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Problem of Tightness of Casting Alloys and Castings Made from them – New Research Methods

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Abstract

The article concerns the work on tightness as a functional property of casting alloys (primarily, cast iron). The authors' methodology for tightness testing is presented. In the methods that have used thus far, tightness tests have been carried out on samples that are shaped like small disks; through these, a medium/penetrator in the form of a low-viscosity liquid is forced through. The measure of the tightness is the value of the pressure that the sample is able to transfer without penetration. The authors developed a modification of the test method using disks and proposed a new method in which the sample takes the shape of a sleeve. The modification includes the application of the penetration method to reveal the moment of the beginning of the penetration through the sample wall during the tightness test. Using the new research methodology, the tightness of grey cast iron samples was assessed as a function of the shape index of the graphite precipitates (f_K), and research was carried out on the effect of the solidification rate of cast iron on its tightness. The tests covered grey cast iron and modified grey cast iron. The effect of the cooling rate on the tightness of the tested alloys was indirectly determined. At the stage that is described in the paper, the presented research was of an initial nature and was focused on refining the research methodology. The combination of the traditional method of testing the tightness of castings by using liquids with the visualisation of the penetrant method was also used to assess industrial castings.

Keywords: Tightness, Cast iron, Graphite shape index, Penetration method

1. Introduction

Tightness is the ability of a wall to resist liquids and gases that exert certain pressures on it and strive to penetrate it. In the cases of cast iron castings, this material feature is of particular importance in many areas of production; these are mainly the automotive industry, the construction of electric motors, compressors, water/gas fittings, boilers, and radiators; in these areas, the basic criterion for assessing the quality of their castings is their tightness. In the case of various types of cast iron (but also other alloys), the tightness depends on the structure (which can be very diverse). In micro-areas, there may be discontinuities in the metal matrix that were caused by graphite precipitation in the case of cast iron or shrinkage or gas porosity, microcracks, or non-metallic inclusions. Practically every boundary of the adjacent phases in the structure is a kind of discontinuity along which gas- or liquid-penetration paths can run. The more of these boundaries and discontinuities in the structure, the easier it is for gas or liquid to penetrate them (and the lower the tightness). In the case of grey cast iron, discontinuities dominate at the graphite-matrix boundary. The more of these discontinuities and the longer each of them is, the less tightness there is (generally speaking). In the case of Al-Si alloys, those boundaries that determine the tightness are

the surfaces that separate the α phase from the silicon eutectic or from the primary silicon precipitates in the microstructure. The condition for the penetration of a gas or liquid through a selected medium is the presence of a discontinuity in the structure (which means that it is a porous medium). The degree of the porosity of the medium is often characterised by its so-called permeability (or its ability to be penetrated by a liquid or gas). Tightness is a feature that is inverse to permeability and is described by the following equation:

$$H_1 = \frac{p \cdot F \cdot \tau}{Q \cdot \eta^{0,35}}, \quad (1)$$

Where:
H1 – tightness of material.
p – pressure exerted on wall (Pa);
F – surface area through which fluid penetrates (m2);
τ – penetration time (s);
Q – amount of fluid that will penetrate wall in time τ (kg or m^3);
η – dynamic viscosity coefficient (Pa ·s).

The unit of such tightness is as follows:

$$jH_1 = 1(Pa \cdot s)^{0,65}/m. \quad (2)$$

Formula (1) expresses the tightness of a sample with a wall of a specified thickness. If the tightness being determined in this way is referred to a thickness of 1 m, value H_0 (called the specific tightness) is obtained. Therefore, the tightness of a wall with a thickness of "g" will be as follows:

$$H = H_0 \cdot g^n, \quad (3)$$

Where:
g – wall thickness (m);
H_0 – specific tightness (related to 1 m);
n – coefficient (2–3) (n = 3 is usually assumed).

It results from Formula 3 that, at a specific tightness, the general tightness of a given part of a casting increases proportionally to the third power of the thickness; in the case of cast iron and the specificity of crystallisation, however, the structure becomes coarser as the wall thickness increases (which leads to a decrease in the specific tightness) [1].
The measure of tightness (H_{02}) is also sometimes [2,3] the pressure of the measuring fluid at which a tightness begins to appear on the external surface of the sample that is related to the square of the wall thickness (in Formula 3, n takes on a value of 2) [1]. The unit of specific tightness is, then, as follows:

$$jH_{02} = 1\left[\frac{Pa}{m^2}\right] = 1N/m^4.$$

Tightness tests can be divided into industrial and laboratory tests – their common feature being the exposures of castings or samples to fluids that are under high pressure [1–3].

