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Comparative Analysis of Properties of Steel Rebars in Bangladesh Produced From Induction Furnace and Blast Furnace Billets

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Abstract

In Bangladesh, steel used in infrastructure is mostly in the form of reinforcing bars (rebars). In the current study, grade-500 steel rebars produced from billets of induction furnace (IF) and blast furnace (BF) origin were tested, analyzed and compared. The tensile test showed that yield strength of all the samples were higher than the requirement of 500MPa but the tensile to yield (T/Y) ratio in the BF bars were lower while the IF bars had higher T/Y ratio indicating higher load bearing capability. The chemical composition revealed slight variation in the manganese content. However, alloying elements like chromium, molybdenum, nickel and copper in the BF bars were significantly lower compared to the IF bars. The macro and micro inspection of the sample cross-sections revealed the martensite area was greater in the BF bars compared to the IF bars which was necessary to develop adequate yield strength due to lighter chemistry.

Keywords: Steel rebars, Induction furnace, Blast furnace, Mechanical properties, Alloying elements.

1. Introduction

Steel is the most desirable engineering material with applications in about everywhere for its wide range of properties at comparatively lower cost [1]. It is consumed at the largest quantity in the construction industry globally and works as an indicator of development for any country by means of per capita steel consumption. With the recent infrastructural development in Bangladesh, it has been forecasted that per capita steel consumption may be doubled as soon as in five years. Thus, there is a growing demand of steel particularly in the form of reinforcing bars or rebars and hundreds of steel rolling plants are meeting the demand by producing steel rebars of different grades [2].

Almost all of the steel plants use continuous cast billets for rolling steel which are produced in the steelmaking plants by melting scraps with induction furnace. Although reduced drastically, still a small quantity of billets are imported by different steel plants [3] which are mostly produced primarily from iron ores by means of blast furnaces and subsequent processes. Typically the pig iron from blast furnaces are refined and necessary alloying elements are added by means of basic oxygen or electric furnaces in order to achieve the desired steel grade [4] whereas in the induction furnace practices, the primary raw material for steel making is the scrap which are refined to a certain degree in order to achieve the desired chemical composition but the raw materials play a very important role as the scope of chemical composition change is minimal [5]. Since the development of the thermo-mechanical treatment (TMT) technology and beginning of grade 500W steel production in the country, the majority of the steel demand in the construction sector has been for this particular grade for its high strength compared to the older twisted and hot rolled bars as well as superior corrosion resistance to some extent (6,7,8). This grade of rebar is manufactured by complying with the requirements of BDS ISO 6935-2 standard as well as BS 4449 standard which provides the limits and ranges for the strength as well as chemical composition in the products (9,10). The tensile and chemical requirements as per standard for 500W rebars are as in Table 1 and 2.

Table 1. Standard tensile property requirements for grade 500W rebar products

Standard	Grade	Yield strength (MPa), min	T/Y ratio, min	%elongation at maximum force (GL: 200mm), min	%elongation after fracture (GL: 5D), min
BDS ISO 6935-2 (2015)	B500CWR	500	1.15	7	14
BS 4449 (2005)	B500C	500	1.15	7.5	14

Table 2. Standard chemical composition requirements for grade 500W rebar products

Standard	Grade	%C, max	%Mn, max	%Si, max	%P, max	%S, max	%Cu, max	%N, max	%CE, max
BDS ISO 6935-2 (2015)	B500CWR	0.24	1.66	0.65	0.058	0.058	-	0.014	0.55
BS 4449 (2005)	B500C	0.24	-	-	0.055	0.055	0.85	0.014	0.52

The carbon equivalent (CE) is calculated by the equation below (9,10),

$$\%CE = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Cu + \%Ni}{15} \tag{1}$$

Typically, the requirement for the billets is based on the chemical composition of the targeted grade to be rolled as per the relevant standard. It is the particular standard based on which the billet plants specify the chemical compositions and prepare the billets for the subsequent processes.

The present study aims to analyze, compare and correlate the chemical compositions, tensile properties as well as the macrostructural features of the rebars produced from scrap-based induction furnace billets and the imported ore-based blast furnace billets and obtain an idea of the rebar performances with regards to the standard requirements.

2. Materials and experimental methods

Six 16mm rebar samples were collected from different steel plants which use imported billets as well as manufacture billets predominantly by melting scraps with the induction furnace as raw materials for rolling TMT bars. These samples were prepared for different tests to be conducted. The samples were cleaned of any rusts by means of a wire brush and tagged from 1 to 6. Samples 1, 2 and 3 were confirmed to be from the imported billets of blast furnace origins at the time of collection and the remaining bars were manufactured from locally produced billets of induction furnaces using predominantly scraps. 500mm sections were cut from the bars for performing tensile test to determine the yield strength, ultimate tensile strength and T/Y ratio of the rebars.

