Chapter 9

Accuracy Improving Methods in Estimation of Graphite Nodularity of Ductile Cast Iron by Measurement of Ultrasonic Velocity

Minoru Hatate, Tohru Nobuki and
Shinichiro Komatsu

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/50596

1. Introduction

Ductile cast iron is one of the very useful and economical engineering materials and it is often used as the material for the members that are required good mechanical properties such as high tensile strength and high elongation. The microstructure of ductile cast iron basically consists of two kinds of basic components: the metallic matrix and many spheroidal graphite nodules dispersed among the matrix. As the bonding strength at the boundaries between the matrix and the graphite nodules is considered to be very little or nothing at all and also as the mechanical properties of the graphite nodules themselves are considered to be much less than those of the matrix, the tensile properties of ductile cast iron are considered to depend mostly upon the two kinds of conditions of the matrix. One of the conditions of the matrix is its microstructure (such as ferrite, pearlite and others), and the other one is the graphite nodularity which determines the continuity condition of the matrix. The latter is usually expressed by a kind of comparison number called “graphite nodularity” or “graphite spheroidizing ratio” which indicates how much the outer shapes of the graphite nodules are close to those of perfect spheres.

In a case of a ductile cast iron product under a tensile load the graphite nodules are considered to act as voids or cavities. This means that the presence of graphite nodules produces a kind of discontinuity effect to the matrix. Therefore, in the case of 100 % in graphite nodularity, which means that the outer shapes of the graphite nodules are almost perfect spheres, the continuity condition of the matrix produced by these graphite nodules is considered to be the best, and good mechanical properties of ductile cast iron can be expected. However, when the outer shapes of graphite nodules collapse from perfect spheres to the CV (compacted vermicular) side, the continuity condition of the matrix becomes worse and it results in some decreasing in mechanical properties of the ductile cast iron, especially in tensile strength, elongation and fatigue strength. Therefore, many users of ductile cast iron products tend to demand higher graphite nodularity values for the producers of the ductile cast iron products.

One of the authors belongs to a research group of nondestructive evaluation of the properties of castings in The Japan Foundry Engineering Society, and one time they held a round robin test of ultrasonic velocity for several ductile cast iron specimens with some ten different laboratories of companies and research institutes. Although they used same specimens in all the laboratories they found that the reported values of the ultrasonic velocity of a same specimen varied considerably at each laboratory. Then, they held a round robin test once again with the information of the thickness of each specimen. This time each group member measured the ultrasonic velocity of each specimen with a same value for its specimen thickness. As the results they could obtain the ultrasonic velocities which are very close to each other regardless the testing laboratories. This experience informed us that the small error in measurement of specimen thickness may result in a considerable error in the measurement values of ultrasonic velocity and thus in the graphite nodularity estimated. There may be many kinds of approaching methods to improve the accuracy in the measurement of ultrasonic velocity of ductile cast iron, but in this study we tried to approach it from the view point of measurement error in specimen thickness and the other matters related to it.

2. Relations between graphite nodularity and ultrasonic velocity in ductile cast iron

Figure 1 shows the various shapes of graphite nodules which are introduced in one the standards to measure the graphite nodularity (or graphite spheroidizing ratio) of ductile cast iron [1]. Although the graphite shape of the type of the lower far right, which is the closest to perfect spheres among the five shapes shown, is ideal to obtain the best mechanical properties in ductile cast iron from the view point of graphite shape. But sometimes we may happen to have the graphite nodules which have modified to the shapes of the other types shown in the figure due to the fading phenomenon of graphite nodules or others. So, in a case of a duct cast iron whose graphite shapes correspond to plural types of graphite shape shown in figure 1 we usually use a "graphite nodularity" value" to express numerically the average shape of the graphite nodules of the iron. In the case of the standard (JIS:G5502) which classifies the graphite shapes according to figure 1 the nodularity values of the graphite shapes are stipulated to be 0 %, 30 %, 70 %, 90 % and 100 % from the upper far left to the lower far right in the figure 1 respectively [1]. And in a case of a ductile cast iron whose graphite shapes correspond to plural types of them its graphite nodularity value is obtained from the calculation of the weighted average of the "graphite nodularity" and "number of nodules" of each type which are observed and counted through a microscope.

http://dx.doi.org/10.5772/50596

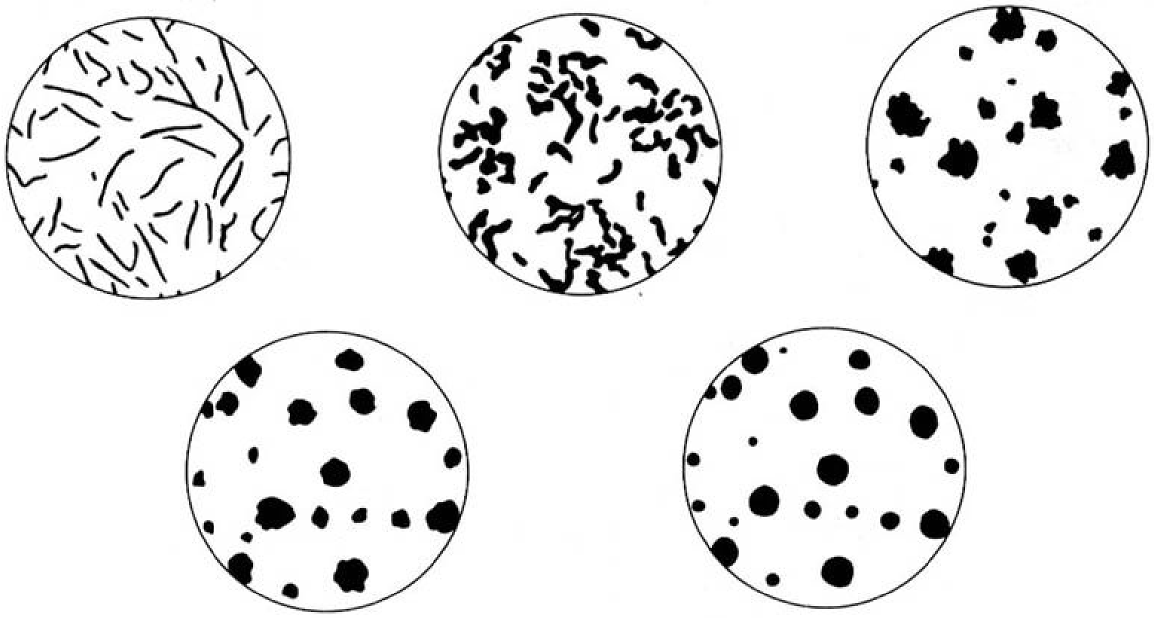

Figure 1. Various shapes of graphite nodules introduced in JIS:G5502 (Nodularity is 0%, 30%, 70%, 90% and 100% from the upper far left to the lower far right respectively) [1].

