Effect of interlamellar spacing on tensile strength gray cast iron with copper variations

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Abstract. Gray cast iron is a type of cast iron which has a flakes graphite forms that have vibration damping properties, as well as good mechanical properties, so this material is widely used in various types of equipment and structures. Addition of necessary elements is one way to improve the mechanical properties of gray cast iron. Giving the portion of copper can increase the formation of graphite on eutectic transformation but reduce the formation of graphite on eutectoid transformation, thereby increasing the amount of pearlite. The results of the SEM (Scanning Electron Microscope) test showed an increased number of pearlites, followed by increasingly interlamellar spacing. Denser interlamellar spacing is obtained by increasing the percentage of a copper element in gray cast iron. The results of tensile testing conducted in this study also showed that an increase in the percentage of copper is able to increase the tensile strength. So, it can be concluded that an increase in the portion of the amount of copper element produces closer interlamellar spacing and increases thereby its tensile strength

1. Introduction

Gray cast iron is one type of cast iron alloy of iron, carbon, and silicon, in which higher carbon content is dissolved in the solid solution of austenite at eutectic temperature. Carbon that exceeds the solubility of austenite will form graphite flakes. Gray cast iron generally contains 2.5% - 4% carbon, 1% - 3% silicon can be added to achieve the desired microstructure (minimum of 0.1% Mn in gray cast iron and a maximum of 1.2% in pearlitic). Sulphur and Phosphorus are present in small quantities as impurities [1, 3]. The properties of gray cast iron include good strength at high temperatures, machinability, modulus of elasticity, wear resistance, and castability of thin-wall products, so that gray cast iron is widely used for various types spare parts in a wide variety of machines and automotive components. Like other cast iron metals, the addition of alloying elements is used to improve the properties of gray cast iron [3].

In general, alloying elements can be classified into three categories. Silicon and Aluminium belong to the first group that increase the formation of graphite and ferrite formation but decreases strength and hardness [4, 5]. The second group contains Nickel, Copper, and Tin, which increase the formation of graphite and the amount of pearlite phase, which subsequently increase strength and hardness [6, 7]. Chromium, Molybdenum, Tungsten, and Vanadium belong to the third group of alloying elements that decrease the formation of graphite and form solid solutions of αFe [3, 8].

The phases in gray cast iron affect mechanical properties, as revealed in some literature. The increasing volume fraction of the pearlite can improve the mechanical properties. As Gladman and

Pickering concluded, the mechanical properties of steel material are not merely determined by the pearlite content but also by the microstructure characteristics. The most important characteristics of the individual phase are the distance between cells and the grain size of pearlite and ferrite [9]. Research conducted by Modi *et al*. confirmed that the strength of ferrite is related to grain size by following the Hall-Petch formula. Likewise, the strength of the pearlite phase also follows the Hall-Petch formula, which is directly related to the interlamellar spacing distance [10].

Several studies have been carried out by Hsu C. H and Lin K. T in ductile cast iron. The content of Cu slightly above 1 % (e.g., 1.13 wt. %) in ductile cast iron induces formation of the predominantly perlite matrix with a large volume fraction of graphite particles and consequently improves hardness, and ultimate tensile strength [11]. However, this study does not discuss the reason for the increased tensile strength with the addition of these elements. L. Collini *et al*. Examined pearlite in cast gray microstructure in three different casting companies. These three companies produce gray cast iron, which has different mechanical properties (tensile strength, fatigue limit) despite having the same phase. Some factors, such as the shape of lamellar graphite, grain size and the presence of inclusions may have given significant influences to the material properties [12].

Research conducted by ELSawy *et al*. Some factors studied the effect of Manganese, Silicon and Chromium on wear resistance and microstructure of gray cast iron, which is applied to sugar factories. It can be concluded that the addition of chromium is able to increase wear resistance due to increased carbide fraction [8]. Zhou Wenbin researched the effect of Niobium on the formation of the NbC phase. The experimental results show that increasing Niobium content improves eutectic graphite and interlamellar distance pearlite spacing is reduced. Based on thermodynamic calculations the formation of NbC occurs before the eutectic reaction. The reduction in interlamellar distance spacing of pearlite mainly due to the reduction in eutectic temperatures with the addition of niobium. In addition, properties including hardness and wear resistance increase after the addition of niobium [13].