Approximately 50mm sections were collected for analyzing the chemical composition of the rebar samples. The cross section of the samples were ground and polished to obtain a flat and clean surface and the chemical composition was analyzed by means of an optical emission spectrometer.

For macro and micro inspection of the martensite ring, 30mm long samples were cut and surfaces were prepared by grinding and then polishing with different grits of emery papers followed by fine polishing in wet condition on a polishing cloth. 2% nital was used as the etching agent to reveal the grains and the martensite ring in the samples and then the ring thickness was measured with a digital microscope at different positions and the average was calculated to be considered as the representative thickness. The core microstructures comprising of ferrite and pearlite were observed at 100x magnification with a metallurgical microscope.

3. Results and discussion

Chemical composition

The rebar samples were tested for chemical composition and the results are as in Table 3. All the samples conformed to the standard requirements described in Table 2. However, there were clear differences in the chemical composition between the BF bars and the IF bars most significantly in terms of the concentration of alloying elements like chromium, copper, nickel and molybdenum as well as the concentration of phosphorus and sulfur. The carbon equivalent was also clearly differentiable between the rebars of two different origins.

Table 3. Chemical composition of the rebar samples

Sample ID	%C	%Mn	%Si	%P	%S	%Cr	%V	%Mo	%Cu	%Ni	%CE
16-1	0.22	0.70	0.21	0.013	0.0082	0.0069	0.0041	0.0042	0.012	0.022	0.34
16-2	0.18	0.87	0.20	0.026	0.010	0.013	0.0014	0.0042	0.0091	0.0056	0.33
16-3	0.20	0.74	0.26	0.012	0.0049	0.0055	0.0006	0.0045	0.0037	0.0042	0.33
16-4	0.18	0.74	0.23	0.034	0.030	0.14	0.0039	0.025	0.14	0.13	0.36
16-5	0.21	0.77	0.23	0.032	0.029	0.13	0.0033	0.015	0.12	0.050	0.38
16-6	0.23	0.73	0.26	0.035	0.026	0.17	0.0038	0.0092	0.24	0.065	0.41

The chemical composition of the samples 16-1 to 16-3 revealed very small concentration of Cr, V, Mo, Cu, Ni etc alloying elements. This is due to the blast furnace output pig iron which the primary raw material for the steelmaking in case of the imported billets as pig iron contains trace concentration of such elements in its composition [11] and mainly comprises of carbon, manganese, silicon, phosphorus and sulfur as the constituent elements along with iron. These elements are refined and reduced in the subsequent processes in order to achieve the desired chemical composition and during these steps very small amount of alloying additions are made in general requirement cases. The resultant carbon equivalent of these rebars were also found to be lower than 0.35% which could be attributed to the low concentration of such elements.

The samples 16-4 to 16-6 were produced from induction furnace billets, manufactured after smelting, refining predominantly scraps of different types inherently containing varying concentrations of alloying elements as mentioned in Table 4 followed. In case of induction furnace steelmaking, such elements are often very difficult to remove or reduce to a large extent [5] resulting in an inherently higher concentration of alloying elements particularly Cr, Cu, Ni and Mo in comparison to the BF rebars. As a result of the high alloying element concentration, the carbon equivalent of these samples were also higher compared to the other samples.

Another notable point is the concentration of phosphorus which is very low in the BF bars than the IF bars because of the operational limitation of the induction furnaces to remove phosphorus by means of oxygen [12].

Tensile properties

The tensile test result of the rebars are tabulated in Table 4. From the results it can be seen that the yield strength of all the samples were greater than the minimum requirement of 500MPa for the desired grade according to the mentioned standards in Table 2. Both of the elongations were also found to be significantly higher than the requirement. However, the T/Y ratio of the sample 16-2 was found to be lower than the minimum requirement of 1.15 while the value was found to be at marginal in sample 16-1. The ratio was found to be comfortably higher in the IF bar samples with the ultimate tensile strength found more than 100MPa greater than the observed yield strength in samples 16-2 and 16-3. The primary reason for the high tensile strength and as a result, high T/Y ratio in the IF bars can be attributed to the comparatively richer chemical composition particularly in terms of Cr, Cu, Mo and Ni. Among these four elements, Cr and Mo are carbide forming elements and tend to form carbides causing precipitation hardening of the steel rebars and increasing the tensile strength [13]. These elements also work as grain growth inhibitors to obtain finer grains in the final microstructure which also contributes to the high tensile strength, hence high T/Y ratio. The BF bars, containing only trace amount of such alloying and strengthening elements show lesser capability to withstand the stress at similar strain level resulting in comparatively lower tensile strength and T/Y ratio.