As described in the section of introduction the graphite nodularity determines the continuity condition of the matrix, and it relates largely not only to the mechanical properties but also to the ultrasonic velocity in ductile cast irons. Figure 2 is an example which shows the relation between graphite nodularity and ultrasonic velocity of ductile cast irons [2]. Although a little bit wide band is seen along the main thick line, the figure indicates that the ultrasonic velocity is largely related to the graphite nodularity in ductile cast iron. The width of the band is considered to be mainly related to the other factors beside graphite nodularity such as the amount of graphite (which may correspond to the carbon content of the iron), the sizes of graphite nodules (which may correspond to casting thickness), kind of heat treatments if any, and others. However, in a case of mass production of the products of one kind this band may become narrower and a more precise relation line is considered to be obtained.

Figure 2 indicates that the measurement of ultrasonic velocity is a useful method to evaluate or estimate nondestructively and also simply the graphite nodularity of ductile cast iron. However we find that the difference in ultrasonic velocity caused by the difference in graphite nodularity is not so large comparing to the ultrasonic velocity value itself, i.e. the difference in ultrasonic velocity which corresponds to the difference in graphite nodularity between 60 % and 80 % is merely some 130 m/s among the some 5630 m/s which is the velocity at the point of 80 % in graphite nodularity. As the range of graphite nodularity between 60 % and 80 % is the range subjected mainly to be inspected at a common commercial foundry factory, and as the difference of the ultrasonic velocity in this range is very small comparing to some 5630 m/s which is the velocity at the point of 80 %, the measuring methods of ultrasonic velocity are considered to require very high accuracy in many points.

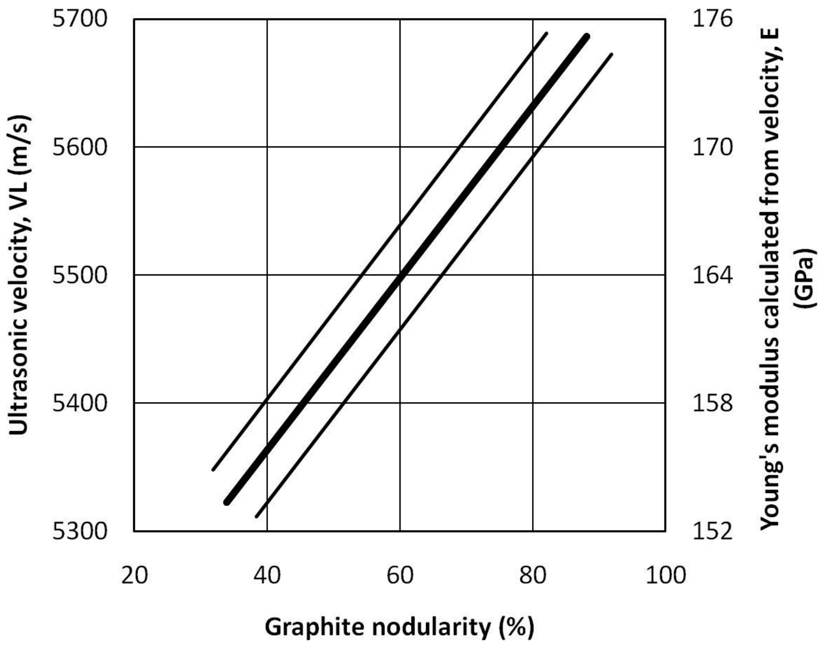

Figure 2. An example of the relation between graphite nodularity and ultrasonic velocity in ductile cast irons [2].

The ratio (R) of the difference of ultrasonic velocity (=130 m/s) between 60 % and 80 % in graphite nodularity to 5600 m/s (the standard ultrasonic velocity of ductile cast iron) is calculated as follows and is found to be relatively small.

$$R = 130(\mathrm{m} / \mathrm{s}) \;/\; 5600(\mathrm{m} / \mathrm{s}) = 0.0232 = 2.32\ \%$$

As the difference of 20% in graphite nodularity corresponds to this difference of 2.32% in ultrasonic velocity, the difference of 1 % in graphite nodularity corresponds to the difference of only 0.116 % in ultrasonic velocity. Figure 2 and the detailed values introduced above are the data of one example and these may be somewhat different in details in other cases of experiments, but they are considered not to be so different from this figure within the material field of ductile cast irons. Therefore we should know that the measurement of ultrasonic velocity should be conducted with very high accuracy all the way.

Figure 3 shows another example which indicates a practical usage of ultrasonic velocity in ductile cast iron. This figure shows a relation between the tensile strength of ductile cast iron and its product of ultrasonic velocity and Brinell hardness [3]. This figure shows a very good correlation between them, and the reason for this can be explained as follows. The tensile strength of an ordinary ductile cast iron (ferrite/pearlite mixed in matrix microstructure) is considered to be determined mainly by two basic factors concerning to its microstructure. The one factor is the graphite nodularity which determines the continuity condition of its matrix and thus the ultrasonic velocity. The other factor is the microstructure condition (mainly the volume fractions of ferrite and pearlite) of its matrix, which is considered to be largely related to its Brinell hardness. As these two factors of the microstructure are considered to determine synergistically the basic tensile strength of ductile cast iron, the product of the ultrasonic velocity value and the Brinell hardness value is considered to become a kind of index value to estimate roughly the tensile strength of an unknown ductile cast iron.

