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Microstructural and Thermomechanical Characterization of the Bassar Remelted Steel

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Abstract This article presents the microstructural and thermomechanical study of the Bassar remetlted steel obtained from melting Bassar as-smelted steel. Bassar as-smelted Steel is steel made by direct reduction of Bandjeli iron ore in a natural draught furnace. Bandjeli village is located in the Bassar Region in the Republic of Togo (West Africa). The Bassar remelted steel was obtained by melting at 1370°C of Bassar as-smelted Steel in a high frequency furnace to eliminate inclusions and pores contained in the Bassar as-smelted Steel. The microstructural and mechanical analyses show that the Bassar remelted steel is homogeneous and contains no defects compared to as-smelted steel. The microstructure of the remelted Steel is formed of ferritic grain whose average size is more than 0.5 mm. Some precipitates are observed in grain and grain boundaries. Heat treatment shows that the average grain size increases as the annealing temperature increases. For the sample annealed at 600°C for one hour, its tensile strength is 338 MPa and the strain rate is 20%. The mechanical properties of the Bassar remelted steel decrease after annealed at 800°C and 950°C for one hour.

Keywords: *Bassar Steel, Bassar remelted steel, natural draught furnace, microstructure*

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1. Introduction

The Bassar region of northern Togo has been the locus a major ironworking activity over many centuries. Bassar iron smelters elaborated steel by direct reduction of iron ore in a natural draught furnace [1,2,3,4]. This steel has a rate of carbon which varies in between 0.1%-2% and contains pores and inclusions of charcoal or cinders [1,2,5]. This kind of furnace was only discovered in West Africa at Bandjeli in Togo [1,2,6,7]. The smelters of this Bassar village produced by early 20th century about 200 tons of steel ingots smelted by year [2,6,7]. The Kabyè blacksmiths had transformed this steel to supply a vast net of trade of manufactured tools such as agricultural tools and weapons [6,7].

The smelted material has a microstructure formed of ferritic grain and some precipitates within grain and at grain boundaries [2]. Bassar as-smelted steel presents good mechanical and chemical properties suitable for agricultural tools [8] weapons such as swords [5,9], arrowhead, and spear [8,10]. However the presence of inclusions and pores in Bassar as-smelted steel does not allow this steel to be used for industrial applications. Furthermore few scientific studies on enhancing the Bassar knowhow or the product obtained were made [1,2,6,7].

The aim of this article is to determinate the microstructural and mechanical properties of the alloy obtained by melting the Bassar steel in order to eliminate the as-smelted pores and inclusions.

2. Materials and Methods

2.1. Elaboration of Bassar as-smelted Steel (BS)

Bassar steel is elaborated by direct reduction of iron ore in a natural draught furnace. The furnace filling is done in alternative layers. A total of 108 kg of charcoal and 35 kg of crushed iron ore are needed. The detailed procedure, described in reference [2] leads to as-smelted casting steel ingot of about 12 kg.

2.2. Elaboration of Remelted Steel

Some pieces of steel are first cut of the Bassar as-smelted steel ingot and cleaned to take out the oxides formed at its surface; then dried by compressed air. These specimens are melted at 1370°C in a high frequency furnace. The liquid metal obtained is moulded in a form of rod that is named Bassar Remelted Steel (BRS).

2.3. Experimental Procedure

Some samples of Bassar as-smelted Steel and Bassar Remelted Steel are cut then polished and etched around 5 seconds using the solution of nital 3% before being examined under the optical microscope and the scanning electron microscope (SEM).

The XRD diagrams were obtained using a D5000 Bragg-Brentano type apparatus from Siemens in reflection mode. The wavelength of copper (kα= 1.5406 Å) was used in a step scan mode range 20°≤ 2θ≤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 tests were conducted on Bassar Remelted Steel samples at room temperature in an INSTRON 5966 machine at a strain rate ($\dot{\varepsilon}$) 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. Prior to the tests, the specimens were annealed at 600°C, 800°C and 950°C for 1 hour then water quenched followed by mechanical polishing, to remove the surface layers affected by the annealing. From the tensile load-versus displacement data, yield strength (YS) and the ultimate tensile strength (UTS) were determined. The total elongation was determined from the displacement at specimen rupture.