Table 4. Tensile properties of the rebar samples

Sample ID	Rebar diameter, d (mm)	Yield strength , Y (MPa)	Ultimate tensile strength, T (MPa)	T/Y ratio	%Elongation at maximum force (GL:200mm)	%Elongation after fracture (GL: 5d)
16-1	16	535	615	1.15	8.5	20.5
16-2	16	550	625	1.14	9.0	22.0
16-3	16	525	610	1.16	8.0	21.0
16-4	16	550	645	1.17	9.5	23.0
16-5	16	545	645	1.18	10.0	22.5
16-6	16	535	645	1.21	10.0	23.0

Macro and micro analysis

The average martensite ring thickness of the rebar samples along with the percentage of martensite ring area are given in Table 5 and the macrostructure of the cross-section of the samples are shown in Figure 1.

Table 5. Martensite ring measurement of the rebar samples (measured at 50x magnification)

Sample ID	Nominal cross sectional area (mm^2)	Average martensite ring thickness, (mm)	Martensite ring area, (mm^2)	% Martensite ring area
16-1	201	1.641	73.96	36.8
16-2	201	1.552	72.60	35.9
16-3	201	1.602	74.40	36.7
16-4	201	1.417	63.69	31.2
16-5	201	1.483	66.20	32.3
16-6	201	1.351	62.90	30.5

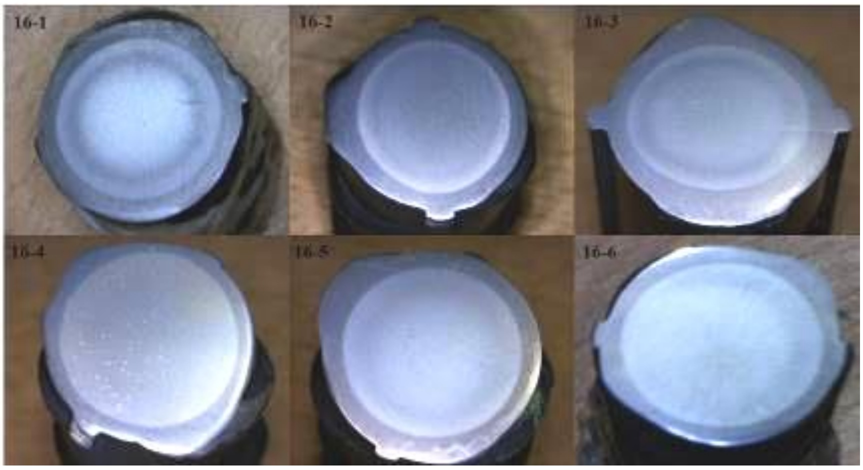

Figure 1. Ethced macrostructure of the rebar samples

The etched macrostructures revealed the martensite ring surrounding the outer portion of the rebar samples resulting from the rapid quenching of the rebars in the TMT processing. This martensitic zone was followed by a transition zone comprising of mixed bainite, martensite, ferrite and pearlite and finally the core was composed of ferrite and pearlite. The transition zone was more pronounced in BF bar samples which was also due to the lower concentration of alloying elements as low alloy additions increases the critical cooling rate of the martensite transformation. In order to develop adequate yield strength and tensile strength, thus, greater degree of quenching was required which in turns resulted in comparatively thicker martensite ring as can be seen from Table 5. The martensitic ring area in the BF bars were greater than 35% of the nominal cross sectional area of in contrast to the IF bars where the average martensitic ring area was found to be around 31%. Due to the comparatively richer chemical composition providing some additional core strength to the structure, a lesser martensite formation was sufficient to achieve the required level of yield strength for the desired grade while also providing sufficient ductility to the rebars due to comparatively greater ferrite-pearlite core area [14].