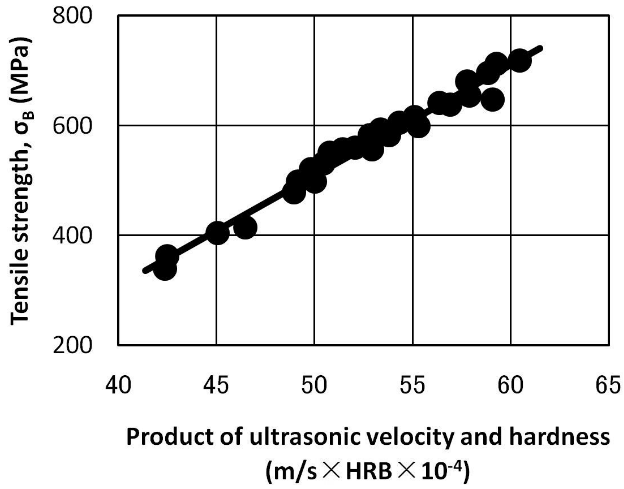

Figure 3. An example of the relation between tensile strength and product of Brinell hardness and ultrasonic velocity in ductile cast iron (ferrite/pearlite matrix) [3].

The close relationship between ultrasonic velocity and graphite nodularity in ductile cast iron is considered to be produced from the close correlation between modulus of elasticity and ultrasonic velocity in solid materials, which is shown in equation 1.

$$V = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \tag{1}$$

where, V is ultrasonic velocity, E is modulus of elasticity, ρ is density and ν is Poisson's ratio.

The modulus of elasticity of ductile cast iron is affected largely by the continuity condition of the matrix, and the continuity condition of the matrix is determined by graphite nodularity. In other words, the graphite nodularity determines the continuity condition of the matrix, and the continuity condition of the matrix determines the modulus of elasticity, and the modulus of elasticity determines the ultrasonic velocity.

Shiota and Komatsu (one of the authors of this paper) once reported a paper on the close relationship between graphite nodularity and tensile strength of ductile and CV cast irons from the view point of “the effective sectional area ratio” of matrix which is determined by graphite nodularity [5]. The continuity condition of matrix mentioned above is similar to the view point of that paper.

3. Experimental procedures

The measuring equipments of ultrasonic velocity used in this study were a NDT tester of type “AD-3212/3212A” made by A&D and a transducer named “V110” made by “PANA-

METRICS" in Japan. The frequency used was 10 MHz. Figures 3 and 4 show the NDT tester and the transducer used in this study respectively. Several kinds and groups of the specimens were prepared in order to investigate the influence of several kinds of errors concerning to specimen thickness. The details of the specimens used will be introduced at each section in the Results and Discussions. The words "specimen thickness" used in this paper means the distance for the propagation of ultrasonic waves in a specimen and it is sometimes referred as "specimen length" or "specimen width" in some literatures.

Figure 4. Ultrasonic velocity tester used.

Figure 5. Transducer used.

4. Results and discussions

4.1. Affection of measurement error in specimen thickness

As mentioned in the introduction the measurement error in specimen thickness is considered to be produced easily by the difference in inspector and/or time of the measurement. Then, in order to see a sample case of this kind of error we asked several students who had no measurement experience at first to measure the ultrasonic velocity of a carbon steel (S35C) bar specimen with 32 mm and 40 mm in diameter and length respectively. Figure 6 shows the results of the measurements. This figure indicates that the measurement results varied largely depending on inspector and time of the measurements even in a case of a same specimen. As we found that these large errors had been produced mainly from the rough measurement manners of the specimen thickness by the amateur students we discussed on the scale (magnitude) of the errors in ultrasonic velocity which can be created by the measurement error of specimen thickness more precisely.

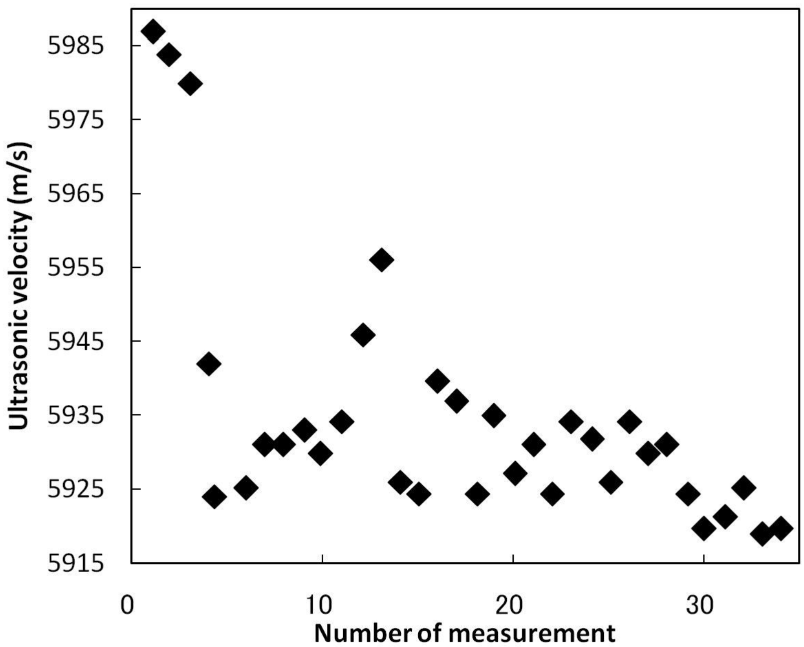

Figure 6. An example of measurement error in ultrasonic velocity for a same specimen caused by the difference of inspectors and time.

