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Characterisation of Locally Available Cast Iron Scraps In Nigeria for Production of Pump Cylinders

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ABSTRACT
The work analysed various grades of cast iron scraps, determined the quantity of additives in them and assessed their suitability for the production of Bore Hole Hand Pump (BHHP) cylinders. The material properties of the cylinders produced in HEDI from the scrap were compared with the Indian Mark II (assumed standard) cylinders, under the same experimental conditions. The average hardness obtained were 47.80 and 47.24; 43.23, 43.24, 44.50, 42.40, and 40.42 in HRC. The average impact energy in Joules, were 1.76 and 1.78; 2.44, 1.90, 2.34, 2.38, and 2.10 and the average tensile strength in N/mm^2 obtained were 242.02 and 256.13; 231.44, 216.06, 269.49, 253.64 and 249.01, for the two foreign cylinders and the five casted samples in each test respectively. Spectroscopic analysis results for the chemical composition gave average carbon contents of 4.18% and 3.96% for the two foreign cylinders and 5.16% for the five casted samples, average silicon contents of 1.77% and 1.69% for the two foreign cylinders and 3.43%, 4.06%, 3.87%, 3.92%, and 3.63% for the five casted samples and 2.8% for SON respectively, the average iron contents of 88.0% and 86.9% for the two foreign cylinders and 75.5%, 78.7%, 79.9%, 76.3%, and 75.4% for the five casted samples respectively. The results indicate that the locally produced cylinders compared favourably well with the Indian Mark II.
SIGNIFICANCE: The study would be useful in the production of BHHP cylinders and other components from Cast Iron scraps. It will reduce or eliminated dependence on foreign technology by development of the local technology for the production of the BHHP spare parts. The work will ensure availability of standardized spare parts for local fabrication of BHHP Cylinders and thereby create jobs, reduce poverty and empower the youths in the area of fabrication of BHHP Cylinders.
KEYWORDS: Cast iron, Impact, Hardness, Tensile, Spectrometal, Metallography

I. INTRODUCTION

Cast Iron are regulated by the control of the amount, type, sizes and distribution of the various carbon formations. The important factors are casting design, chemical composition, type of melting scraps, melting process, rate of cooling in the mould and subsequent heat treatment. (Jain, 2005)

Cast Iron, like steel, always contains the five elements carbon, silicon, manganese, sulphur and phosphorus, but has a far wider range of composition; such a range might be carbon 2.5 to 4.5%, silicon 1.0 to 3.0%, manganese 0.4 to 1.0%, and sulphur 0.05 to 1.5%. (Davies and Oelmann, 1983) Cast Irons represents the largest amount of all metals cast, and can easily be cast into intricate shapes. They generally posses several desirable properties, such as wear resistance, hardness and good machinability. (Kalpakjian and Schmid, 2000)

Cast Iron has been known and widely used as an engineering material for more than 200 years (Davies and Oelmann, 1983). It has served as a versatile material in many applications in machine building, automobile, agriculture and the textile industry among others. (Olasupo, et. al., 2003)

A lot of machines and machine components have been imported into the country, most of which are of cast iron and many now junked and out of use and are available as scraps.

This work will assess various grades of the available cast iron scraps and determined the additives in the samples by spectroscopic analysis to determine the iron, carbon and silicon contents. Corrosion test were also carried out to determine the corrosion tendency of the samples. Other tests conducted were mechanical and physical tests. The mechanical tests include hardness, tensile and impact tests. The results obtained were compared with those obtained for the HEDI Cylinders and the Indian Mark II Cylinder (Assumed Standard).

II. METHODOLGY

The following methods were adopted in the work:-

- Literature review of the properties of cast iron and existing work on Cast Iron production;
- Design and casting/production of BHHP Cylinders from the scraps;
- Assessment of various grades of Cast Iron and the additives in the Cast Iron scraps;
- The tests conducted are:-
  (a) Mechanical Test (Tensile, Hardness and Impact Tests),
  (b) Chemical Composition Test (to assess Iron, Carbon and Silicon contents),
  (c) Corrosion Test (to assess the corrosion tendency) on the samples,
  (d) Metallurgical Test (Microscopic Structure Tests) on the samples;
- Finally, comparison of the properties of the components manufactured from scraps with those of Indian Mark II (assumed standard).