The purpose of this study was to determine the effect of the interlamellar spacing pearlite, on the tensile strength, which was carried out on gray cast iron material. The relationship between tensile strength and interlamellar distance was analysed. For this purpose, gray cast irons (FC200) with variations of Copper content (Cu 0.3%; 0.4%; 0.5% and 0.7%) were used to produce variations of interlamellar spacing of pearlite.

2. Methodology

This research was conducted by determining the fixed and varied parameters, where the Copper element in gray cast iron (FC 200) was varied in a percentage of Cu 0.3%; 0.4%; 0.5% and 0.7%. Other parameters such as the cooling rate, the type of moulding sand used, the size of the test sample cast module, alloying elements, etc. are considered constant. Sample patterns were then made with sizes and shapes according to the JIS Z 5501 standard. Patterns are used as a mall for mould making using green sand Figure 1a [14].

During the melting process, the chemical composition of the gray cast iron is controlled to achieve the target. Optical Electron Spectrometer (OES) ARL 4350 was used to determine the chemical composition. After achieving the desired composition, the gray cast iron liquid is poured into a ladle that has previously been given Copper. The amount of Copper is according to the calculated weight percentage. The liquid is then poured into the mould.

Preparation of metallographic sample includes grinding, polishing and etching in a 5% nital solution (5 ml of HNO3 dissolved in 99 ml of ethanol (95%) or methanol (99%)) [15]. The microstructure was observed using scanning electron microscope (SEM) brand Hitachi SU 3500 and Olympus GX71 with DP 12 Optical Microscope (OM) structural analyser software. Testing SEM (Scanning Electron Microscope) is conducted to analyze the microstructure of a phase with a higher accuracy, which is necessary to observe the pearlitee phase and analyseze the interlamellar spacing distance of pearlite.

Tensile testing is carried out by preparing a test sample of a size that is in accordance with the proper standard JIS Z 2201. The sample size of the type 8C with a test diameter of 20 mm is applied Figure 1b [16].

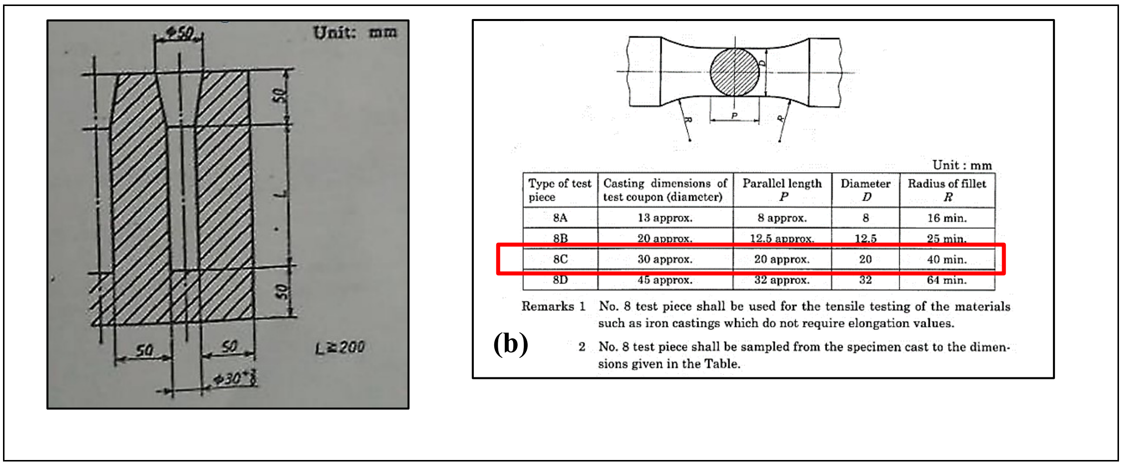

Figure1. (a) The shape and size of the mould according to JIS G 5501 standard, (b) tensile test sample form refers to JIS standard Z 220.

3. Results and discussion

3.1. Composition testing

Table 1 is the result of composition testing conducted the alloying process: In general, the composition of the metal has met the target, although there were slight deviations in the Copper contents (0.299% instead of 0.3% and 0.381% instead of 0.4% as targeted) Excessive contents of Copper occurred also for the target of 0.5% and 0.7%. The testing of chemical composition showed instead of those target copper contents of 0.529% and 0.744%. However, the deviation of copper contents remained in the range of observed area.

Table 1. Composition test results.