1.1. Tightness-testing methods

Industrial tightness tests are characterised by a multitude of solutions that have been developed for specific research purposes, types of construction (casting), technical requirements, materials, levels of expected tightness, etc. In industrial practice, a very large number of castings that are made of most types of cast iron, aluminium alloys, and copper alloys are typically used; these are castings of household and industrial fittings, various types of valves and gate valves, pumps, compressor elements, etc. The tests are performed on castings in their raw states, after preliminary processing, or after the assembly of the devices of which they constitute parts. The tightness criterion comes down to determining the ability to transfer/withstand a critical value of liquid or gas pressure or determining the pressure at which the casting loses its tightness (the medium tightness through the wall). Therefore, a specific part (or a set of assembled parts as a device) is assessed.
Laboratory tests have a different goal; these come down to assessing the selected material (alloy) in terms of its ability to resist the penetration of a liquid/gas through its structure. The methodology for testing the tightness of materials have not been standardised. An analysis of the literature has led to the conclusion that the methods that have been used thus far differ primarily in the shapes and dimensions of the samples that have been subjected to tightness tests [4].
Fig. 1 shows the head of the apparatus for testing the tightness of cast iron, and Fig. 2 shows the samples that are used (which are most often in the shape of discs or cylindrical). Cylindrical samples were produced in two versions: with a smaller diameter (D1 = 26 mm) or larger (D1 = 41 mm). The thicknesses of the measuring walls were 1.5 ÷ 2.0 mm in both cases. Considering the relatively high tendency of casting alloys to form non-homogeneous internal structures, one should strive to ensure that the test includes larger sample cross-sections, larger test surfaces, etc. in the tests of the properties of such materials. In this sense, cylindrical samples (Fig. 2b) are structurally better, as the surfaces of the tested walls are many-times larger than in the case of samples in the form of discs (Fig. 2a). Moreover, flat cast iron samples tend to break under pressure (as has been confirmed by researchers).

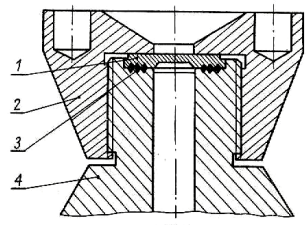
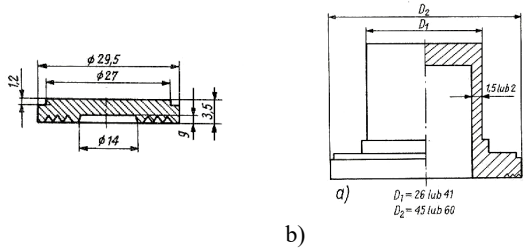


Fig. 1. Schematic diagram of head for testing tightness of cast iron [1,5,6]: 1 – sample; 2 – nut; 3 – gasket; 4 – head



a) b)

Fig. 2. Typical sample shapes that are used in cast iron tightness tests [7]

2. Own research

2.1. Purpose and methodology of research

The research pursued three objectives: 1 – developing a new (modified) laboratory method of testing the tightness of alloys (primarily, cast iron); 2 – determining the relationship between the shapes of the graphite precipitates and the tightness of the cast iron; and 3 – assessing whether it was possible to predict their tightness on the basis of the non-destructive ultrasonic testing of the cast iron. The implementation of the objectives that are defined in this manner is described below.

2.2. New/improved tightness-test methods

A tightness-test stand that was similar to those that were used in many previous studies [5,6,8] is shown in Figure 4. The tightness tests of the cast iron were carried out on the samples that were shown in Figure 2a at a pressure that was within a range of P = 10–20 MPa. The measure of the tightness was the determined pressure at which the penetrating medium (kerosene) penetrated the tested sample. This variant of the technical solution was characterised by two difficulties and problems: some samples were prematurely cracked (Fig. 4.) when increasing the measuring pressure (instability and large spread), and the use of a transparent medium (kerosene) made it difficult to determine the initial phase (pressure) of the liquid penetration through the tested sample (Fig. 3).

