TECH FRONTIERS

Hierarchical addition of niobium: Microstructure, mechanical and wear behaviour of grey cast iron

In the present research work, the effect of niobium (Nb) addition to grey cast iron (GCI) and the solidification microstructure has been investigated. The experimental result shows that the addition of Nb content is beneficial for refining the graphite flakes and reduces the pearlite lamellar spacing. The microstructure of the developed GCI is studied by scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDS). The result presents hard NbC phase in the microstructure attributing higher hardness with improved wear resistance

AK PRAMANICK, A KUMAR, H DAS, P TALUKDAR

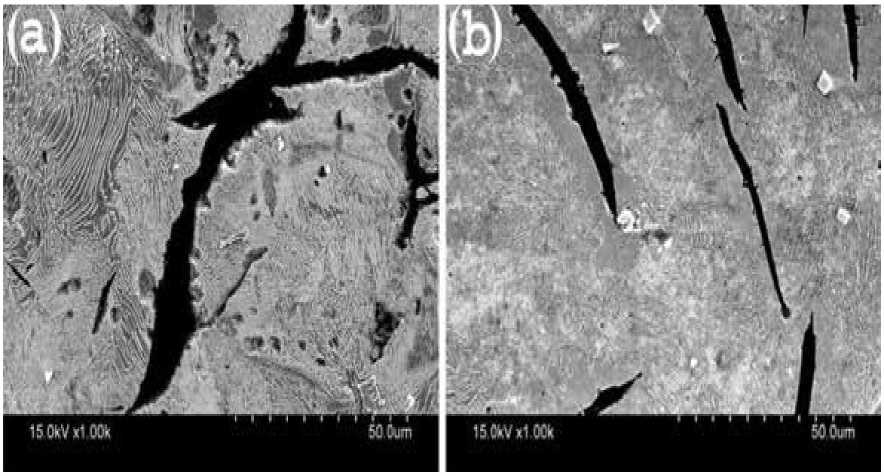
WITH the growing demand for industrial applications of grey cast iron (GCI) due to its advantageous properties and high reliability, researchers are working on the improvement of properties of GCI by alloy addition. GCI is used for several automotive components such as cylinder sleeve, brake disc, flywheel etc[1-4] owing to its excellent castability, corrosion resistance, machinability, in addition to its low melting point, high damping capacity, and relatively low cost.[5, 6] Researchers[5-7] reported that the graphite morphology and volume fraction are the major determining factors for GCI's properties. Previously, few researchers noticed that small additions of niobium (<0.5%) could improve the abrasion resistance and tensile strength of cast iron.[7–12] Based on this idea, grey cast iron has been developed indigenously in the National Institute of Foundry and Forge Technology (NIFFT), India with hierarchical addition of niobium to understand the effect on microstructure, mechanical properties and wear phenomenon.

Steel scrap, pig iron, petroleum coke and ferro-silicon charges were used in production of cast iron. After melting FeNb (65% niobium content) is added in the furnace and agitation is done for proper mixing. The melt was tapped at a temperature 1480°C. The molten metal was tapped into the experimental ladle (20 kg capacity) along with post inoculants Fe-Si to produce the experimental alloys of specified chemical composition. The metal was cast into standard 220 mm x 35 mm test bar in green sand mould. The samples were removed from sand mould at room temperature. Chemical composition is analysed by spectral and chemical methods. Chemical composition of six different developed GCI is shown in **Table1**.

