EXPERIMENTAL INVESTIGATION ON THE EFFECT OF TIN (SN) IN GRAY CAST IRON TO IMPACT STRENGTH HARDNESS AND MICROSTRUCTURE

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Abstract - Alloy elements such as copper, chromium and tin are used in order to prevent some disadvantages of the gray cast irons in recent years. Copper is one of the most used one among them. It is known that copper increase both hardness and tensile strength by increasing perlite ratio in microstructure. Tin on the other hand has similar effects on some mechanical properties of gray cast iron even though the amount is used sparingly. The effects of tin (Sn) on mechanical properties and microstructure of gray cast iron are investigated by adding five different ratios of tin (0.03%, 0.06%, 0.09%, 0.12%, 0.15%). The samples are compared to two reference samples with different chemical compositions. 0.4 % copper (Cu) was added to one of the reference samples. The other reference sample was left without any alloy element additions. Samples were prepared for impact experiments according to dimensions given in ASTM E-23 standard and they were used in Charpy impact test. After impact tests were done, samples were collected and they were examined in respect of microstructure and hardness for their comparison to each other. The highest impact strength value was achieved on the sample that does not have any copper or tin alloys in it as 4.49 J according to the impact test results. The lowest impact strength, on the other hand, was measured as 3.55 J on the sample that contains 0.09% Sn. The impact strength of the 0.4% Cu alloy sample was measured as 4.37 J. The highest hardness value according to the Brinell Hardness Test was measured as 177 HB for the 0.12 tin (Sn) sample. The lowest hardness value was measured as 145 HB for the sample that does not have any Cu or Sn alloys in it. The sample with only copper alloy has a hardness value of 157 HB. Additionally, the lamella type of the samples was detected to be A3 and A4 and the highest perlite ratio was observed in the sample that contains 0.12% tin alloy. The lowest perlite ratio is seen in the sample that does not contain Sn and Cu.

Index Terms - Brinell Hardness, Gray Cast Iron, Impact Strength, Microstructure, Tin (Sn),

I. INTRODUCTION

A lot of alloy elements have been tried in order to increase hardness of gray cast iron. The most used ones among them are copper and chromium. On the other hand, Thwaites et al. showed that tin addition to gray cast iron decreases impact strength [1]-[2]. However Houre et al. indicated that Sn addition up to 0.05% increases impact strength of gray cast irons but they also stressed that Sn addition further reduces the impact strength of relatively big diameter rods (between 25.4 and 38.1 mm). There is no significant change in impact strength for smaller diameter rods (smaller than 25.4 mm) with the addition of Sn up to 0.5% [3]-[4]. Graphite length decreases clearly and thus an increase occurs in impact toughness when Sn content increases between 0.003 and 0.057% in mass according to Lyu [5]. Tin as another alloy that increases hardness of gray cast iron has a place in the related literature [6]-[7]-[8]. Lacaze et al. detected that tin addition after 0.05% is harmful to hardness according to their study on sphero (nodular) cast iron [9]. Nevertheless Morrogh revealed that tin can be added as an alloy to cast iron up to 0.13% in his work [10]. Brinell hardness value increases by means of the tin addition to cast iron according to the report by S. Dawson et al. in 2001 [11]. Novytskyy et al. stated that hardness of the cast iron is directly proportional as it increases with increasing perlite ratio in the matrix of the microstructure and perlite amount in the morphology increases with increasing tin amount, according to their work in 2007 [12]. Elwood et al. emphasized that gray cast iron having more stable and higher hardness values can be produced by adding tin. The hardness values of the cast iron increases rapidly with the increasing tin rate until the structure becomes perlite and it becomes almost fixed after perlitic ratio indicates saturation [6]-[7]-[8]. Tin is a good alloy element in order to control the microstructure according to the study that Davis J. conducted in 1967 about the effect of tin on gray cast iron but it leads to brittleness when used more than the proper amount [4]. On the other hand, Shaban et al. showed that tin increases graphite width to length ratio and compact graphite amount [13]. Adding excessive tin (Sn) into vermicular cast iron enhances the trend of over-cooling (super cooling) and some of them in the melting system solidify due to the metastability while some of them solidify as free cementite [14].