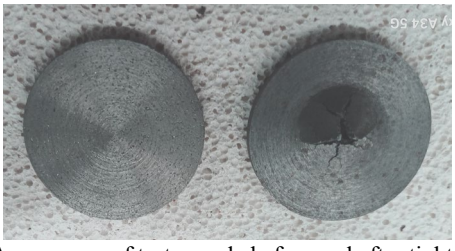


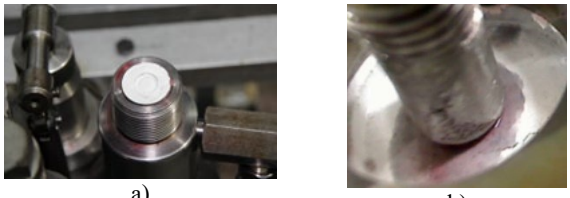
Fig. 3. Appearance of test sample before and after tightness test

Therefore, the test method was modified; this included two elements:

1. Firstly, red-stained kerosene was used for easy visualisation, and the top (observed) surface of the sample was covered with a developer that was used in the non-destructive testing in the penetrant method (Fig. 5a).
2. Secondly, the element that corrected the research technique was the use of a steel rod to support the upper surface of the specimen, which allowed us to eliminate the phenomenon of the hydraulic breaking of the specimens (Fig. 5b).

The new solution is shown in Figure 5. On the one hand, the introduced changes made it easier to determine the moment of the penetration of the medium through the sample, and on the other hand, the phenomenon of the sample cracking during the measurement was eliminated. This allowed for tightness tests of grey cast iron even when it was characterised by low strength.

Fig. 4. Cast iron tightness-test benches



a) b)

Fig. 5. Samples for tightness testing in new measurement version: a) sample before test; b) sample during measurement

2.3 Test results with modified method

As was shown by an analysis of the results of the previous tests [3,5,8], the leading factors that determined the tightness of non-alloy grey cast iron were the forms of its graphite precipitates and, in the case of cast iron with flake graphite, its density. The density of the cast iron depended on its share of graphite in the structure – the more it contained, the lower the density. Therefore, all of the factors that would affect the amount of graphite precipitation would also affect the density. It should be recalled that these were the chemical composition (as described by indicators such as Sc and CE) and the rates of the crystallisation and cooling of the cast iron. The share of graphite in the structure of cast iron will increase with increases in Sc and CE as well as with decreases in the rates of its crystallisation and cooling.

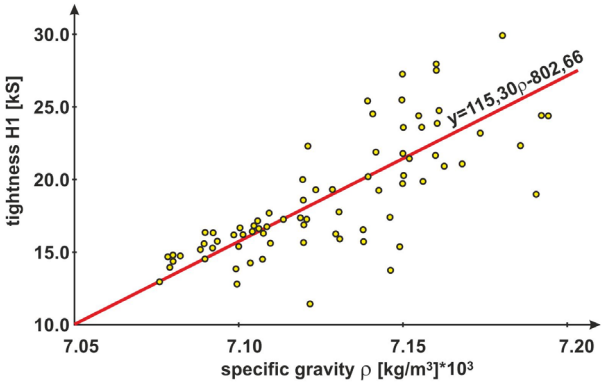


Fig. 6. Influence of density of grey cast iron on its tightness [8]

As part of our own research using the described test methodology with the use of the samples that are shown in Figs. 2a and 3, a series of tightness measurements were carried out for cast iron, which was characterised by a stabilised chemical composition but had a different form of graphite that was obtained by the post-furnace treatment of the metal in a liquid state. The cast iron was subjected to the spheroidization process using the PE flexible duct method, introducing appropriate amounts of FeSiMg master alloys in a controlled manner; the final content of the Mg in the cast iron varied within a range of 0.005–0.040%. The obtained cast iron with a controlled and variable graphite form in a wide range was called "Vari Morph" cast iron [9–11]. A group of cast iron grades whose chemical compositions were close to the eutectic value were subjected to tightness tests: (C = 3.3 ÷ 3.6%, Si = 2.6 ÷ 2.95%, Mn < 0.25; P < 0.02%; S < 0.01%; Mg = 0.005 ÷ 0.040%).

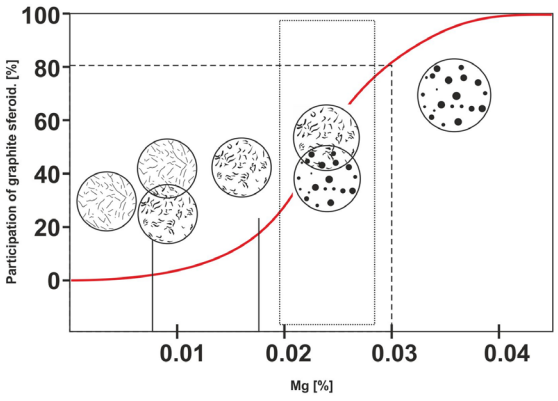
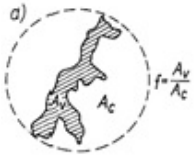