III. EXPERIMENTATION

3.1 Preparation of Specimens

The specimens were produced by sand casting. The charge materials consist of cast iron scraps from automobile engine blocks, cylinder heads, machine tool bases/frames, crankshafts, and flywheels. These materials were melted in the Engineering Materials Development Institute (EMDI) Akure's 100Kg Rotary Furnace, EMR 100 model. The furnace was initially pre-heated for about 30 minutes before charging the scraps. It was then charged with the scraps and heated until the scraps melted. The molten metal was then poured into the prepared dried green sand moulds of the cylinders. The specimens were machined to specifications before tests were carried out on it. The specimens comprise two samples of India Mark II cylinder component and five samples of HEDI hand pump cylinder.

3.2 Hardness test

The hardness test was performed using the Rockwell hardness tester. A load of 150kg was applied with 120^o diamond cone as an indenter. Five readings were taken for each of the seven specimens (i.e. two for the foreign cylinder and five for the HEDI cylinders), and average values were taken for each of the specimen.

3.3 Tensile test

The tensile test was performed using universal testing machine. The specimens were prepared according to ASTM specifications, i.e. original gauge length (L_o) of 50mm and diameter of 12.5mm. The tests were conducted to the failure (fracture) of the specimens. The maximum load (M_L) at fracture was read directly on the machine. The specimens elongated up to the maximum applied load at which fracture took place. The gauge length increased due to the applied load, this length was measured by the use of vernier caliper, and recorded as final gauge length (L_1). The extension (ΔL) was evaluated, L_1 - L_o. Three readings were taken for each of the seven specimens (i.e. two for the foreign cylinder and five for the HEDI cylinders), and average values were taken for each of the specimen.

3.4 Thoughness/Impact test

The specimens prepared were 5 X 10mm by 75mm long. The impact test was performed using impact testing machine. The charpy test method was adopted, which involved the released of pendulum from a high position to give a striking energy. The pendulum placed at 150^o and on release, the pendulum weight fell under gravity, striked the specimen at the bottom of the swing with considerable kinetic energy. This broke the specimen which was positioned horizontally across the anvil. The process absorbed some energy, which was read through a dial calibrated in Joules. Five readings were taken for each of the seven specimens (i.e. two for the foreign cylinder and five for the HEDI cylinders), and average values were taken for each of the specimen.

3.5 Chemical composition test (Spectrometric analysis)

The chemical compositions of the specimens were obtained by the use of Spectrometal analyzer. The results were displayed on the computer screen and printed out.

3.6 Metallography

The surfaces of the specimens for microscopic (metallographic) examination were prepared by grinding, polishing and etching respectively. A modern metallurgical microscope with binocular viewing facility was used for the examination of the specimens. Photomicrographs were obtained by taking the photographs of the microstructures of the specimens.

IV. RESULTS AND DISCUSSIONS

4.1 Results

The results of the various tests conducted are presented in the tables 1 to 4.

Table 1: Evaluated Tensile Results

SPECIMEN	M_L (N)	CSA(mm^2)	L_1 (mm)	□ L (mm)	UTS(N/mm^2)	% e
FOREIGN I	16,639.04	68.75	50.08	0.08	242.02	0.16
FOREIGN II	17,608.96	68.75	50.10	0.10	256.13	0.20
HEDI I	13,886.39	60.00	50.13	0.13	231.44	0.26
HEDI II	17,583.70	60.00	50.12	0.12	293.06	0.24
HEDI III	16,169.45	60.00	50.10	0.10	269.49	0.20
HEDI IV	15,218.57	60.00	50.08	0.08	253.64	0.16
HEDI V	14,940.63	60.00	50.15	0.15	249.01	0.30

Table 2: Hardness Results (The values are in HRC i.e. Hardness value on C scale)

SPECIMEN	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	AVERAGE
FOREIGN I	47.6	47.8	47.9	47.9	47.8	**47.80**
FOREIGN II	47.2	47.2	47.4	47.2	47.2	**47.24**
HEDI I	43.3	43.3	43.1	43.2	43.3	**43.23**
HEDI II	42.6	42.8	42.8	42.5	42.8	**43.24**
HEDI III	44.9	44.7	44.7	44.7	44.7	**44.50**
HEDI IV	42.4	42.5	42.3	42.4	42.4	**42.40**
HEDI V	40.4	40.3	40.5	40.5	40.4	**40.42**