Usually, the measurement of ultrasonic velocity of a specimen is conducted by contacting a transducer to one surface of a specimen, and the ultrasonic velocity of the specimen is obtained by the calculation from the two measured values. The first one is the specimen thickness which corresponds to the distance between the surface facing to the transducer and the surface that reflects the ultrasonic waves, and the second one is the round-trip propagating time of ultrasonic waves between these two surfaces. The ultrasonic velocity of a specimen is calculated by using the equation 2.

$$V = \frac{2L}{T} \tag{2}$$

where, V is ultrasonic velocity, L is specimen thickness and T is round-trip propagating time of ultrasonic waves. The "2" in the numerator corresponds to the round trip propagating distance of the ultrasonic waves. In many cases of ductile cast iron products their thickness (L) to be objected for the measurement of ultrasonic velocity are up to some 100 mm or so and they are usually measured by using vernier calipers (slide calipers). The minimum measurement unit by a conventional vernier caliper is 0.05 mm. Following to the equation 2, we tried to figure out how much velocity error (E_V) would be created in the case that a measurement error of 0.05 mm was made in the specimen thickness of 50 mm. And also we tried to calculate how much graphite nodularity error (E_N) would be created in this case assuming that the difference of 130 m/s in ultrasonic velocity corresponds to the difference of 20 % in graphite nodularity which was mentioned in Figure 2.

$$\text{Velocity error } (E_V) = \frac{2 \times 0.05(\text{mm})}{50(\text{mm})} \times 5600(\text{m / s}) = 11.2(\text{m / s})$$

$$\text{Nodularity error } (E_N) = \frac{11.2(\text{m / s})}{130(\text{m / s})} \times 20(\%) = 1.72(\%)$$

These results indicate that a small measurement error of 0.05 mm in specimen thickness, which is usually paid very small attention because of its being the minimum measuring unit of vernier caliper, may result in a considerable error in ultrasonic velocity measured and thus graphite nodularity estimated. These values shown above are for the case of 50 mm in specimen thickness but these values are considered to increase in the case of specimen thickness less than 50 mm and to decrease in the case of specimen thickness larger than 50 mm. Then, we discussed to see the co-relationships among the four valuables relating to each other deeply ; true specimen thickness (L), measurement error in specimen thickness (E_L), measurement error in ultrasonic velocity (E_V) and measurement error in graphite nodularity (E_N). The measurement error in ultrasonic velocity may be calculated by equation 3, and the measurement error in graphite nodularity estimated from E_L may be calculated by equation 4.

$$E_V(\text{m / s}) = \frac{2 \times E_L}{L} \times 5600(\text{m / s}) \tag{3}$$

$$E_N(\%) = \frac{E_V(\text{m / s})}{130(\text{m / s})} \times 20(\%) \tag{4}$$

Figure 7 shows the relations of Equation 3 which is the relation between ultrasonic velocity error (E_V) and specimen thickness (L) in the cases of measurement errors (E_L) of 0.05 mm, 0.1 mm, 0.2 mm and 0.5 mm in specimen thickness. This figure indicates that even a small measurement error of 0.05 mm which is the minimum measurement unit of a conventional vernier caliper creates considerably larger ultrasonic velocity errors, especially in the range of relatively smaller values in specimen thickness. These results may indicate that we need to use a micrometer instead of a vernier caliper and to measure the thickness for several times precisely in order to obtain good measurement results especially in the case of a relatively smaller specimen thickness.

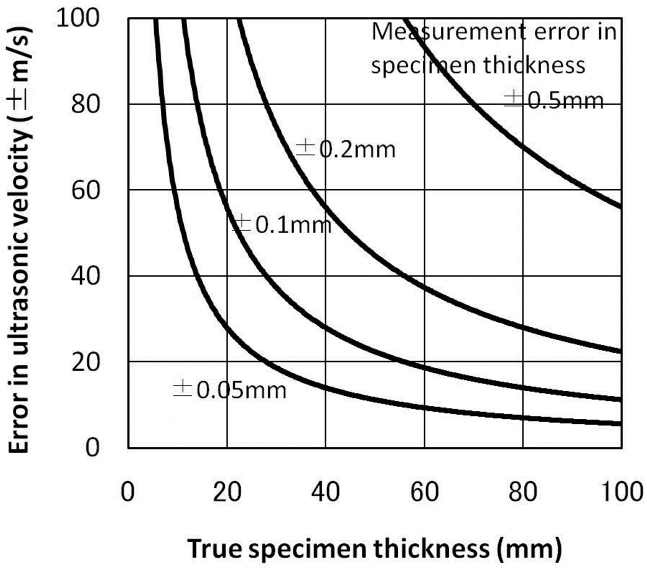

Figure 7. Relations between the specimen thickness and the ultrasonic velocity error at various measurement errors in specimen thickness.

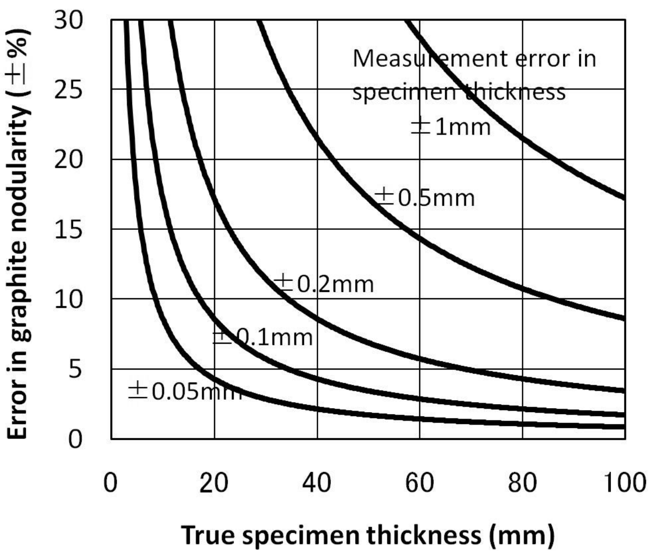

Figure 8. Relations between the specimen thickness and the graphite nodularity error at various measurement errors in specimen thickness.

Figure 8 shows the relation of Equation 4 which is the relation between graphite nodularity error (E_N) and specimen thickness (L) in the cases of measurement errors (E_L) of 0.05 mm, 0.1 mm, 0.2 mm and 0.5 mm in specimen thickness. This figure indicates the similar tendencies to those of Figure 7, because E_N is in direct proportion to E_L as shown by Equation 4. These equations and figures indicate that the measurement error of 0.05 mm in specimen thickness of 20 mm creates some 4.3 % in the error of graphite nodularity, which can't be ignored easily in actual production of ductile cast iron products. These results are considered also to recommend the inspectors to use a micrometer instead of a vernier caliper and to make more precise measurements in specimen thickness especially in the case of a relatively small specimen thickness.