Fig. 7. Effect of magnesium content in cast iron on form of graphite [9–11]

The effect of the Mg content in the cast iron on the form of graphite precipitates is shown in Figure 7. The forms of the graphite precipitates have been attempted to be described numerically in several ways – each time, based on a flat image of the metallographic composition. The separation of the graphite is described by a circle (Fig. 8), and on the basis of the area of the graphite separation and the area or circumference of the circle that described the separation, the so-called graphite form index "f" was calculated. Table 1 shows the values of this indicator for the different forms of the graphite and the different ways of making the calculations.



$$f = \frac{A_V}{A_c}$$

Fig. 8. Scheme of shapes of graphite precipitate cross-sections [8]

Table 1.
Indicators of shapes of graphite precipitates [4]

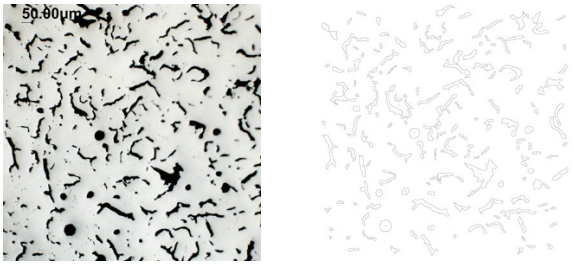
Graphite section						
Graphite surface area / [%] Circle surface area	$f = \frac{A_{Graph}}{A_{cicle}} \cdot 100$	90.8	79.5	57.5	34.6	12.7
Graphite shape factor (ξ)	$f = \frac{A_{Graph}}{A_{cicle}}$	0.91	0.80	0.58	0.35	0.13
Graphite surface area (A_{Graph}) / Graphite diameter (P)^2	$\xi = \frac{A_{Graph.}}{P^2}$	*0.080*	*0.070*	*0.060*	*0.045*	*0.030*

In the case where the graphite form is homogeneous in the metallographic structure of cast iron, the approximate value of the shape index can be evaluated on the basis of the diagrams that are given in Table 1. If mixed forms of graphite are present in the cast iron (Fig. 7), such a method of determining the shape index would be incorrect. The authors proposed to use the method of determining the graphite precipitate shape index as a weighted average of the indices for the adjacent forms. The procedure for determining the average shape indices is described in [9–11].

The determination of the graphite shape index was preceded by a computer analysis of the metallographic structure. Using the Image J image-analysis program, the microscopic images were subjected to stereological analysis. Figure 9 shows, in the form of an example, an image of the microstructure in a digital recording and the image after being processed by the Image J program. Each separation of graphite was described by the program with an indicator of the shape of the graphite according to Equation 2.

The graphite-shape index f was determined for each separation according to [7] and according to Equation (2), where:
Av – graphite precipitate area [mm^2];
Ac – the area of a circle with a diameter equal to the largest particle dimension [mm^2].
The "f" shape index theoretically varies within a range of 0.0 to 1.0; under real conditions, this varies from 0.20–0.95.
The graphite-shape-index changes were assumed within the following limits:

0.00–0.34 (for flake graphite);
0.35–0.64 (for vermicular graphite);
0.65–1.00 (for spheroidal graphite).



a) microstructure image b) Image J

Fig. 9. Microstructures of cast iron (VM) – with mixed graphite form

In the next step, the numbers of precipitates with the shape coefficient "f" within the individual intervals were counted, and their percentage shares in relation to all of the graphite precipitates were determined. A separate mean "f_K" index was defined for each interval; this was the basis for calculating the main indicator of shape "f" based on the weighted average.

For the example of the selected structure that is shown in Figure 9, the intermediate results of the graphite-shape analysis that were obtained in the adopted calculation procedure are summarised in Table 2.

Table 2.
Selected parameters of graphite precipitation

Parameter	Value
Average number of precipitates per mm2	167
Total Area Occupied by Graphite Precipitation	10%
Medium Feret Diameter	0.048 mm
Average Perimeter of Secretions	0.138 mm

Table 3 and Figure 10 present the results of the calculations of the percentage shares of three forms of graphite: flap, vermicular, and ball-structured (shown in Figure 9). The leaflet form dominated (45.7%), while slightly fewer precipitates were classified as vermicular (36%) and small amounts were ball-formed (18.3%). On the basis of the calculations that were carried out, it was shown that the average shape index of the graphite precipitates was "f_K" = 0.43.