Table 3: Impact Test Results

Energy absorbed during the tests (**J**)						
SPECIMENS	**TRIAL 1**	**TRIAL 2**	**TRIAL 3**	**TRIAL 4**	**TRIAL 5**	**AVERAGE**
FOREIGN I	1.8	1.7	1.8	1.8	1.7	**1.76**
FOREIGN II	1.8	1.8	1.8	1.8	1.7	**1.78**
HEDI I	2.4	2.5	2.5	2.5	2.3	**2.44**
HEDI II	1.9	1.9	1.9	1.9	1.9	**1.90**
HEDI III	2.3	2.4	2.4	2.3	2.3	**2.34**
HEDI IV	2.3	2.3	2.3	2.6	2.4	**2.38**
HEDI V	2.1	2.1	2.1	2.1	2.1	**2.10**

Table 4: Spectrometric Analysis Results for the Specimens

SPECIMEN	% C	% Si	% Mn	% S	% P	% Fe	% Others
FOREIGN I	4.18	1.77	0.63	0.27	0.094	88.0	5.056
FOREIGN II	3.96	1.69	0.58	0.27	0.18	86.9	6.42
HEDI I	>5.16	3.43	0.47	0.35	0.041	75.5	<15.049
HEDI II	>5.16	4.06	0.54	0.37	0.038	78.7	<14.132
HEDI III	>5.16	3.87	0.51	0.29	0.029	79.9	<10.241
HEDI IV	>5.16	3.92	0.38	0.31	0.045	76.3	<13.885
HEDI V	>5.16	3.63	0.56	0.24	0.036	75.4	<14.974
SON	3.0	2.8	0.8	0.1	1.2	-	-

4.2 Discussion of results

4.2.1 Mechanical Test Results

4.2.1.1 Tensile Strength Results

The values obtained for the Tensile Strengths for both Foreign and HEDI Cylinders are favourably comparable. They have Tensile Strength values of between 231.44 N/mm^2 – 293.06 N/mm^2. The Foreign Cylinders have values of 242.02 N/mm^2 and 256.13 N/mm^2 respectively for the two (2) cylinders subjected to tests while HEDI Cylinders has 231.44 N/mm^2 and 293.06 N/mm^2 as the lowest and highest values respectively of the five (5) cylinders subjected to the same tests. The Foreign Cylinders has an average value of 249.07 N/mm^2 while HEDI Cylinders has an average value of 243.92 N/mm^2. This shows that the values for the two Foreign Cylinders fall in the range of HEDI Cylinders values. The Nigerian Industrial Standards specified a minimum of 200N/mm^2 and all the values obtained from the tests conducted are higher than 200N/mm^2 for both Foreign and HEDI Cylinders subjected to the same tests. It is presented in Figure 1.

4.2.1.2 Hardness Test Results

Similarly, the values obtained for the Hardness test results for both Foreign and HEDI

Cylinders are favourably comparable. They all have similar hardness values of between 40 – 48 HRC; though Foreign Cylinders have higher values of 47.24 HRC and 47.80 HRC respectively for the two (2) cylinders tested compared to HEDI Cylinders having 40.42 HRC and 44.50 HRC as the highest and lowest values respectively for the five (5) cylinders subjected to the same tests. The Foreign Cylinders has an average value of 47.52 HRC while HEDI Cylinders has an average value of 42.75 HRC. The Nigerian Industrial Standards specified hardness values of 160 – 220 HB. Considering the highest value of 220 HB, this is equivalent to 22 HRC, for Nigerian standard. This shows that all the values obtained from the tests conducted are almost the same for both Foreign and HEDI Cylinders subjected to the same tests under the same conditions. They are, however, higher compared to the Nigerian Standards. It is presented in Figure 2.

4.2.1.3 Impact Test Results

However, for the Impact tests results, the Foreign Cylinders have lower values of 1.76J and 1.78J for the two (2) cylinders under test, compared to HEDI Cylinders which have 1.90J and 2.44 J as minimum and maximum values respectively of the five (5) cylinders subjected to same tests. The Foreign Cylinders have an average value of 1.77J while HEDI Cylinders have an average value of 2.23J. This shows that the Impact test values for the two Foreign Cylinders are lower compared to those of HEDI Cylinders values. The Nigerian Industrial Standard did not specify the value for the impact property of Cast Iron; hence no comparism was made with the Nigerian Standard in this case. It is presented in Figure 3.