Table1: Chemical composition of developed grey cast iron (Wt%)

Sample no.	C	Si	Mn	P	S	Nb
S1	2.81	1.82	0.209	0.08	0.044	0.209
S2	2.89	1.83	0.207	0.08	0.036	0.207
S3	2.99	1.95	0.208	0.079	0.040	0.208
S4	3.29	2.0	0.80	0.09	0.043	0.80
S5	3.33	2.12	0.83	0.07	0.045	0.83
S6	3.63	2.3	0.82	0.08	0.038	0.82

Figure1: SEM microstructure of sample (a) S2 and (b) S5



Macro-hardness of the samples is measured with FIE-3000(H) Brinell hardness tester using 3000 kgf static load and 15 sec dwell time. The tensile specimens are machined as per ASTM E8 standard. The wear tests are conducted on a Ducom (TR-20LE-M5) pin on disc wear testing machine by keeping the load (3 kg), speed (700 rpm) and sliding time (300 seconds), constant for different composition of the samples.

To understand the effect of Nb on the microstructure, two samples of chemical composition (S2 and S5) were considered for the SEM and EDS study. SEM micrographs of sample S2 and S5 are shown in **Figure1** (**a**) and (**b**) respectively. For both the cases, microstructure consists of lamellar graphite and type A graphite morphology. With increment in the Nb addition from 0.207 wt% to 0.83 wt% attributing refinement of graphite and reduction in pearlite spacing.

SEM with EDS analysis corroborated the formation of blocky niobium carbide (NbC) as exhibited in **Figure2** (**a**) and (**b**) (highlighted by the black arrows). The probable reasons behind the refinement mechanism of graphite owing to NbC are as follows: (a) Fine NbC particles merged with each other enhancing the formation of blocky chunk of X and Y shaped. Remaining fine NbC particles acted as a heterogeneous nucleation site for the graphite during eutectic reaction resulting refined graphite morphology by augmenting the nucleation rate; (b) niobium hindered carbon movement during solidification resulting in restricted growth of graphite and enhance the formation of refined graphite [12].

Figure3(**a**) exhibits that hardness increased linearly with increment of both carbon equivalent and niobium. Effect of niobium on hardness and wear resistance for different samples are shown in **Figure4**. It should be noted that wear rate measured by the mass loss percentage and the decrease in the wear rate specify the better wear resistance. It is noticed that as the niobium content increased, both the hardness and wear resistance improved. As the wear progress of grey cast iron, the hard phase acted as the first friction surface and contact lining material. That's why the wear resistance greatly depends on the nature, distribution, and size of the niobium rich hard phase.

Figure2: SEM with EDS analysis for (a) S2 and (b) S5

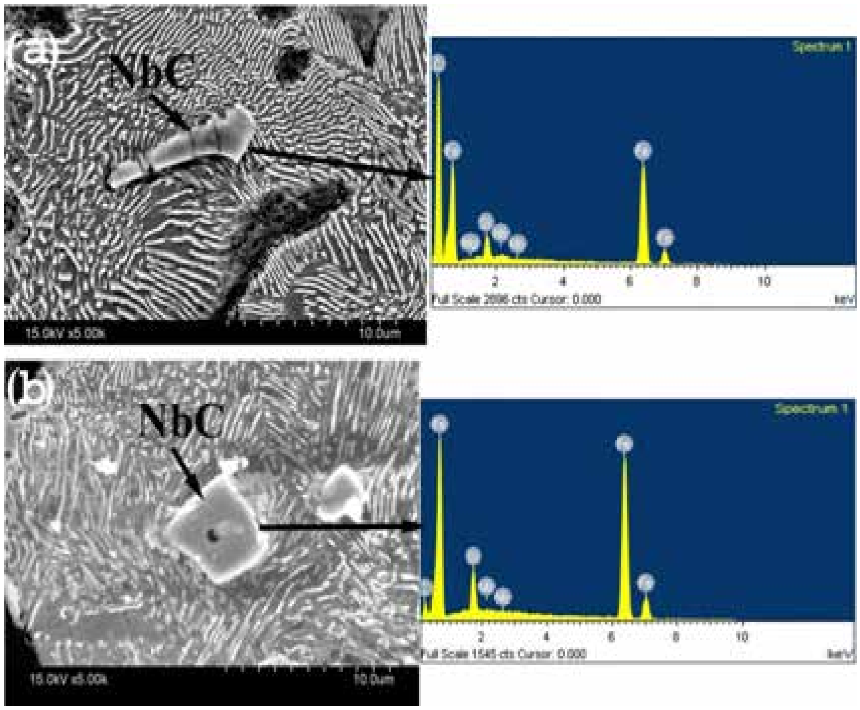


Figure3: Comparison of (a) Brinell hardness measurement values of different samples and (b) Tensile strength