In the study on the effect of the graphite precipitate shape on the tightness of "Vari Morph" cast iron (with a variable form of graphite), an empirical relationship was sought between the tightness age index of the cast iron (e.g. time to penetration at constant pressure) as a function of the averaged shape index "f_K".

Table 3.
Analysis of graphite shape index "f_K"

Type of graphite	N	%	Average "F" Index in range	"f_K" indicator
flake graphite	75	45.7	0.25	
vermicular graphite	59	36.0	0.47	0.43
spheroidal graphite	30	18.3	0.79	

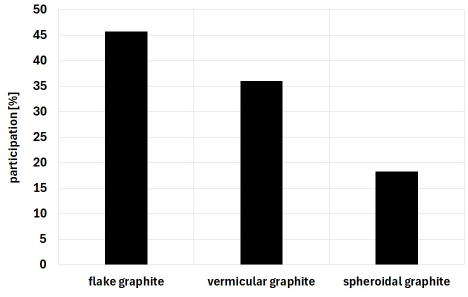


Fig. 10. Shares of individual types of graphite among all precipitates

In accordance with previous works in this area, tightness tests were carried out at pressures of 20.0 or 40.0 MPa; the time after which the penetration began at a given pressure was determined. The research was of a comparative nature; those samples with low degrees of porosity (which was a derivative of the shape of the graphite, i.e. samples with fine precipitates of ball graphite are often "impermeable") had very high tightness levels. In the case of the other forms of graphite, the tightness depended on the so-called graphite shape index "f_K" – the lower the value of the index, the lower the tightness and the shorter the penetration time.

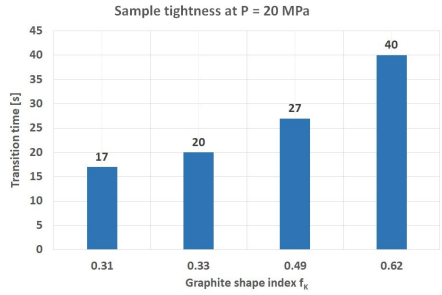


Fig. 11. Relationship between shape index of graphite cast iron and its tightness

Figure 11 shows the results of the research on the effect of the graphite shape index f_K on the tightness of the cast iron; these were determined for values within an f_K range of 0.30 ÷ 0.62. At higher f_K values (f_K > 0.65), no tightness of the medium through a 2.0-mm-thick sample at 20 MPa could be observed – even after several minutes. Such material can be considered to be "tight"; however, the function was exponential in the examined scope (Fig. 12).

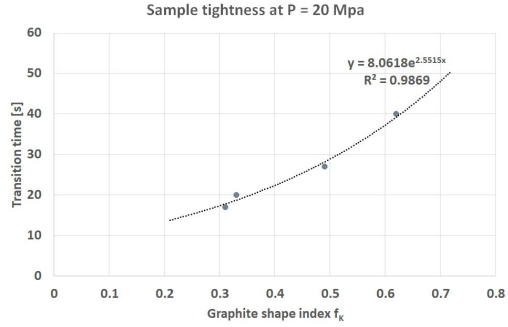


Fig. 12. Relationship between graphite-shape index in cast iron and its tightness

2.3. Investigations of effects of cooling rate on tightness of cast iron

In the cases of samples with the same chemical composition, the tightness of grey cast iron depends on the amounts and sizes of its graphite precipitates. Both of these parameters depend on the rates of the solidification and cooling of the cast iron. In order to verify this thesis, tests were carried out by making several castings in one mould – cylinder-shaped samples with different diameters and lengths.

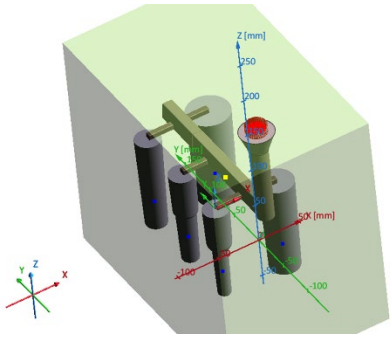


Fig. 13. Virtual mould image with trial ingots

The dimensions of the ingots and their solidification moduli are given in Table 4. The cylindrical specimen module corresponds to plate castings with thicknesses of 7.5 to 22.5 mm, i.e. the range of the wall thicknesses of water-fitting castings (valves, gate valves, and dampers) that were made of modified grey cast iron.