4.2.2 Chemical Test Results

The tests conducted show carbon contents greater than 5.16% in the HEDI Cylinders which is much higher than the carbon content in the imported ones (which have 3.96% and 4.18% respectively for the two cylinders). Both values are much higher than the Nigerian Industrial Standard (which specified 3.0%) but near the maximum value of 4.5% revealed in the Literature. This reduces the percentages of Iron contents in the HEDI samples. However, according to Faires (1965), in Gray Cast Iron, the excess carbon is uncombined, and at fracture is gray. The higher values obtained can be attributed to the melting processes and forms of scraps used.

Similarly, there are higher Silicon contents (3.43 – 4.06%) in the HEDI Cylinders compared to those of the imported ones (which have 1.69% and 1.77% respectively for the two cylinders) and the Nigerian Industrial Standard (which specified 2.8%) as against the standard ranges of between 0.5 – 3.0% or 1.0 – 3.0% as revealed in the Literatures. This also contributed to the reduction of the percentages of Iron contents in the HEDI samples. These higher values can be attributed to the melting processes and forms of scraps used. The Literature revealed that when silicon content is raised to about 3%, a Gray Cast Iron is formed, even when rapidly cooled. Low silicon contents of below 1.3% favoured the production of White Cast Iron. In between these two is a compacted Graphite Cast Iron. Therefore, Foreign Cylinder can be regarded as Compacted-Graphite Iron and HEDI Cylinder can be considered as Gray Iron because of the higher Silicon in the samples.

Other elements are almost of the same composition for both Foreign and HEDI Cylinders. They however, have higher values compared to the Nigerian Industrial Standards' Specifications.

The spectroscopic results which gave the chemical compositions discussed above showed that HEDI samples have higher Carbon, Silicon and Copper contents and lower Phosphorus contents than the foreign samples. It is presented in Figures 4 to 6.

4.2.3 Metallurgical Test Results

The photomicrographs of the prepared samples viewed through the metallurgical microscope during the test were shown on the plates 1 - 3. The photomicrographs showed the structural arrangement of (or the network of) flake graphite platelets, which are dispersed throughout the metal matrix. This matrix is the major factor controlling its mechanical properties. The structure of the imported cylinder is more closely packed than those observed in the two (2) HEDI cylinders viewed through the microscope.

V. CONCLUSION

The work studied and assessed the various grades and the level of additives in Cast Iron. From the research and the results obtained from the various tests conducted on both the Foreign and HEDI samples and the comparison with the Nigerian Industrial Standards values.

Mechanical tests results are favourably comparable in all cases where the hardness values in HRC obtained were 47.80 and 47.24 for the two foreign cylinders; 43.23, 43.24, 44.50, 42.40, and 40.42 for the five casted samples; and 22 (minimum value) for SON respectively; while the impact energy in Joules, J, obtained were 1.76 and 1.78 for the two foreign cylinders; 2.44, 1.90, 2.34, 2.38, and 2.10 for the five casted samples; and the tensile strength in N/mm^2 obtained were 242.02 and 256.13 for the two foreign cylinders; 231.44, 216.06, 269.49, 253.64, and 249.01 for the five casted samples; and 200 (minimum value) for SON respectively. The chemical tests (spectroscopic) results obtained includes chemical compositions: where Carbon contents in % obtained were 4.18 and 3.96 for the two foreign cylinders; >5.16 for all the five casted samples; and 3.0% for SON respectively; while Silicon contents in % obtained were 1.77 and 1.69 for the two foreign cylinders; 3.43, 4.06, 3.87, 3.92, and 3.63 for the five casted samples; and 2.8% for SON respectively; and Iron contents in % obtained were 88.0 and 86.9 for the two foreign cylinders; 75.5, 78.7, 79.9, 76.3, and 75.4 for the five casted samples respectively. No value available for SON. The higher carbon and silicon contents in the HEDI samples favoured the production of gray cast iron. The chemical (spectroscopic) result showed that HEDI samples have higher carbon, Silicon and Copper contents and lower Phosphorus contents than the foreign samples, hence HEDI samples will have higher corrosion tendency than the foreign samples Finally, the results above indicate that the locally produced cylinders compare favourably well with the Indian Mark II Cylinders. Hence, cast iron scraps are very suitable for the production of pump cylinders.