4.2. Affection of specimen temperature

As the previous section indicated that a small amount of measurement error in specimen thickness may result in a considerable error in graphite nodularity especially in the case of relatively smaller thickness, the authors tried to investigate on the affection of specimen temperature which might be considered to produce some measurement error in specimen thickness because the thermal expansion effect is expected to be produced by the difference of room temperature. Figure 9 shows the measurement results of ultrasonic velocity in the case that a S35C specimen bar with 32 mm in diameter and 80 mm in length was subjected to change its specimen temperature variously between 18 and 26 ℃.

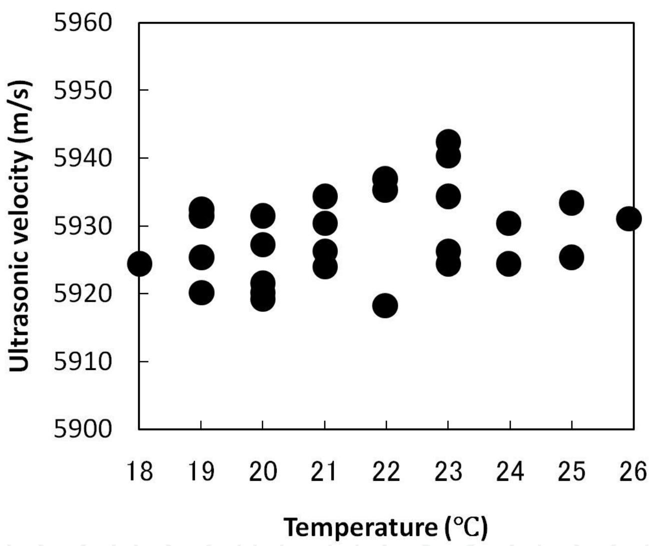

Figure 9. A measurement example of the relation between specimen temperature and ultrasonic velocity (S35C bar).

This figure indicates no significant tendency of the affection of specimen temperature to ultrasonic velocity measured. We also tried to calculate the affection of specimen temperature from the view point of thermal expansion effect. The followings are the calculations for the measurement errors in ultrasonic velocity (E_V) and graphite nodularity (E_N) which may be created by the temperature difference (t) of 20 ℃ in the case that only the specimen thickness becomes larger by the thermal expansion effect and all the other variables are constant. Here, V_0 and L_0 are the ultrasonic velocity and the specimen thickness respectively of the specimen in the original state, and V_1 and L_1 are those in the specimen in the state of 20 ℃

above the original state, and T is the propagating time which is assumed to be constant. The coefficient of linear expansion (α) and the basic value of ultrasonic velocity (V_0) were supposed to be 12 x 10^{-6} (1/℃) and 5600 (m/s) respectively for ductile cast iron.

$$E_V = V_1 - V_0 = L_1 / T - L_0 / T = (1 + at)L_0 / T - L_0 / T = at\ L_0 / T = at\ V_0$$
$$= 12 \times 10^{-6}(1/\square) \times 20(\square) \times 5600(\mathrm{m/s}) = 1.34(\mathrm{m/s})$$
$$E_N = E_V \times 20(\%) / 130(\mathrm{m/s}) = 1.34(\mathrm{m/s}) \times 20(\%) / 130(\mathrm{m/s}) = 0.206(\%)$$

These calculation results are considered also to indicate that the difference in specimen temperature caused by the difference of room temperature within some 20 ℃ gives only a little affection to the measurement error in ultrasonic velocity of ductile cast iron.

4.3. Affection of surface finishing

In many cases at foundry factories the ultrasonic velocity measurement of ductile cast iron products is performed by placing a transducer to the surface of one surface which has been machine-finished to be skin-free and flat by means of using a grinder or a similar equipment, but in many cases the surface of the other end which is subjected to reflect the ultrasonic waves has been left in the condition of as-cast or shot-blasted. In this section we tried to investigate the affection of surface finishing on the measurement errors of ultrasonic velocity of ductile cast iron products.

Figure 10. The specimens with three kinds of surface conditions (as-cast, machined and shot-blasted: 100 mm square, continuously cast bar).

Figure 10 shows the square shaped specimens of ductile cast iron we used in this section. The material of these specimens is a continuously cast square bar of ductile cast iron with 100 mm in two sides, and the heights of the specimens are varied into four kinds from 12.5 mm to 75 mm. This material of continuously cast ductile iron bar was selected for the reason of expectation for better homogeneity in the microstructures of all the specimens with various kinds of thickness because of its uniform solidification rate comparing to those of the materials cast by the other kinds of methods. In order to investigate the affection of surface condition of specimen three kinds of specimens whose surface conditions varied for three kinds were prepared. The surfaces which are subjected to contact to a transducer are machine-finished surfaces in all the specimens but the surfaces which are subjected to reflect the ultrasonic waves were varied for three conditions which are “as-cast”, “machine-finished” and “shot-blasted”, which means that the three kinds of specimens, whose combinations of surface conditions are (a) machined surface / as-cast surface, (b) machined surface / machined surface, and (c) machined surface / shot-blasted surface, were prepared and conducted to the measurement of ultrasonic velocity.

Figure 11 shows the test results of ultrasonic velocity of the specimens whose thickness is 12.5 mm which is the smallest among all the specimens we made, and Figure 12 is the test results of the specimens whose thickness is 75 mm which is the largest among all the specimens.

For each specimen the measurement of ultrasonic velocity was carried out for five times, and the five results of each specimen are illustrated in the figures with a line which connects all of them. So in these figures, the lines indicate only that the data connected by each line are of one specimen, and the order of the data along the X-axis and the inclinations of the lines have no significant meaning at all. However this kind of illustration method is considered to be useful to examine the difference between the averages of the data of each group with comparison to the scale (size) of variation among the data within each group.