Table 4.
Tightness-test ingot dimensions

Lp.	Diameter d [mm]	Coagulation modulus [cm]
1	15	0.375
2	20	0.500
3	25	0.625
4	35	0.875
5	45	1.125

A visualisation of the results of the solidification simulation that was made with the use of the Magma Soft program is shown in the following figure.

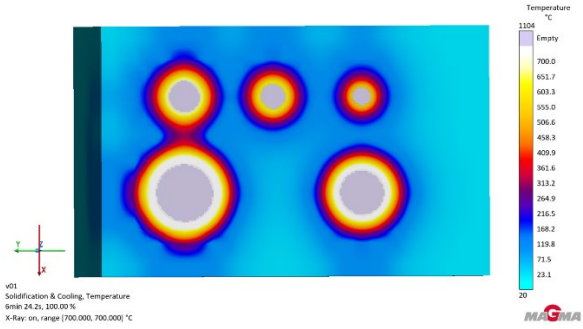


Fig. 14. Solidification of cylindrical ingots with modulus within range of M = 0.375–1.125 cm

In order to determine the actual course of the cooling and to determine the rate of the crystallisation of the cast iron in each mould cavity, K-type thermocouples were centrally placed in the axes of the symmetries of the ingots, and the courses of the temperature changes were recorded. The results of these measurements are shown in Figure 15.

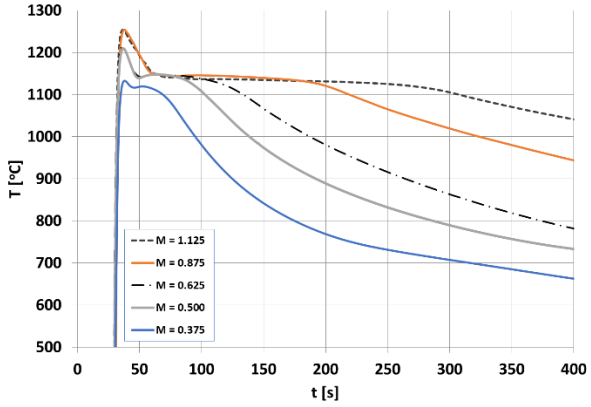


Fig. 15. Cooling- and solidification-temperature courses of test ingots with diameters (as shown in Table 4)

The crystallisation rate is most often defined as the ratio of the changes in the temperature of an alloy during its transition from a liquid to a solid state to the duration of this process (dT/dt). In the case when the alloy solidifies with a high proportion of eutectics and a small proportion of the pre-eutectic phase, such a method of assessing the speed of the transition from the liquid to solid states is imprecise; in the cases of eutectic alloys, this can be considered to be "unsuitable". In the studies that were described above, the crystallisation times of each of those that were shown in Figure 13 were determined on the bases of the recorded AT cooling curves and the derivatives of these ATD waveforms. Then, the so-called linear crystallisation rate (understood as the ratio of the solidification modulus of the ingot [which describes the directional growth of the solidified layer] to the duration of this process) was determined. The results of this analysis are presented in Fig. 16. Another way to describe the crystallisation rate is to determine the 1/t index, which is the reciprocal of the time that it takes for the melt to transition from the liquid to solid states. The simulation of the process (Fig. 14) showed that, although the volumetric cast iron solidifies, the process is directed from the outer walls to the axes of the symmetries of the cylindrical samples.

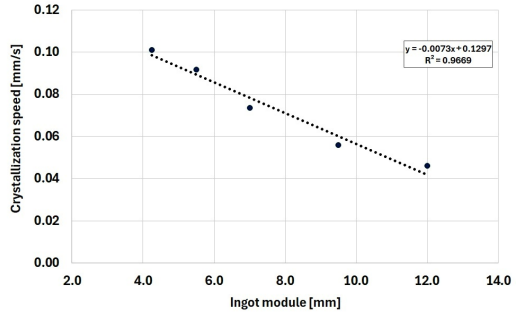


Fig. 16. Effect of solidification modulus on crystallisation rates of cast iron ingots

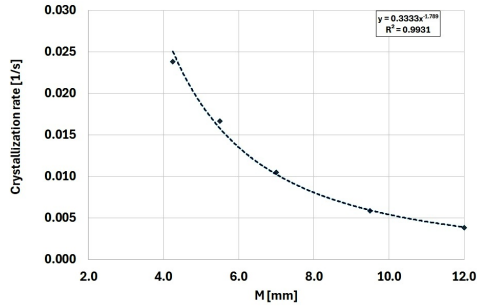


Fig. 17. Effect of solidification modulus on crystallisation rates of cast iron ingots