The effects of tin on hardness and impact resistance are experimentally investigated by adding tin (Sn) to gray cast iron material at 5 different ratios (0.03%, 0.06%, 0.09%, 0.12%, 0.15%).

II. EXPERIMENTAL

The experimental samples were prepared in foundry conditions by casting impact samples into mold in the presence of tin (Sn) and copper (Cu) additions. Acquired results of produced samples by experiments

under proper devices are investigated and results are evaluated. Two reference samples with different compositions and five experimental samples with different chemical compositions that contains tin (Sn) were prepared. The first reference sample does not contain any copper or tin additives. The second reference sample only contains copper additive and has no tin additive. Remaining five experimental samples have only tin additive at different ratios.

The samples in the extent of this study were cast into foundry molds that were prepared previously at proper conditions and proper casting temperatures. Casting temperature was determined as 1320 ^{o}C (+/-10). The inoculation amount during the casting phase of the samples was determined as 0.4% in weight as a standard. The inoculation process was done in the pot. Ferro-silica contains low amount of Ca was used as inoculate. The chemical composition results of the cast sample are given in Table 1.

Table 1: Spectral analysis of the samples to be investigated (%)

Spectral Analysis	C	Si	Mn	Cu	Sn
1 Unalloy	3,471	1,812	0,463	0,067	0,001
2 (0,4 Cu)	3,471	1,812	0,463	0,435	0,001
3 (0,03 Sn)	3,471	1,812	0,463	0,067	0,030
4 (0,06 Sn)	3,471	1,812	0,463	0,067	0,060
5(0,09 Sn)	3,471	1,812	0,463	0,067	0,090
6 (0,12 Sn)	3,471	1,812	0,463	0,067	0,120
7 (0,15 Sn)	3,471	1,812	0,463	0,067	0,150

A. Impact Test

A sand mold was prepared at 30 mm diameter and 70 mm length for the impact test and casting process was done at the proper casting temperature ((+/-10) 1320 ^{o}C). The impact samples at 10x10x55 mm dimensions compatible to the sizes of the ASTM E-23 standard were prepared by processing precisely in CNC turning and milling machines from the casted samples in the extend of the work (Figure 1).

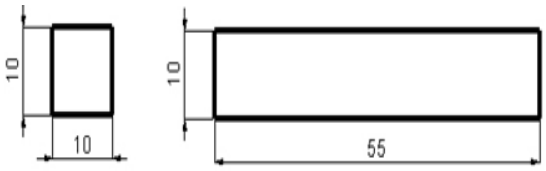


Figure 1: Impact sample according to the sizes in ASTM E-23 standard (10x10x55mm)

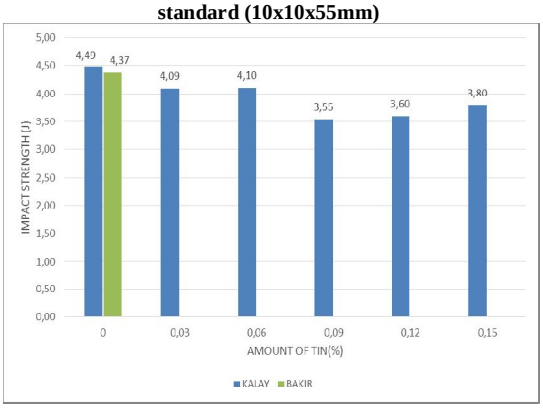


Figure 2: Results of the impact test

Charpy impact test was done in impact device that is 300 Joule type and has 770 mm hammer arm length, 20.5 km hammer, 160^{o} hammer drop angle at 20 ^{o}C ambient temperature. No additional notching was done because the samples are lamella graphite cast iron. Tests were repeated three times for each parametrical change and averages of the repetitions were taken. Results of the impact tests are given in Figure 2.