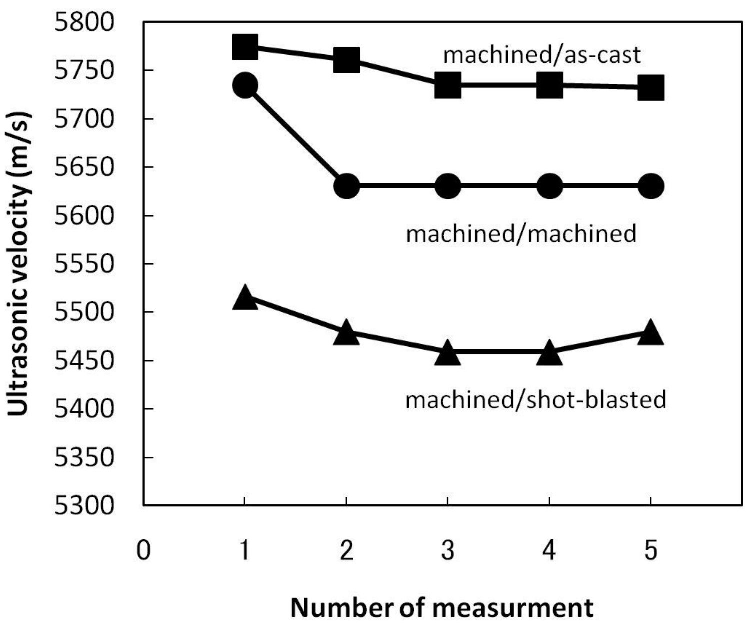

Figure 11. Comparison of the ultrasonic velocity measured by the specimens with various combinations of surfaces (Specimens 12.5 mm thick).

Figure 11 for the specimens 12.5 mm thick shows that the difference between the largest data and the smallest data in each specimen looks much larger than those in the figure 12 for the specimens 75 mm thick. This is considered to be due to the tendency that the measurement error in specimen thickness results in a larger measurement error in ultrasonic velocity in the case of a specimen with a smaller thickness than in the case of a specimen with a larger thickness, which was described in the former section of this paper.

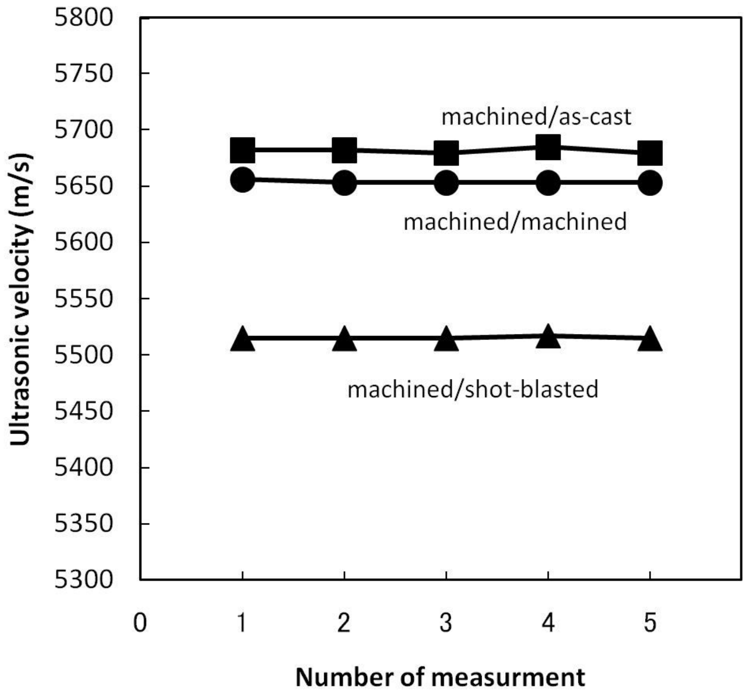

Figure 12. Comparison of the ultrasonic velocity measured by the specimens with various combinations of surfaces (Specimens 75 mm thick).

When we compare the order of the average values of the ultrasonic velocities of these three kinds of specimens in both figures, we can see that the ultrasonic velocity becomes somewhat larger in the case of "machined/as-cast" than in the case of "machined/machined", and also we can see that it becomes somewhat smaller in the case of "machined/shot-blasted" than in the case of "machined/machined". This means that the order of the values of ultrasonic velocities measured by these three kinds of specimens becomes the order shown below. (Note that the surface for the transducer is always a machined surface.)

machined/as-cast > machined/machined > machined/shot-blasted

Among all of the three kinds of the specimens the specimen of machined/machined is considered to be the best to measure the true ultrasonic velocity of the material because its microstructure is more uniform through all the entire length (thickness) of the specimen than the other two specimens with the skins of different kind. This may also be confirmed from the test results that the average ultrasonic velocity of the specimen 12.5 mm thick with machined surfaces is very similar to that of the specimen 75 mm thick with machined surfaces. However, in the case of the specimens with an as-cast surface or a shot-blasted surface the microstructure of the layers beneath these surfaces of reflection is considered to be somewhat different from that of the original material and some measurement error in ultrasonic velocity might be created by this inhomogeneity in microstructure.

Some reasons may be considered for the tendency of becoming somewhat larger of ultrasonic velocity when it is measured by specimens with as-cast surface. From the view point of the measurement error in specimen thickness, the undulation in the as-cast surface, which may be found more often and/or more largely than in the case of machined surface, may cause the specimen thickness to be measured somewhat larger than the true thickness (average of the undulation) of the specimen because the vernier caliper always touches the top of the highest peak in the undulation. As the transmission time is measured by the ultrasonic waves which may be considered to reflect at the cutting section of the average thickness (mid height of undulation) of the specimen, the ultrasonic velocity calculated from equation 2 is considered to pretend to be somewhat larger than the true velocity. Another reason may be considered from the view point of microstructure. Usually the microstructure of the layer of the as-cast surface differs from that of the material inside due to its rapid solidification, oxidization by air, chemical reactions with molds and others. Right now we haven't examined precisely yet, but we estimate that the ultrasonic velocity may be a little bit larger in the as-cast layer than in the material portion beneath the layer because of its finer and harder microstructure and smaller amount and size of graphite nodules due to its rapid solidification.