3. Results and Discussion

3.1. Microstructural Properties

3.1.1 Bassar Steel

Figure 1 is a SEM micrograph taken from a Bassar as-smelted Steel sample that was not etched. A large pore is clearly seen in the micrograph. Optical micrograph (Figure 1b) shows a big inclusion. Figure 1c and Figure 1d micrographs indicate that BS has a biphasic microstructure formed of ferritic grains (bright) in a perlite matrix (grey area). The SEM micrograph (Figure 1c) shows that the perlite phase has a lamella structure.

Many carbon inclusions were observed in the Bassar as-smelted Steel sample without knowing whether they were amorphous carbon or graphite.

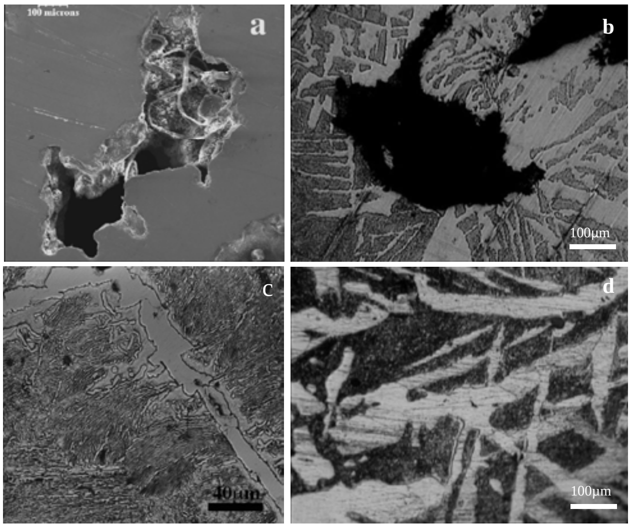

Figure 1. SEM micrographs (a, c) optical micrographs (b, d) of Bassar Steel

3.1.2. Bassar Remelted Steel

Figure 2 is the optical micrograph of Bassar Remelted Steel. The microstructure of this steel is formed of large grains of polygonal ferrite which diameter is fairly superior to 0,5 mm. Some sub grain boundary can also be seen in the microstructure. Two kinds of grains are observed, one in clear contrast with a smooth surface and the other having a streaky surface containing a dispensing of precipitates that can be easily observed in Figure 2b. These precipitates also appear at grains boundaries and are probably carbides.

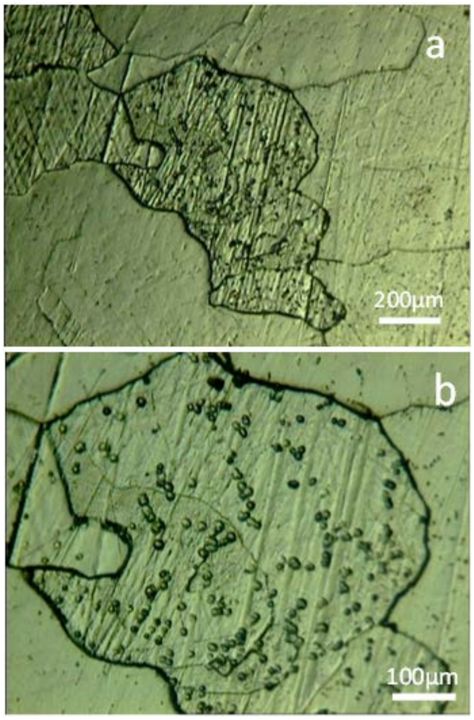

Figure 2. Optical micrographs of Bassar Remelted Steel (BRS)

The Bassar Remelted Steel has a homogenous microstructure. The re-melting of the Bassar as-smelted Steel has eliminated its elaborations defaults such as pores and inclusions.

Figure 3 is the XRD patterns of the Bassar Remelted Steel sample. The X-rays diffraction patterns indicate the presence of cubic centred ferrite (bcc-Feα) with a cell parameter of 0.2869 nm and tetragonal cementite (t-Fe3C). This result confirms the microstructural observations and indicates that the Bassar Remelted Steel is mainly composed of ferrite with a few proportion of cementite.