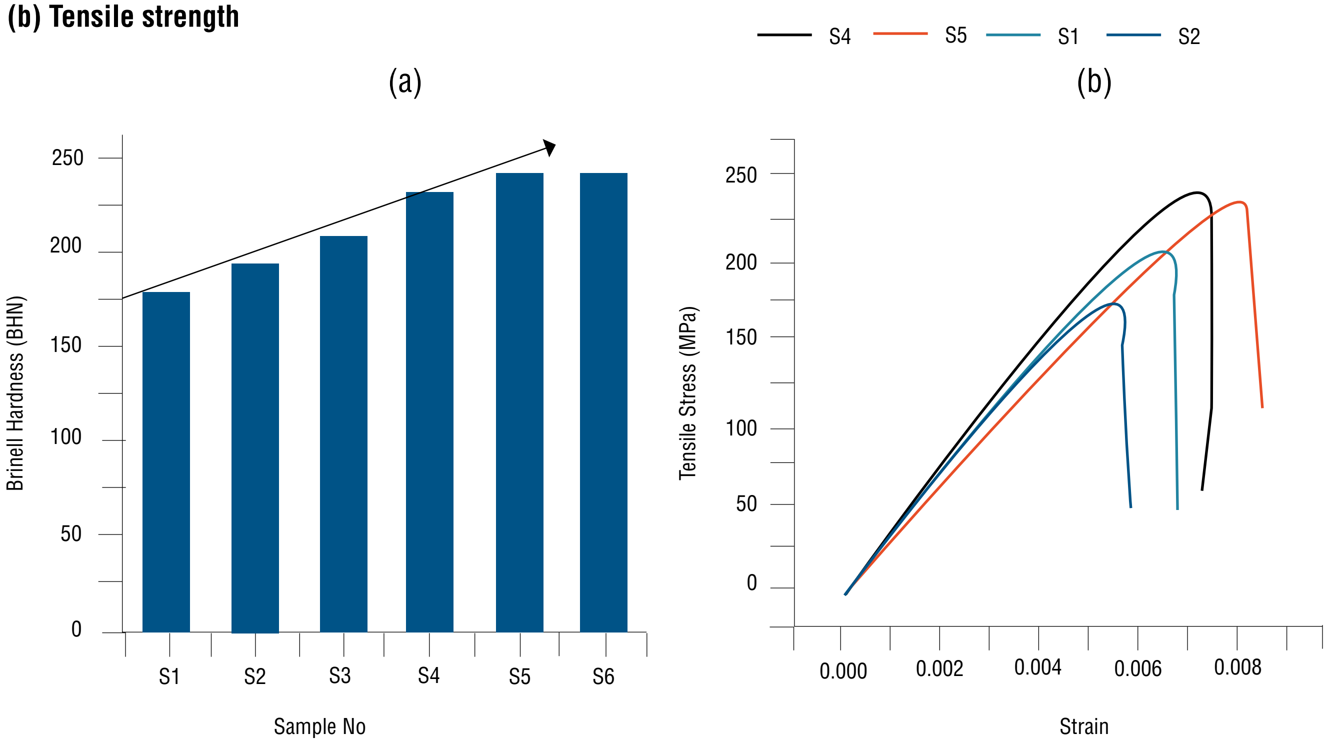
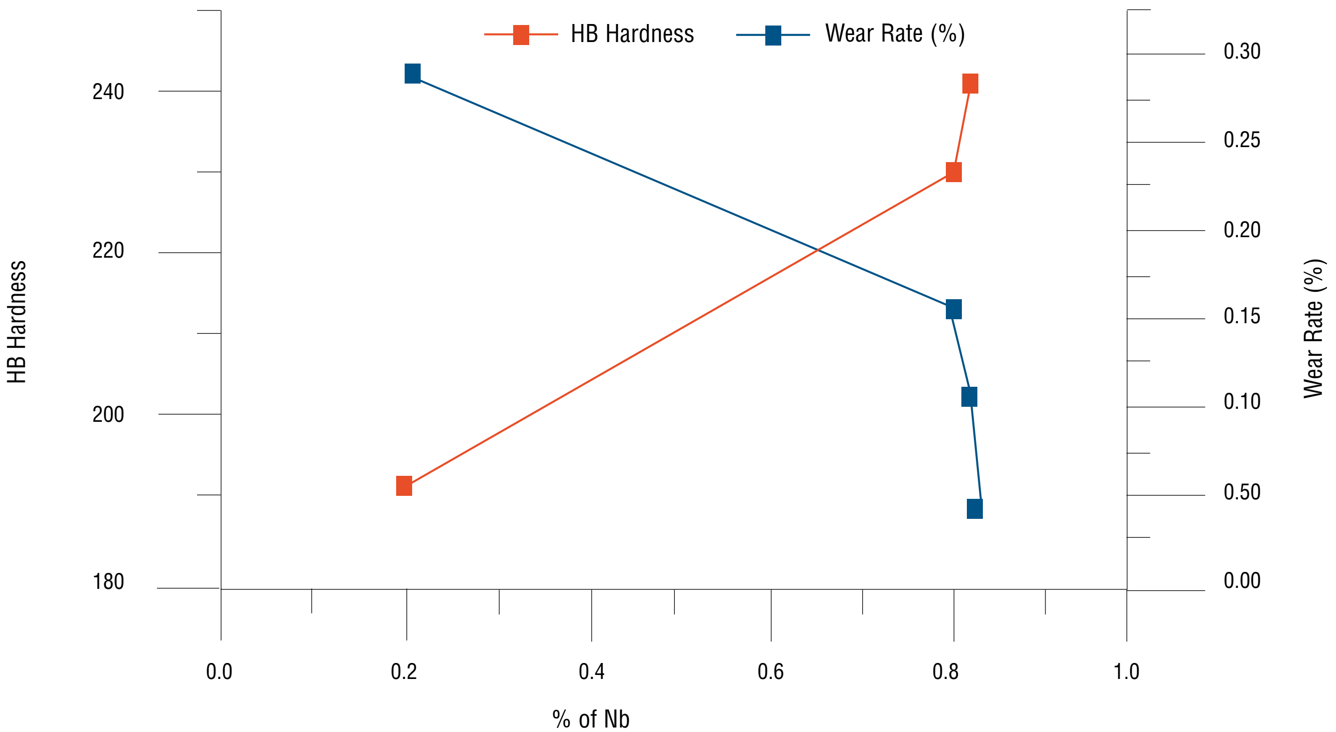


Figure4: Comparison of hardness and wear rate with varying Nb content



Size of NbC precipitation and refinement of graphite and lamellar structure justifying the higher strength, hardness and better wear resistance property in case of S5 (0.83 wt% Nb) compared to S2 (0.207 wt% Nb).

Concluding remarks

Hierarchical addition of niobium in GCI from 0.209 wt% to 0.83 wt% enhance mechanical performance and wear resistance property by reducing cell size leads to shorter and finer graphite flakes with refined pearlite and NbC formation.

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The authors AK Pramanick, A Kumar, and P Talukdar are with the National Institute of Foundry and Forge Technology, Hatia, Ranchi; H Das is with the Metallurgical and Material Engineering Department, Jadavpur University, Kolkata.
Corresponding author: ajitpramanick@gmail.com

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