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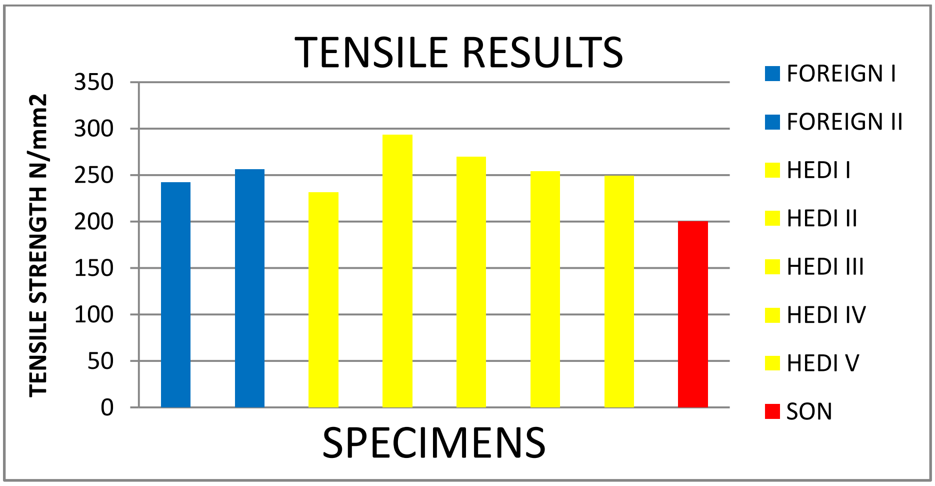