Cu Addition	Alloying elements (%)						
	C	Si	S	P	Mn	Cu	Fe
0.30%	3.395	1.884	0.012	0.013	0.605	0.299	93.717
0.40%	3.456	1.866	0.013	0.012	0.597	0.381	93.598
0.50%	3.409	1.897	0.012	0.012	0.601	0.529	93.464
0.70%	3363	1.876	0.012	0.013	0.604	0.744	93.309

3.2. Metallographic testing

Metallographic testing carried out before etching is aimed to analyze the distribution, shape and the size of graphite formed. Meanwhile, the test after etching by using a 3% nital etching is used to analyze the phase formed and the percentage of phase produced.

As shown in Figure 2a to 5a, in general, there is no difference in term of the shape, distribution, and size of graphite for all of the four variations. The graphite has a lamellar shape with a random distribution of A-type, while the graphite size of 4 is confirmed [17].

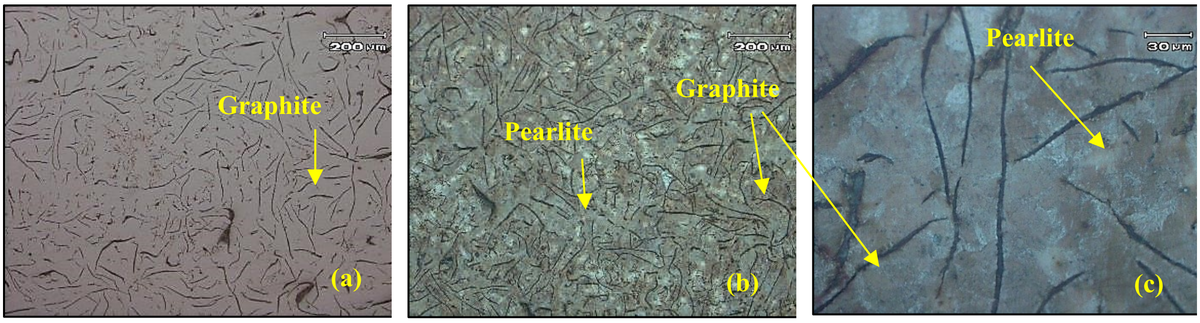

Figure 2. (a) Micrographs of 3% gray cast iron Copper not etched, (b) etched with 3% Nital, (c) etched with 3% Nital in higher magnification.

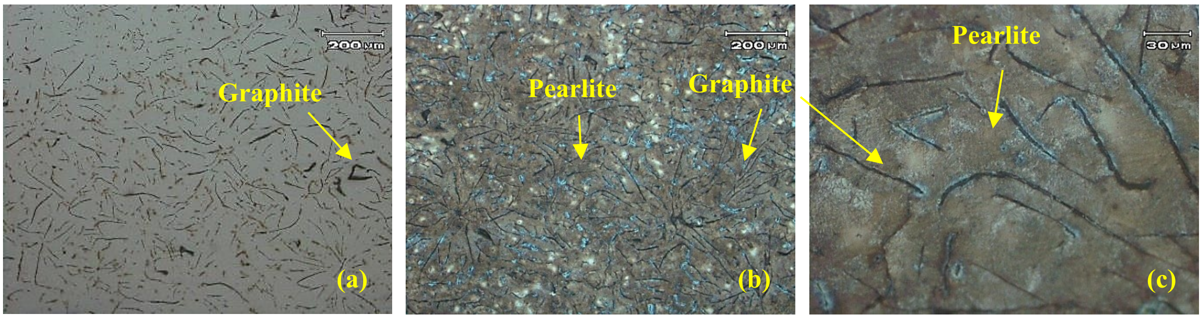

Figure 3. (a) Micrographs of 4% gray cast iron Copper not etched, (b) etched with 3% Nital, (c) etched with 3% Nital in higher magnification.