B. Hardness Test

Hardness test was done on the samples that were cut from the samples used in impact tests. Brinell hardness method was used for the test. Required metallographic processes were done to the hardness test samples in convenience with TS EN ISO 6506-4 2014 standard for the Brinell hardness test. Hardness values were measured from three different locations of the hardness samples that are at the center and near the corners as shown in Figure 3.

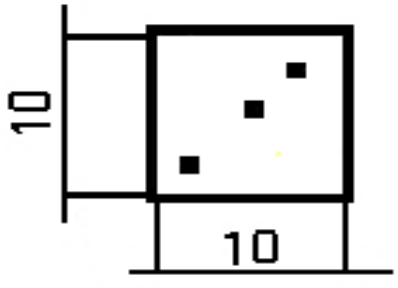


Figure 3: Locations of the Brinell hardness measurement

The ball diameter was selected as 2.5 mm and the load was selected as 187.5 kg. Hardness tests were repeated three times for each hardness test and their averages were taken. The results of Brinell Hardness tests are given in Figure 4.

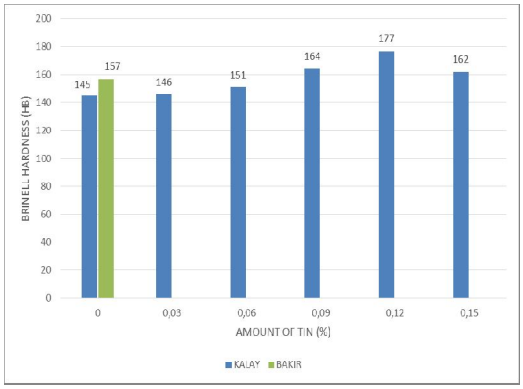


Figure 4: Hardness results (HB)

C. Microstructure Examination

The samples that were cut precisely from the impact samples were examined in metallographic microscope with 10x zoom by taking images after the samples were subjected to required metallographic processes for microstructure examination. The etching process that is done in order to see the perlite and ferrite structures in the microstructure of the samples was

done for 8 to 10 seconds in 2% nital solution. The microstructure results are given in Figures (5, 6, 7, 8, 9, 10, 11).

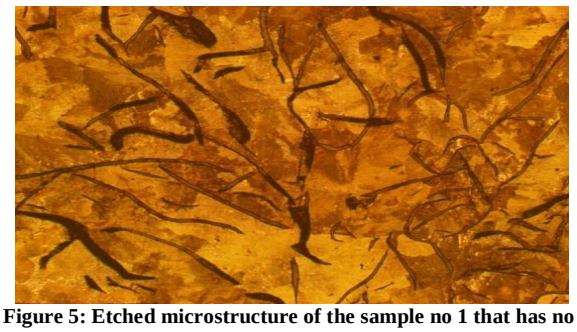


Figure 5: Etched microstructure of the sample no 1 that has no Sn and Cu at 10x zoom