2.3.1. New laboratory method for testing tightness of casting alloys

As part of the search for better solutions in the field of tightness-testing methods, the authors proposed to conduct tests on samples that were in the shapes of sleeves with bottoms (cylinders). Compared to the samples in the forms of discs, sleeves made it possible to test much larger surfaces; this was important in the cases of the cast samples. A larger tested surface allowed us to assess the tightness of larger casting volumes, which was important given the usually heterogeneous structures of the cast elements. The basic shape of the test specimens is shown in Figure 18. The inner diameter of the sleeve was 14 mm, and its working height was 28 mm; this meant that the tested area was about 13 cm^2 – nearly nine-times greater than the surface of the disc (Fig. 2a). The probability of revealing tightness was, therefore, much higher than in the case of the flat samples (discs).

Compared to the previous solution in the field of tightness testing on cylindrical samples [7], changes were made in the methodology: the elements that were used in the penetrant tests were used. The pressurised medium (penetrator) was stained red, and the outer surface of the sample was covered with a white contrasting developer. This method of testing facilitated the detection of tightness at the very beginning of the penetration of the medium through the sample wall. The thread at the bottom of the sample made it easy to mount on the test bench, and the threaded small hole in the upper part of the sample was used to vent the sample when it was filled with the liquid medium (penetrator).

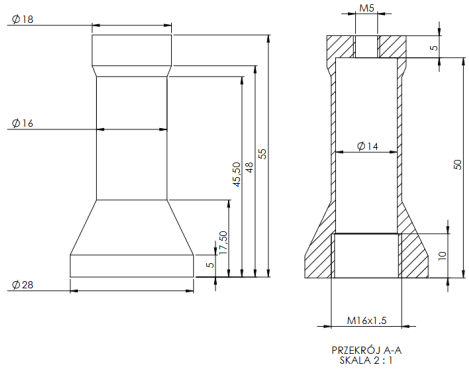


Fig. 18. Appearance of specimens for tightness testing of metal alloys

The samples were assembled at the tightness-test stand (Fig. 19), which was equipped with a hydraulic pump for manual pressure generation and a pressure gauge to control the working pressure. The mounted two-mirror system allowed for the real-time tracking of the sample surface around its circumference (Fig. 20).

Fig. 19. Prototype tightness-test bench

Fig. 20. System of mirrors for tracking surfaces of samples from three sides in real time

Tightness tests that used the new method were carried out for two grades of cast iron: unmodified (EN GJL 200 class) and modified (EN GJL 250). Their basic line-ups are given in Table 5.

Table 5.
Basic line-ups cast iron

Cast iron	C [%]	Si [%]	Mn [%]	P [%]	S [%]
unmodified	3.45	2.20	0.250	0.021	0.010
modified	3.16	1.56	0.157	0.023	0.005

Graphite precipitates, which determine the tightness of cast iron, are classified according to PN EN ISO 945, showed that, in the case of the unmodified cast iron, the graphite was classified as I A 3/4, and in the case of the modified cast iron, the graphite was classified as I A 5/6. With the examined range of the changes in the solidification modulus of the ingots (M = 0.375–1.125 cm), the sizes of the graphite precipitates in the individual grades of the cast iron differed slightly – by one class. There was a difference between the cast iron grades – by nearly three size classes. Ultrasonic tests, in which the speed of the wave depended mainly on the amounts and sizes of the graphite precipitates, confirmed the microstructure tests. Figure 21 shows the results of the ultrasonic tests for both cast iron grades.

For a given grade (modified/unmodified), the differences in the wave velocity in the individual samples were small (slightly more than 100 m/s), while the differences in ΔCL were above 1200 m/s when comparing the cast iron grades. It could be concluded that the results of the tightness tests would follow the results of the tests of the graphite precipitation and the speed of the ultrasonic wave.

