BFS may have induced a slight hardening effect which could explain the better mechanical resistance of BFS.
(3) The BFS presents low carbon steel mechanical properties but a very low total strain probably due to the presence of precipitates and/or Phosphorus.

Acknowledgements

The late BOUYO Mathieu is gratefully acknowledged for giving the samples examined in this work. This project was supported by the French government through the "Service de Coopération et d'Actions Culturelles" of the French Embassy in Lomé, Togo.

References

[1] Phillip de BARROS, 1986, Bassar: a quantified, chronologically controlled, regional approach to a traditional iron production centre in West Africa, Africa, vol. 56, no. 2, pp. 148-173.
[2] Hans Peter HAHN, 1997 : Techniques de la métallurgie du fer au Nord Togo (Collection « Patrimoines » n°6).
[3] Pali Kpelou, Gnande Djeteli, Ayi Djifa Hounsi, Hans Peter Hahn, Tiburce Ahouangbe Aboki, Kossi Napo. A Reproduction of the Ancient Bandjeli's Steel-Making Process. International Journal of Materials Science and Applications. Vol. 3, No. 5, 2014, pp. 217-225.
[4] Pali KPELOU, G. DJETELI, A. HOUNSI, K. NAPO et T. A. ABOKI; Etude métallurgique du fer brut traditionnel de Bandjeli; Rev. Ivoir. Sci. Technol., 20 (2012) 24-34.
[5] Philip de Barros, 1981. The Iron industry of Bassar. Nyame Akuma 18: 57-8.
[6] N. YAMAGUCHI, A trial to reproduce an ancient iron-making process in Chiba prefecture; ISIJ International, Vol. 37 (1997), No. 2, pp. 97-101.
[7] Jang-Sik PARK, Traditional Japanese Sword Making from a Tatara Ingot As Estimated from Microstructural Examination, ISIJ Int., Vol. 44 (2004), No. 6, pp. 1040-1048.
[8] R. Balasubramaniam, On the corrosion resistance of the Delhi iron pillar, Corrosion Science 42 (2000) 2103±2129.
[9] Nobuo NAKADA, Masaru FUJIHARA, Toshihir TSUCHIYAMA and Setsuo TAKAKI, Effect of Phosphorus on Hall-Petch Coefficient in Ferritic Steel, ISIJ International, Vol. 51 (2011), No. 7, pp. 1169-1173.
[10] Pali KPELOU, Gnande DJETELI, Tiburce Ahouangbe ABOKI, Ayi Djifa HOUNSI, Kossi NAPO, Microstructural and Thermomechanical Characterization of the Bassar Remelted Steel, Materials Science and Metallurgy Engineering, 2016, Vol. 3, No. 1, 8-11.
[11] S. K. Chaurasia, Ujjwal Prakash and Vikram Dabhade, Effet of Phosphorus on Microstructure and Mechanical Properties of Iron-Based Alloys Processed Through Powder Forging, Metallogr. Microstruct. Anal. 2017.
[12] S. K. Chaurasia, Ujjwal Prakash, Vikram Dabhade, S. K. Nath, Effect of Phosphorus Addition on Dry Sliding Behavior of Fe–P Alloys Prepared by Powder Metallurgy, Metallography, Microstructure, and Analysis 2018.