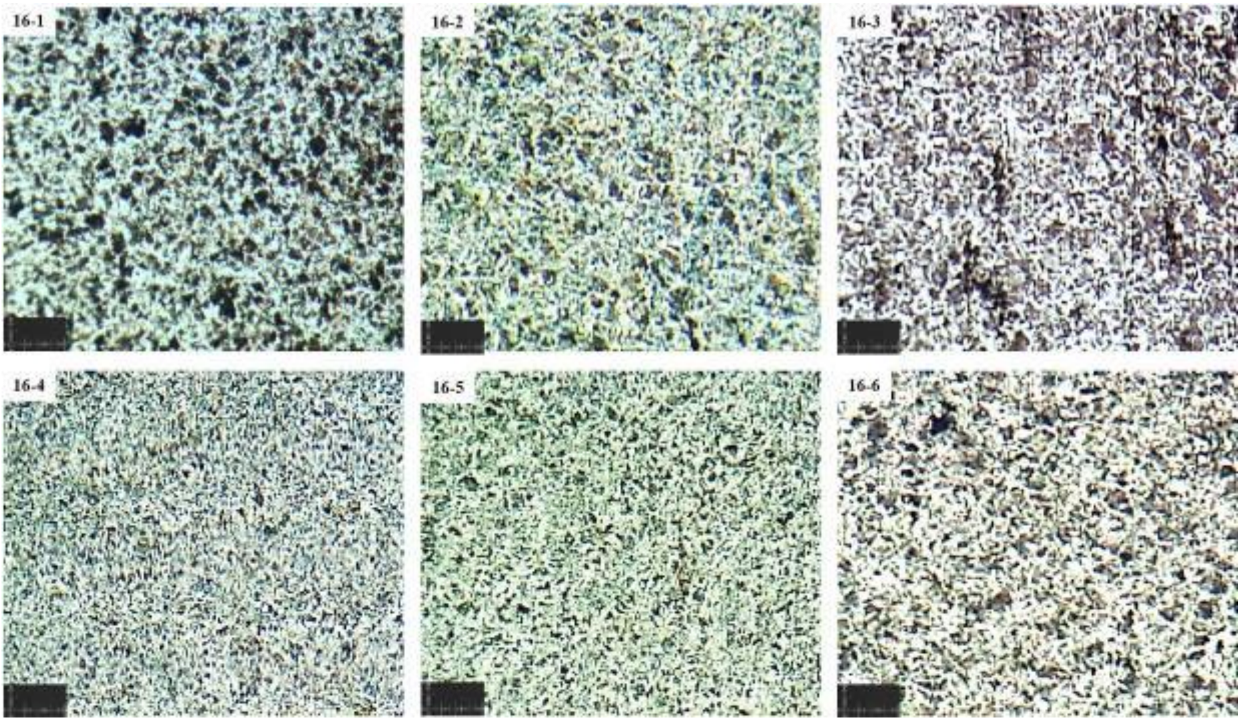

Figure 2. Ferrite-pearlite core microstructure of the rebar samples (100x)

The ferrite-pearlite core microstructures of the rebar samples are as in Figure 2. The core grains in the IF bars were observed to be comparatively finer than the BF bars which could also be correlated with the chemical composition and presence of grain growth inhibiting elements as mentioned earlier. Such microstructures also enhance the corrosion behavior of the steel rebars due to the finer ferritic and pearlitic grains along with the hardened martensite at the surface due to thermo-mechanical treatment. The higher Cr and Cu content in the IF bars as well as the finer core grains resulting in narrower and finer pearlitic bands could also carry the potential to combine and provide an extended degree of corrosion protection in comparison to the BF bars [15,16].

4. Conclusion

The rebar samples were analyzed in terms of different tests and parameters to investigate the differences in the mechanical, chemical as well as structural features of the steel rebars used in the country which are rolled from billets produced through different manufacturing routes with different predominant raw materials. Based on the investigation, the following conclusions can be made.

1. The BF bars chemical compositions are typically much lighter in comparison to the scrap based IF bars particularly in terms of the alloying and strengthening elements like Cr, Cu, Mo, Ni.

2. The yield strength of all the rebar samples were found more than the required 500MPa along with all the elongation requirements, however, the T/Y ratio of the IF bars were markedly greater than the BF bars which can be attributed to the presence of the strengthening elements in the IF bars at a larger concentration.

3. The martensite ring thickness and the core microstructure of the IF bars were in consistency with the chemical composition and mechanical properties as the IF bars ring thickness were lesser and the core grains were finer than the BF bars while achieving the desired mechanical properties.

4. As the steel industries are gaining capabilities to meet the demands of billets through manufacturing indigenously, the targeted range for chemical composition of the billets for suitable grades should incorporate some degree of alloying additions to render the products more suitable to the structural reinforcement applications and enhance the desired properties by means of rigorous research and study rather than only focusing on the elements mentioned in the standard and aiming for the similar compositions as in the blast furnace billets which were used to be imported.

5. Tailor-made chemical composition and manufacturing billets in such specification and subsequently rolling into rebars with controlled thermo-mechanical processing to develop certain desirable microstructures both at the hardened case and core can also aid in a greater degree of corrosion protection of the rebars which has the scope of further study and research and ensure better performance to cope with the growing need of reinforcing bars in the infrastructural industry.

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