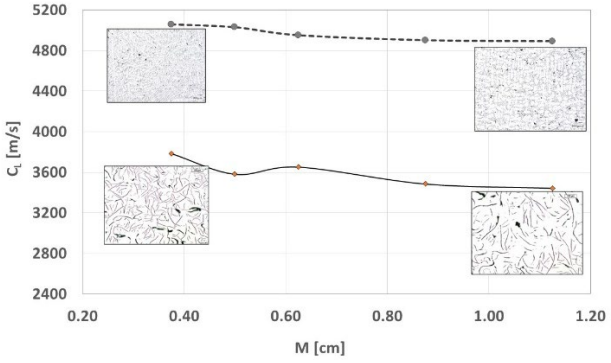


Fig. 21. Effects of solidification modulus of grey and modified cast irons on structures and speeds of ultrasonic waves

Samples with the described metallographic structure were subjected to tightness tests according to the method that was described above on the test stand that was presented in Figures 19 and 20. The tests were carried out at pressures of 10–12 MPa. Taking into account the half-thickness of the sample walls (1.0 mm) as compared to the cases of the flat discs (2.0 mm), a conventional criterion of tightness was adopted: a sample that withstood at least 60 sec of pressure of 10–12 MPa was classified as "tight". Cast iron with such a structure and tightness can be used for compressor castings, head housings, and similar equipment that operates under increased pressures. On the other hand, the cast iron with a test "tightness" of fewer than 60 seconds or where the pumped medium penetrated through the walls of the sample at lower pressures should be considered to be materials that do not meet the tightness criterion. With this criterion defined, all of the modified cast iron specimens met the condition of a "tight" alloy. On the other hand, all of the samples that were made of non-modified cast iron (with the composition given in the table) did not meet this criterion.

Figure 22 presents data on the pressure value after which the penetrator process began to penetrate through the walls of the sleeve specimens. At a solidification modulus of M = 0.50 cm, a certain minimum of tightness could be observed in the cases of both the unmodified and modified cast irons. Perhaps this was due to the weaker supply of the lower part of the specimen by the thicker upper part (Fig. 13), which may have resulted in the appearance of microporosity. In the presented work, this is not the subject of additional research. The fragmentation of the graphite precipitates in the modified cast iron almost doubled the pressure at which the permeation of the liquid medium began.

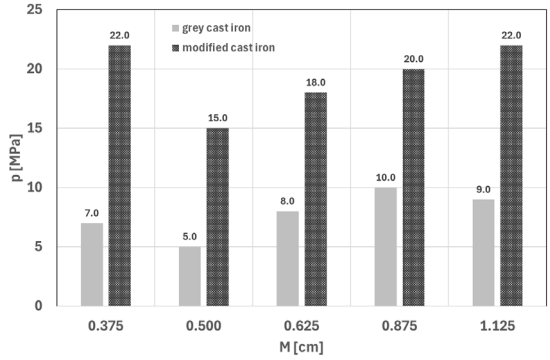


Fig. 22. Values of pressure that caused medium to penetrate through walls of samples for tightness testing.

3. Discussion on research results

The analyses and research that were carried out on the formation of cast iron tightness and the methods of its evaluation allowed for the development of modifications of the existing test methods and for the conduct of tests according to the new method; the purpose of these was to determine the impact of the shape of the graphite and the modification of the cast iron on its tightness. The modification of the tightness-test methods included the introduction of the elements of the penetration method into the tightness test. The penetrator that was used in the tightness test was coloured (as in the penetration test), and the outer surface of the tested sample was covered with a so-called developer of a contrasting colour; this greatly facilitated the visualisation of the penetrator tightness age and tightness assessment. The method was used both for the casting tests and the samples in the laboratory tests.

In the new solution, the effect of the graphite-precipitate-shape index on the tightness of the cast iron was assessed in the field of our own tests. The results of the tests that were performed on the flat disc-shaped samples were shown in Figures 11 and 12. The influence of the shape index was well-described by the exponential relationship being characterised by correlation coefficient R^2 = 0.98. Switching from the flake form to the more compact form caused a "rapid" increase in the tightness of the cast iron.

The tests of the new test method indicated its high sensitivity, and it was possible to distinguish materials with slightly different tightness levels. It was shown that the effective modification of grey cast iron (leading to the fragmentation of the graphite precipitates and reducing the sensitivity of the cast iron to the rate of cooling) is the right direction of technological activities for increasing the tightness of iron castings.

4. Summary

After analysing the results of the research, the following conclusions were drawn:

1. Integrating cast iron tightness testing with the penetrant method of surface discontinuity testing increases the

sensitivity and detection of tightness in laboratory tests and can be used in the tightness testing of castings.
2. It was shown that the tightness-test method that uses tube-shaped samples with bottoms is characterised by greater sensitivity than the method that uses flat samples (discs).
3. It was shown that the tightness of cast iron is well correlated in the graphite shape index, which can be controlled by the ultrasonic method.
4. The wave velocity in grey cast iron can be used to predict the tightness of the cast iron in the walls of its castings.
5. Modifying grey cast iron leads to increases in its tightness.

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