When we compare the two ultrasonic velocities of the specimens with as-cast surfaces in figures 11 and 12, we find that the ultrasonic velocity measured by the specimen 75 mm thick is a little bit smaller than that by the specimen 12.5 mm thick, and also it is closer to that of the specimens with machined surfaces. This is because the amount of the errors created from the undulation and the difference in microstructure of the layer of as-cast surface is constant regardless the specimen thickness, and its affection to the ultrasonic velocity calculated by equation 2 becomes smaller in the case of a specimen with a larger thickness. In the case of the ductile cast iron specimens or the products with the as-cast surfaces made by sand molds we may need to pay more precise attention to the influence of the measurement error created by the undulation or conditions of their as-cast surfaces. In the case of the as-cast surfaces made by sand molds the measurement error in ultrasonic velocity is considered to be made not only from the undulation of the surfaces. The surface which is used for the measurement of specimen thickness by a vernier caliper may be located at the peaks of the roughness made by sand particles, but the surface which mainly reflects the ultrasonic waves may be located at the bottom of the roughness made by sand particles, and the distance between these two surfaces is considered to give a considerable error in ultrasonic velocity measured. Therefore, in the case of measurement of a ductile cast iron product made by sand molds we are recommended to remove the as-cast skins totally not only from the transducer side but also from the reflection side of ultrasonic waves.

Figures 11 and 12 also show that the ultrasonic velocity measured by the specimens with shot-blasted surfaces tends to become a little bit smaller than the true velocity value which is measured by the specimens with machined surfaces. This is considered to be resulted from the affection of the surface layer which has been deformed plastically by shot blasting. As the modulus of elasticity of a ferritic material becomes smaller in a plastically deformed con-

http://dx.doi.org/10.5772/50596

dition than in an elastic condition, the ultrasonic velocity of a ferritic material also becomes smaller in a plastically deformed condition than in an elastic condition because the ultrasonic velocity is in direct proportion to the modulus of elasticity as shown in equation 1. As the ultrasonic waves takes more time to propagate through the surface layer which has been plastically deformed by shot-blasting, the total length of propagation time becomes a little bit longer than in the case of the specimen without the shot-blasted layer. And this seemingly longer time results in a seemingly smaller ultrasonic velocity through equation 1. Therefore, in the case of measurement of the castings with shot-blasted surfaces, we are recommended to remove the plastically deformed layer totally in measurement or to revise the measured values with the results from another experiment using similar materials.

4.4. Affection of non-parallelism of specimens

In an actual measurement of ultrasonic velocity of a specimen we measure the distance and the propagation time between two surfaces: the surface facing to a transducer and the surface for the reflection of ultrasonic waves. In many cases we check the parallelism of these two surfaces by means of the visual checks with inspector's eyes. However our results shown in previous sections have indicated that even a small measurement error in specimen thickness may result in a considerable measurement error in ultrasonic velocity and thus graphite nodularity, and a small non-parallelism in the two surfaces is considered to produce somewhat errors in these measurement results. In this section we investigated on the affection of the non-parallelism of these two surfaces of specimens.

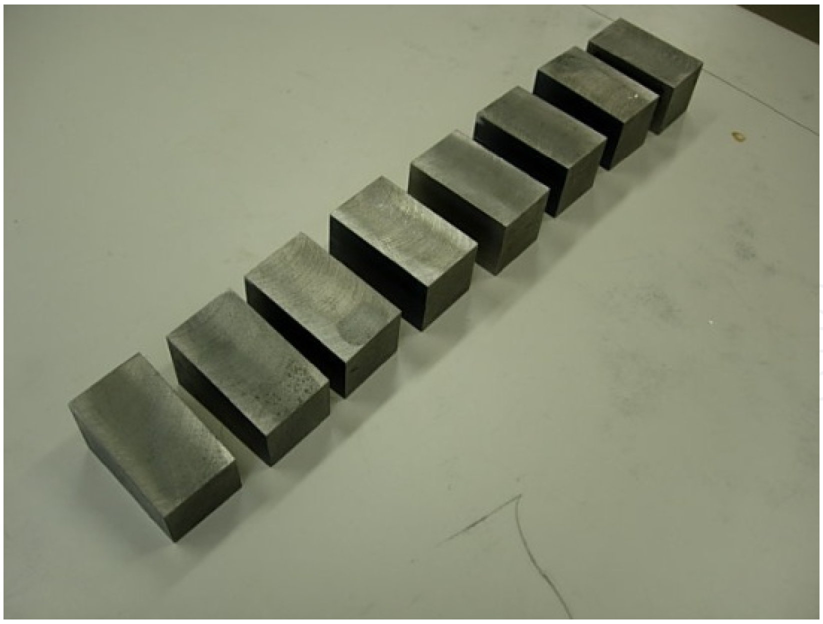

Figure 13. Specimens whose non-parallelism angles are differed variously.

Figure 13 shows the specimens which we used in this section. They are made from a material of continuously cast ductile iron, and the size of each specimen is approximately 30 x 30 x 50 mm.

The surface for reflection of ultrasonic waves of each specimen was made to have an angle of non-parallelism between 0 and 10 degree against to the surface for a transducer. Therefore, even in one specimen the thickness value is not constant. Figure 14 shows an example of a specimen in the group. The ultrasonic velocity of a specimen was measured at the three points marked A, B and C shown in figure 14. The point A corresponds to the largest, the point B corresponds to the average (middle) and the point C corresponds to the smallest among these three points in specimen thickness. The ultrasonic velocity at each point was calculated from the propagating time and the thickness which were measured at each point. For example, the thickness at point A was obtained by measuring the distance from point A to the intersection point of the straight line of the surface for reflection of ultrasonic waves and the straight line which is perpendicular to the surface for the transducer at point A. Although we measured all the specimens shown in figure 13, we found that the affection of non-parallelism between the two surfaces is extraordinarily large, therefore we introduce only about the case of 1 degree which was the smallest among all the specimens we made.

Figure 14. Three measuring points of a specimen (A: largest, B: middle, C: smallest in thickness).