Figure 6: Etched microstructure of the sample that has 0.4% Cu at 10x zoom



Figure 7: Etched microstructure of the sample that has 0.03% Sn at 10x zoom

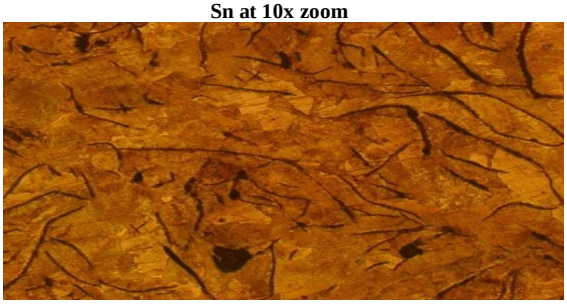


Figure 8: Etched microstructure of the sample that has 0.06% Sn at 10x zoom



Figure 9: Etched microstructure of the sample that has 0.09% Sn at 10x zoom



Figure 10: Etched microstructure of the sample that has 0.12% Sn at 10x zoom



Figure 11: Etched microstructure of the sample that has 0.15% Sn at 10x zoom

III. DISCUSSION AND PROPOSITION

The highest impact strength is detected on the reference sample that has no Sn and Cu additions with 4.49 J when impact test results are viewed. Impact strength of the 0.04% Cu reference sample is seen to be 4.37 J. The lowest impact energy is detected as 3.55 J for the sample that contains 0.09% Sn. It is observed that tin element addition up to 0.09% amount decreases impact strength. Although the impact strength increases for the samples that contains 0.12% and 0.15% Sn, their impact strength values are remained below the impact strength of the reference sample that has no Sn and Cu. The increase in impact strength of the sample that has 0.12% Sn can be explained by the thinning of the perlite structure. It is known that impact strength is inversely proportional with hardness. Hence, results of the present work justify this view. The impact strength of the samples decreases as the hardness values increase. Thawaites[1] stated that tin element that is added to gray cast iron reduces the impact strength in the study that was reported in 1965. Results of the present work also justify this view. Hoare reported that tin increases impact strength of gray cast iron up to 0.05% amount according to the investigation in 1959. The highest impact strength is detected on the reference sample that has no Sn and Cu additions in this work. However fracture energy of the sample that has 0.03% Sn is 4.04 J while the fracture energy was found as 4.1 J for the sample that has 0.06% Sn and a decrease in impact strength is observed as the tin amount increases in the samples after 0.06% Sn value. The highest hardness value is found as 177 HB that belongs to the sample

having 0.12% Sn when the Brinell hardness values of the samples are examined. The lowest hardness value is seen as 145 HB on the reference sample that has no Sn and Cu. The hardness value of the reference sample that has copper (0.4% Cu) is found as 157 HB. This value is viewed as a value between the hardness values of samples having 0.06% Sn and 0.09% Sn (151-164 HB). Microstructure figures support the hardness results. Harness increases with increasing perlite structure. The decrease in the hardness value on the 0.15% Sn sample can be explained by the irregular lamella and increased graphite amount. These hardness results are in consistency with the results of the study of Davis J. in 1967[4]. Davis J.[4] stressed that the increasing amount of tin in gray cast iron increases the perlite amount and therefore Brinell hardness value increases. On the other hand, Ellwood et al.[6-7-8] stated that the Brinell hardness value increases till the perlite amount in the matrix reaches to a saturation in the study of theirs in 1959. They also stated that hardness value remains stable for a while with tin addition after the saturation point (after 0.1% Sn) and they indicated decreases in excess loads. In this study, results supporting and close to the works of Elwood.

It can be said that the tin alloy thins the lamella thickness up to 0.12% when microstructure results are examined (Figure 10). Lamella sizes of the sample having 0.09% tin in Figure 9 are detected as A3-A4 according to the ASTM standards. Lamellas are thinner and shorter comparing to the other samples. For the sample having 0.15% Sn in Figure 11, on the other hand, it exhibited a trend towards more dispersed graphite morphology and pelletizing in certain locations while badges also occur. This result is in consistency with the results of Y. Lyu et al.[5]

The closest value to the sample having 0.4% Cu in Figure 6 (70% perlite) is obtained with the sample having 0.09% Sn (75% perlite) when perlite ratios in the matrix structures are compared. The perlite ratios of the samples having 0.12% and 0.15% Sn increase about 90%. This shows that very little amounts of tin element can change matrix structure of gray cast iron from ferrite to perlite by increasing the precipitation trend of cementite in the morphology of the gray cast iron as not massive cementite but combined cementite.

A. Propositions

Making tin addition for gray cast irons in a pot can be more convenient for alloying efficiency. Some amount of loss can be observed if it is done in oven.

Better mechanical properties can be attained for the produced samples if heat treatment processes such as normalization or tempering are done. Ductile-brittleness transition temperatures could be calculated for impact strength in the extent of the study. However it could not be calculated due to limited feasibility.Tin element with lower amounts can be used for the same effect instead of copper element in order to increase perlite ratios and hence hardness in foundries. Accordingly costs can be reduced further.

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