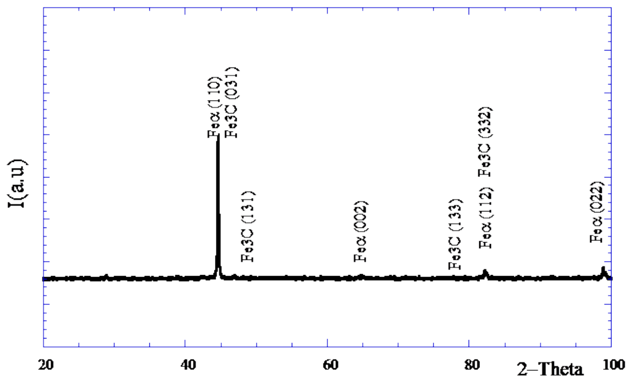

Figure 3. X-rays diffraction (XRD) patterns of Bassar as-smelted Steel (BS)

3.1.2. Bassar Remelted Steel and Annealed

Figure 4 presents optical micrographs of Bassar Remelted Steel annealed at 600°C, 800°C and 950°C for an hour then water quenched. Globally all samples have a granular microstructure formed of equal-axes grains. In certain parts very tiny grain are juxtaposed to large ones as in the microstructure of the sample annealed at 600°C (Figure 4a, b). The average size of big grain is 25µm for this sample. The grain size is 75µm and 100µm for samples annealed at 800°C and 950°C.

The mark of micro hardness of Figure 4d which is done in a whole grain matches with the high size of grains. These results indicate that annealing process lead to the re-crystallization of Bassar Remelted Steel (BRS) with an abnormal grains grow when the annealing temperature increase (Figure 4b, d and f).

The BRS microstructure is formed of large grains of ferrite containing a network of sub grain boundary and precipitates of cementite in grain and grain boundaries. After 600°C annealing, the re-crystallization generates polygonal grains which average size increases with annealing temperature of 800°C and 950°C. The micro hardness of Bassar Remelted Steel is 82 $Hv_{0.3}$ with a slit evolution to 108 $Hv_{0.3}$ after annealing at 950°C. These feeble data and little changes of Vickers micro hardness indicate that the BRS presents a ferritic structure. The BRS would rather be hypoeutectoïde steel [9] in which cementite would precipitate in globule within some grains and grain boundaries. If we consider that during the re-melting, the whole carbon at the beginning in the original Bassar as-smelted Steel is dissolved in the ferritic liquid, Bassar as smelted Steel would have carbon content less than 0.77% in mass [1,2].

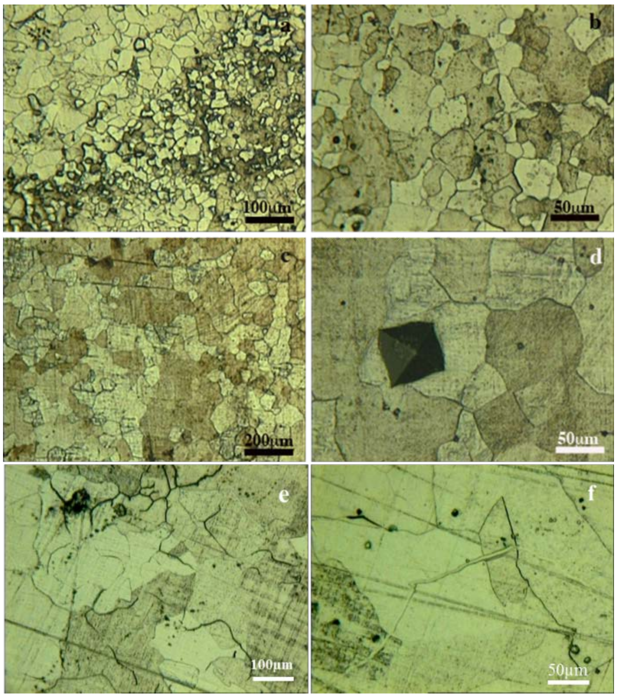

Figure 4. Optical micrographs of BRS annealed at 600°C (a b), at 800°C (c, d) and at 950°C (e, f)

3.2. Mechanical Properties

3.2.1. Vickers micro-hardness

The micro-hardness data of the BRS after annealing are reported in Table 1. A little increase is noticed. The annealed BRS hardness data are quite similar to those of the ordinary carbon steels.