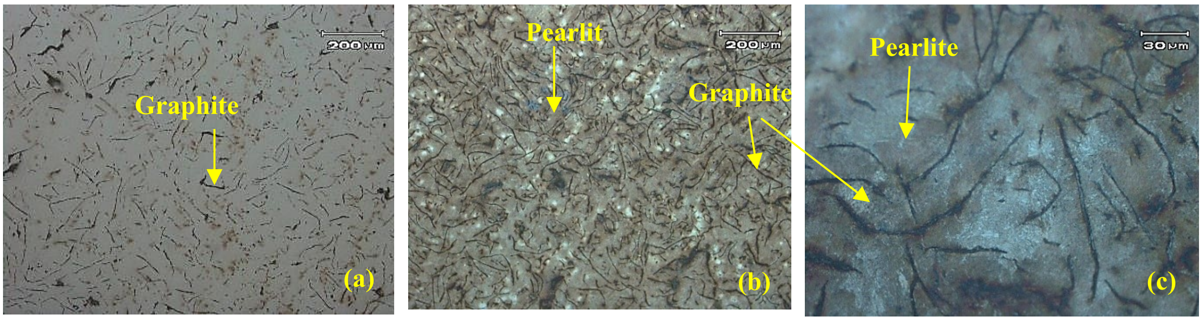

Figure 4. (a) Micrographs of 5% gray cast iron Copper not etched, (b) etched with 3% Nital, (c) etched with 3% Nital in higher magnification.

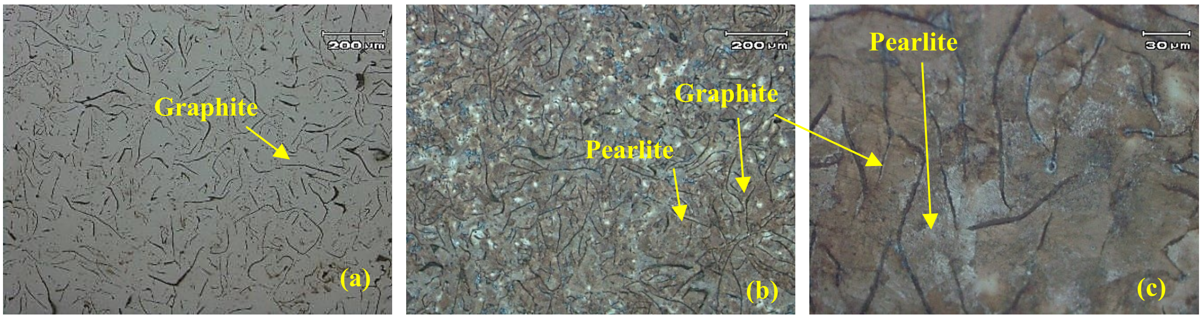

Figure 5. (a) Micrographs of 7% gray cast iron Copper not etched, (b) etched with 3% Nital, (c) etched with 3% Nital in higher magnification.

From Figure 2b and 2c, up to Figure 5b and 5c with variations of 0.3%, 0.4%, 0.5% and 0.7% Copper, it can be seen that in all variations the basic microstructure is pearlite. The phases formed are entirely pearlite or 100% pearlitic. This complies with a study from Bagesh Bihauri *et al.*, which states that Copper is not possible to form free carbides in cast iron. The Copper element maintains the pearlite structure and smoothest pearlite at a concentration of 0.3% The addition of more than 0.3% of copper promote a microstructure of 100% pearlite. Higher copper content forms feiner pearlite (smaller interlamellar distance), which is quantitatively be verified with SEM.

3.3. Distance of interlamellar spacing of pearlite structure
To observe the interlamellar spacing differences that occur after the addition of the element Copper, with variations of 0.3-0.7%, SEM (Scanning Electron Microscope) tests were performed. SEM tests are performed to obtain quantitative values the addition of Copper in gray cast iron. SEM testing is carried out at two different locations in each variation of Copper, and five measurement points for each location. The following are the results of SEM testing can be seen in Figure 6.