Figure 15 shows the results of the ultrasonic velocity measurements at the three points (A, B and C) of the specimen whose non-parallelism angle is 1 degree. At each measuring point we measured velocity for five times, and the results of them were illustrated with a connecting line in the figure. Figure 15 indicates that the largest ultrasonic velocity was measured at point A which is the largest point in specimen thickness among all the three points. The smallest ultrasonic velocity was measured at point C which is the smallest point in specimen thickness among the three, and the ultrasonic velocity at point C which is the middle point between points A and B was measured approximately to be the average of the two at the points A and B. The reason for the relatively larger ultrasonic velocity at point A is considered as follows. Although the ultrasonic waves are sent off at point A they reflect not only at the opponent point (the point where the thickness was measured from) of the point A but also from the points (place) which are smaller than the thickness at the point A because the ultrasonic waves reflect not at one point but at a face with a some kind of area in the surface of reflection. Then, the ultrasonic waves which were used to read the propagation time may contain the affections of the waves reflected at the points which are a little bit smaller in specimen thickness than at the point A, and it results in a little bit shorter time in propagation, and then a little bit larger ultrasonic velocity was measured from equation 2. On the other hand, in the case of the relatively smaller ultrasonic velocity at the point C is also considered to be resulted from the opposite reason to that at the point A mentioned above. Figure 15 also shows that the difference in ultrasonic velocity between the two points A and B is as large as some 170 m/s, which corresponds to the measurement error of some 26% in graphite nodularity. This means that we are strongly recommended to pay much more attention for the non-parallelism of the surfaces for reflection of ultrasonic waves in order to obtain good measurement results.

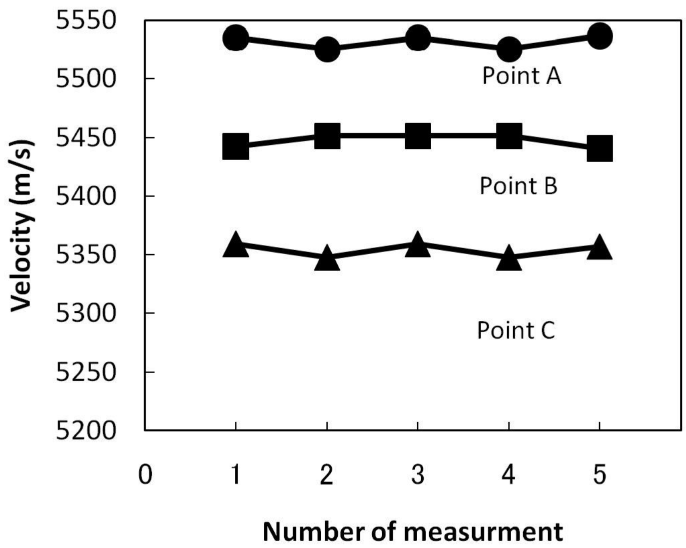

Figure 15. An example of measurement error in ultrasonic velocity created by1 degree of non-parallelism angle between the surface for transducer and the surface for reflection.

In this study we tried to measure the graphite nodularity of a specimen by two steps; measuring the ultrasonic velocity at first and then converting it into graphite nodularity by a relation figure between graphite nodularity and ultrasonic velocity. Recently we see some practical measuring apparatuses which convert the ultrasonic velocity into graphite nodularity automatically and show graphite nodularity directly [6], but even in the case of using those equipments we also need to know the various affections mentioned above and pay much careful attentions for precise measurements in specimen thickness.

5. Conclusions

We investigated on the sources and the scales (magnitude) of the errors in estimation of graphite nodularity of ductile cast iron by measuring ultrasonic velocity from several points of view such as the specimen thickness measurement error, the surface finishing methods, the error of non-parallelism in two surfaces and others, and obtained the following conclusions.

1. The difference of 20 % in graphite nodularity was found to correspond to the difference of some 130 m/s or only 2.3% of some 5600 m/s which is the standard ultrasonic velocity of ductile cast iron. This means the necessity for precise measurements for good measurement results.

2. As the specimen thickness are usually so small comparing to the standard ultrasonic velocity of some 5600 m/s, a measurement error in specimen thickness is expanded largely in the calculation result of ultrasonic velocity. For example, 0.05 mm error which is the minimum unit of conventional vernier caliper may result in the errors of some 11.2 m/s in ultrasonic velocity and some 1.72 % in graphite nodularity in the case of 50 mm in specimen thickness.

3. The ultrasonic velocity and graphite nodularity are measured to be larger than their true values in the case of measurement by the specimens with as-cast surfaces, and they are measured to be smaller than their true values in the case of measurement by the specimens with shot-blasted surfaces, although their skin thickness seems very small.

4. Even a small angle such as 1 degree of non-parallelism between the surface for transducer and the surface for reflection of ultrasonic waves is recognized to create extraordinary large measurement errors in ultrasonic velocity and graphite nodularity.

5. In order to improve the accuracy in estimation of graphite nodularity of ductile cast iron by measurement of ultrasonic velocity we are recommended to know and recognize the amount of the affections of their sources and minimize the errors from such view points as measurement error in specimen thickness, error of non-parallelism of reflection surface, error by existence of the layer of as-cast or shot-blast and others.

Author details

Minoru Hatate, Tohru Nobuki and Shinichiro Komatsu*

*Address all correspondence to: komatsu@hiro.kindai.ac.jp

Kinki University, School of Engineering, Higashihiroshima, Japan

http://dx.doi.org/10.5772/50596

References

[1] Japan Industrial Standards - JIS:G5502.

[2] Japan Foundry Engineering Society. (2004). Investigation on the Nondestructive Evaluation of Properties of Castings. *Research Report* [94], 22.

[3] The Japanese Society for Non-Destructive Inspection. (1991). The Investigation on the Standardization of Non-Destructive Evaluation Technology. *The Report of the year of Heisei 3*, 22.

[4] Japan Foundry Engineering Society. (2004). Investigation on the Nondestructive Evaluation of Properties of Castings. *Research Report* [94], 24.

[5] Toshio SHIOTA and Shinichiro KOMATSU. (1977). The relations between effective sectional area and tensile strength of cast irons. *IMONO (Journal of Japan Foundrymen's Society)*, 49, 602-607.

[6] Dakota Japan Co. Ltd. (2012). *The catalogue for graphite nodularity measuring equipments*, http://www.dakotajapan.com/autoscan/point.html.

IntechOpen