Table 1. hardness data of Bassar Remelted Steel annealed at different temperatures

Annealing temperature (°C)	Vickers hardness (MPa) Average values
600°C	92
800°C	104
950°C	108

3.2.2. Tensile

Figure 5 shows the stress–strain curves of Bassar Remelted Steel annealed at 600°C, 800°C and 950°C for an hour then water quenched at 25°C initially.

The stress–strain curves of BRS annealed present a domain of elasticity. The samples annealed at 600°C and 800°C present Lüders deformation area. This Lüders area decreases after annealing at 800°C and disappears almost completely after annealing at 950°C.

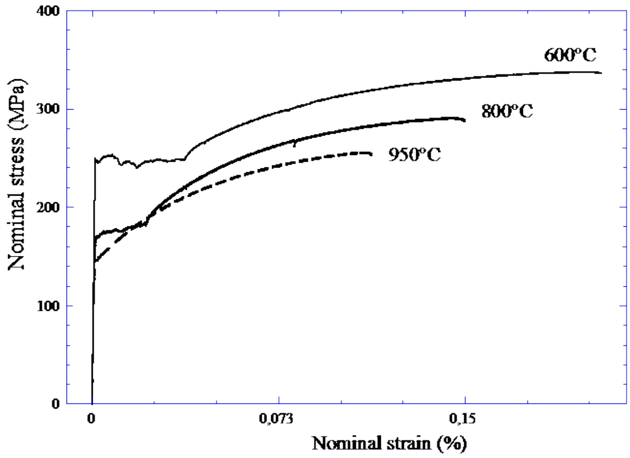

Figure 5. Nominal stress-strain curves of annealed BRS

Table 2 presents the mechanical characteristics such us yield strength (YS), tensile strength (TS), the ultimate tensile strength (UTS) and the total elongation (TE) determined from the deformation at specimen rupture.

Table 2. mechanical parameters data of the BRS annealed at different temperatures

Annealing temperatures (°C)	Mechanical parameters			
	TS (GPa)	YS (MPa)	UTS (MPa)	TE (%)
600°C	197	248	338	20
800°C	149	169	291	14
950°C	145	145	256	11

The mechanical properties of the annealed samples decrease when the annealing temperature increases. The tensile strength, the yield strength and ultimate tensile strength decrease respectively of 26%; 41% and 24% while the annealing temperature increases from 600°C to 950°C.

The tensile strength of Bassar Remelted Steel (BRS) annealed at 600°C is 197 GPa. This value is in the range of those of low carbon steels or austenitic steel [11,12,13]. The Figure 5 shows that the sample annealed at 600°C presents the highest yield strength and the ultimate tensile strength due to the grain refinement [14]. For the annealed samples the Lüders deformation area decreases abnormally probably because of the presence of sub grain boundaries especially for the sample treated at 950°C.

4. Conclusion

The aim of this study was to determine the mechanical and microstructural properties of Bassar Remelted Steel, a material without as -smelted defects such as large pores and inclusions.

The results of ours studies indicate that Bassar Remelted Steel has a homogenous microstructure formed of large polygonal ferrite grain with cementite precipitates at grain boundaries. BRS micro-hardness is 82 $HV_{0,3}$ and it C content is less than 0.77 mass %.

The ultimate tensile strength of the BRS annealed at 600°C for one hour is about 340 MPa and the total elongation is about 20%. These mechanical properties decrease for higher annealing temperatures probably due to the formation of sub-grain boundaries.

The melting of Bassar Steel generates homogenous steel (Bassar Remelted Steel) whose mechanical properties are close to those of common low carbon steel. Bassar Remelted Steel can be therefore used for industrial applications in opposition to Bassar Steel.

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