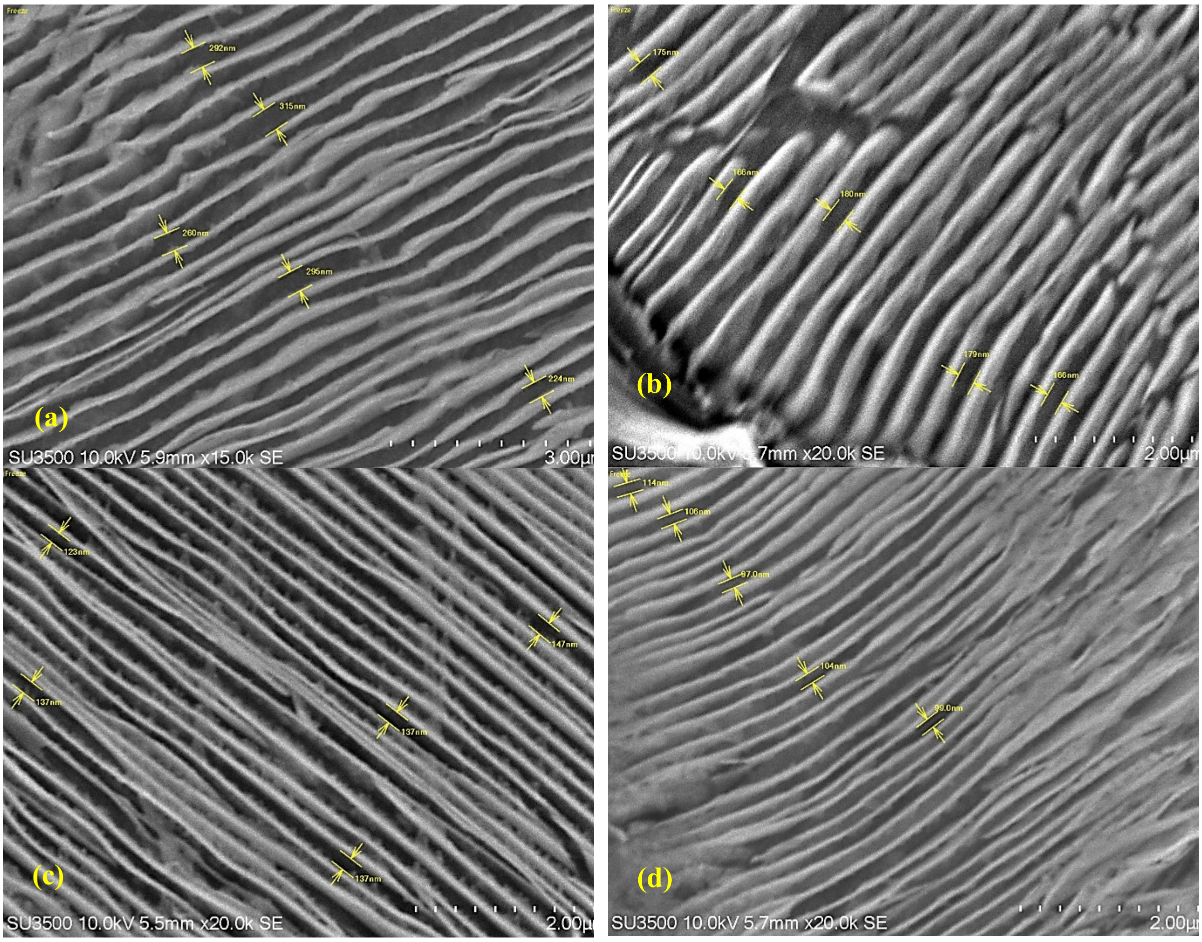

Figure 6. (a) SEM test results of pearlite cast iron containing 3% Copper, (b) 4% Copper 5%, (c) Copper, (d) 7% Copper.

SEM Test Results, as described in Figure6 with a magnification of 15.000–20.000 times reveal the effect of added copper to FC 200 gray cast iron morphologically. It can qualitatively be seen that the increasing copper alloy element promote denser pearlite grains, whereas in quantitative data of the interlamellar distance of pearlite can be measured using SEM. Table 2 shows the interlamellar spacing of pearlite obtained at 2 locations for each variation where each variation was measured at 5 points. Figure 7 describes the interlamellar spacing of pearlite.

Table 2. Interlamellar spacing of pearlite each variation.

Copper content	Interlamellar spacing (nm)					Average (nm)
	Point 1	Point 2	Point 3	Point 4	Point 5	
0.30%	129 292	134 315	128 260	126 295	133 224	203.6
0.40%	175 155	166 161	180 173	179 168	166 169	169.2
0.50%	128 123	145 137	135 137	126 137	115 147	133
0.70%	108 114	104 106	107 97	112 104	112 99	106.3

The results of randomly conducted tests on the distance of interlamellar spacing for each variation are shown Figure 7. The addition of 0.3% Copper results in an average density value of 203.6 nm, while the 0.4% addition produce an average density value of 169.2 nm respectively. The 0.5% addition has an average density value of 133 nm, and 0.7% has an average density value of 106.3 nm.