Figure 1: Evaluated Tensile Test Results for the Specimens

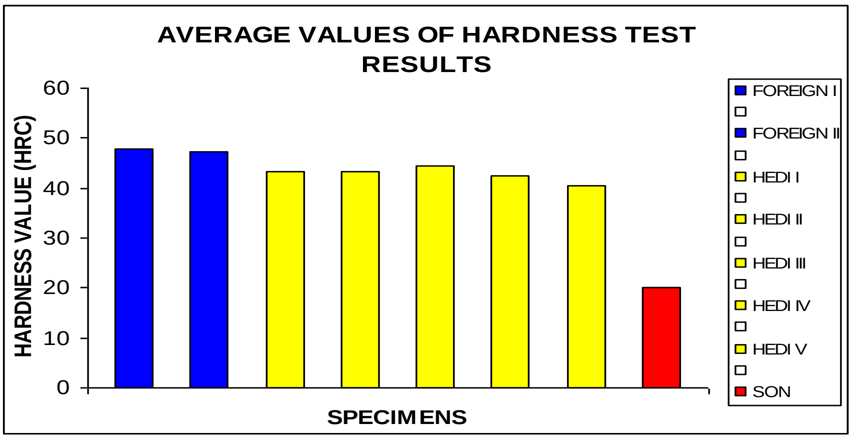

Figure 2: Average Values of Hardness Results for the Specimens

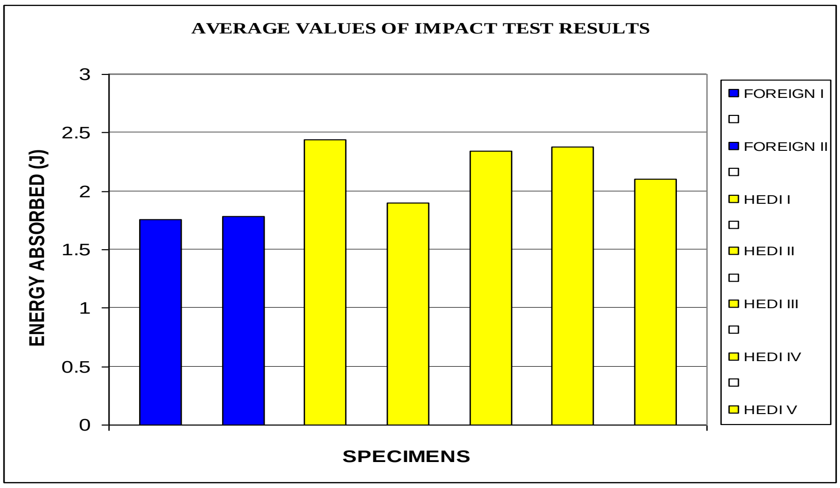

Figure 3: Average Values of Impact Results for the Specimens

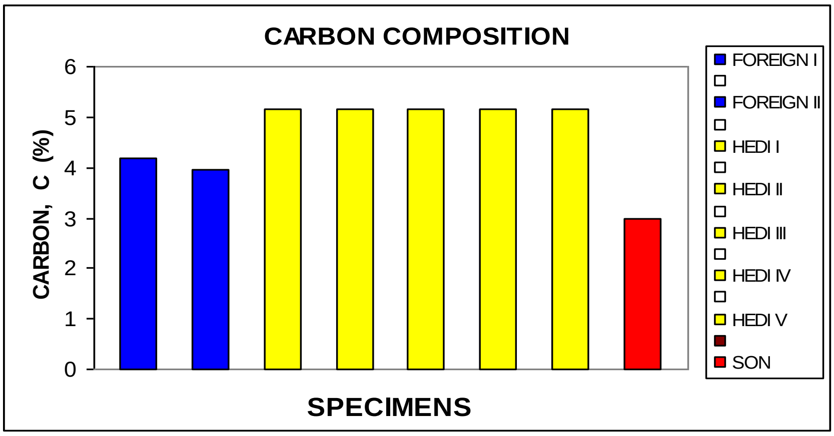

Figure 4: Carbon Composition of the Specimens

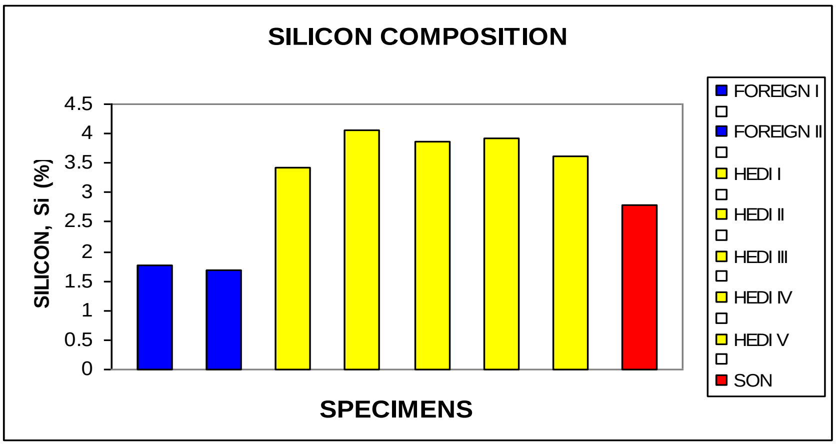

Figure 5: Silicon Composition of the Specimens

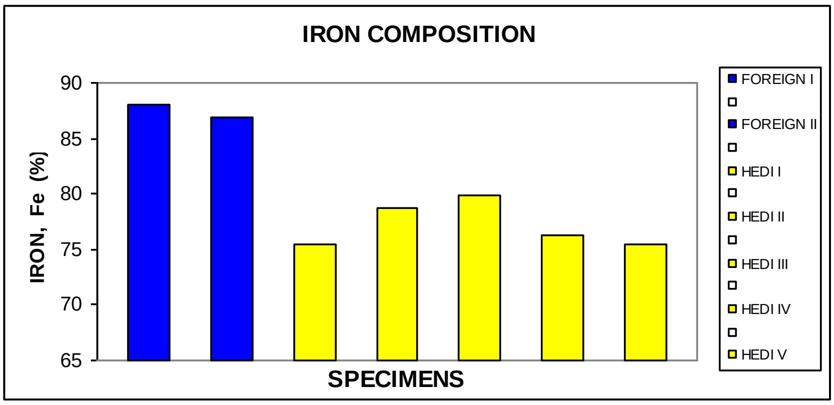

Figure 6: Iron Composition of the Specimens

Plate 1: Photomicrograph of Foreign Sample (Assumed Standard)/Specimen I

Plate 2: Photomicrograph of HEDI Sample/Specimen I

Plate 3: Photomicrograph of HEDI Sample/Specimen II