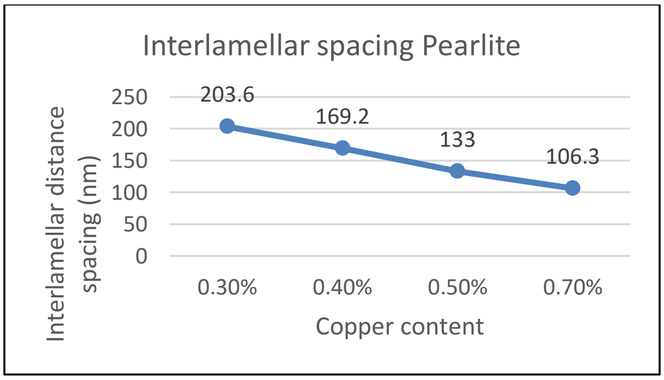

Figure 7. Interlamellar spacing of pearlite.

From these results, it can be concluded that the more increasing the variation of Copper the smaller the value of the density obtained and the closer the distance between the lamellar formed. This conclusion is at in accordance with research conducted by Bagesh Bihari *et al.*, which states that the Copper element can refine pearlite [18].

According to the results, the refinement of pearlite grains occurs due to the presence of alloying elements of carbon. The diffusion of carbon into graphites is inhibited by copper so that diffusion of carbon does not occur. Carbon forms consequently Fe_3C/cementite compounds in pearlite so that the pearlite becomes denser [3, 7]. Copper increases the potential for graphite formation in eutectic transformations but decreases graphite formation in eutectoid transformations, thereby increasing the amount of pearlite [19].

3.4. Tensile testing

Figure8. shows the average values of three data with the smallest standard deviation for each variation of the sample. From Tensile test results describe that the variation of 0.3% Copper produced a tensile strength of 216.463 N/mm^2 which matched to the smallest value, then the variation of 0.4% has increased the value of tensile strength to 233.98 N / mm^2, at variation 0.5% experienced an increase to 240.277 N/mm^2 and 0.7% variation had the highest tensile strength value of 245.323 N/mm^2. Based on the test

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results it can be concluded that the addition of copper alloy elements also increases the value of the tensile strength.

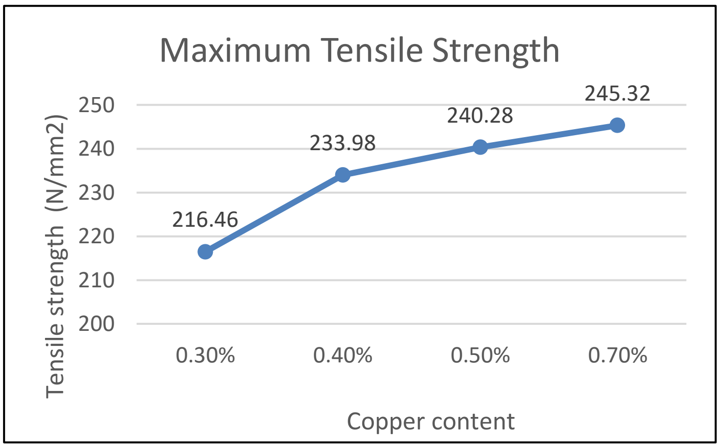

Figure 8. Average tensile strength.

The increase of tensile strength is due to differences in the pearlite phase formed in each variation wherein the increasing content of copper promotes a denser interlamellar spacing of pearlite [3]. This is then confirmed with the hall-petch formula which states that increasing density of interlamellar spacing pearlite or finer pearlite will increase the tensile strength.

4. Conclusions

An increase in the amount of copper in gray cast iron reduces the interlamellar spacing of pearlite. The addition of copper elements from 0.3% to 0.7%, decreased interlamellar spacing. Distance interlamellar pearlite spacing in the microstructure from 203.6 to 106.3 nm. Decrease interlamellar spacing density is caused by the inhibition of carbon diffusion during the eutectoid reaction. These obstacles occur because of the influence of Copper so that graphite is difficult to be formed and the formation of cementite in the pearlite phase is well assisted. an increased interlamellar density of the pearlite phase spacing is conclusively obtained.

The results of tensile testing conducted on a various percentage of copper elements show increased tensile strength relatively, which is considered is due to the dense interlamellar spacing distance or the finer pearlite that occurs.

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