J MATER RES TECHNOL. 2017;6(1):96–100

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jmr&t Journal of Materials Research and Technology

www.jmrt.com.br

Short Communication

Strength evaluation of flake and spheroidal graphite cast irons using diametral compression test

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ARTICLE INFO

Article history:
Received 5 April 2016
Accepted 20 September 2016
Available online 25 November 2016

Keywords:
Diametral compression
Flake Graphite cast iron
Spheroidal Graphite cast iron

ABSTRACT

The diametral compression test also known as the Brazilian test is an old and unique method of measuring tensile strength of brittle materials owing to simple specimen geometry test conditions and quickness of testing. However, its practice in measuring the strength of the metals is quite limited. This work therefore attempts to apply diametral compression test with specimens of thickness to diameter ratio equal to 0.2, 0.4 and 0.6 in determining the tensile and compressive strengths of Flake Graphite (FG) and Spheroidal Graphite (SG) types of cast iron. Cracks developed in the FG and SG specimens indicate that the failures were caused by tensile and shear stress respectively. In case of FG cast iron specimens at lower t/d ratio, the stress state becomes biaxial and influence of tensile stress was found to be higher than the compressive stress. Whereas the biaxial stress condition violates in SG cast iron specimens. The present work concludes the suitability of diametral compression test at any t/d ratio of FG cast iron specimens and only at lower t/d ratios of SG cast iron specimens.

1. Introduction

Strength is the fundamental mechanical property of solids and is widely used to assess the suitability of a material for specific purpose. In general, the tensile strength of a material is determined by conventional tensile test, also termed as uniaxial tensile test. However, in the case of brittle materials like cast iron, this test is observed to be inaccurate due to the scatter of results, eccentricity of loading, gripping difficulties, greater sensitivity to misalignments and position defects [1]. To overcome these problems, a testing method known as diametral compression test/Brazilian test/indirect tensile test was introduced in 1953 to measure the tensile strength of the concrete and then gained popularity because of its simplicity [2,3]. This examination has also been used to measure tensile strength of rock, coal, cemented carbides, ceramics, MMCs, tablets, etc. [4–6].

The diametral compression test is based on the fact that when a circular disk is compressed between two diametrically opposite faces as shown in Fig. 1, tensile stresses develop perpendicular to loading direction and are proportional to the applied compressive force [7].

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http://dx.doi.org/10.1016/j.jmrt.2016.09.005

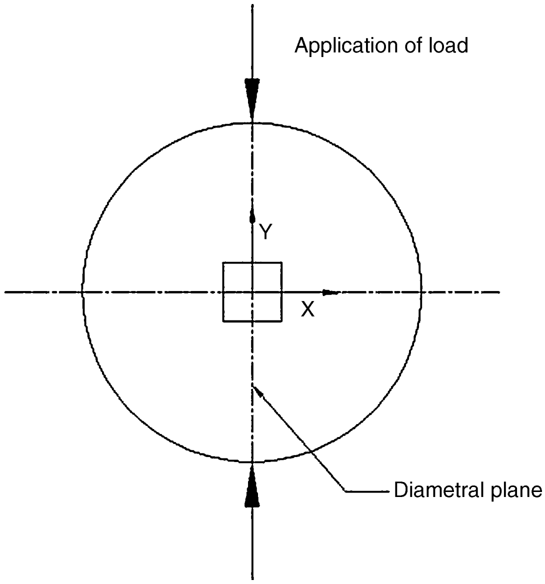

Fig. 1 – Application of load in diametral compression test.

Also the work of Hertz reported in [3,8] says that along the loaded diameter, the normal strength (σ_x) is tension and constant, while σ_y parallel to the loaded diameter is a compressive strength, which increases from $3\sigma_x$ at the center of disk to infinity beneath the loaded points. The shear strength is zero along the diameter plane and hence σ_x and σ_y are the principal stresses on the plane assuming a point load on the disk. Since the failure occurs along the diametral plane of the applied load, it is commonly assumed that the nominal tensile stress causes the disk to fail and the strength values of the diametral compression test are always much lower than other uniaxial tests.

2. Experimental details

The objective of this work is to determine the tensile and compressive strength of cast iron's using diametral compression test and compare those with conventional tensile test results. To conduct this study, two types of cast iron, i.e., Flake Graphite cast iron (FG) and Spheroidal Graphite cast iron (SG) were used.

2.1. *Diametral compression test*

A Universal Tensile Machine (Model TUN-600) shown in Fig. 2 was used to conduct the diametral compression test.

The trials were conducted on 20 mm diameter specimens according to ASTM D3967-08 with varying t/d ratio of 0.2, 0.4 and 0.6. The load was applied along the diametral plane and was noted down for every 0.1 mm increase in deformation. The tensile and compressive strength of specimens was determined following the postulates of Thimoshenko and Frocht [9,10]. According to those assumptions, for stress analysis of a disk considering P as applied load, t is the thickness of disk, D is the diameter of disk, at $x=0$ and for any value of y (i.e. on the diametral plane), tensile strength (σ_x) is constant and equal to $\sigma_x(0, y) = 2P/\pi Dt$. Further, compressive strength (σ_y) along the direction of loading, at the center of disk (y = 0) and at the point of loading ($y = D/2$), is $-(6P/\pi Dt)$ (i.e., $3\sigma_x$) and infinity respectively.

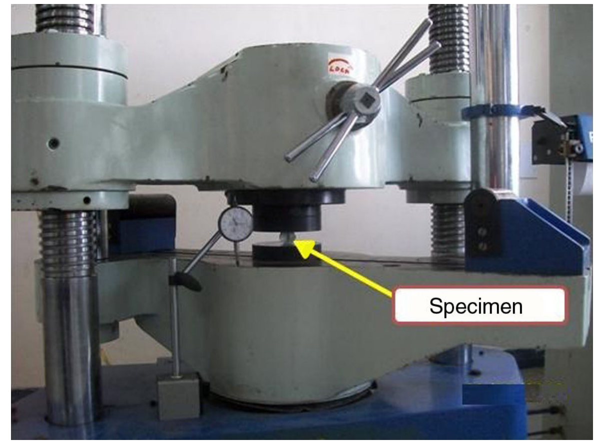

Fig. 2 – Diametral compression test specimen in Universal Tensile Machine.

The sketch of diametral compression test specimen after deformation is as shown in Fig. 3. The compressive fracture stress in the direction normal to flattened portion was assumed to act over a rectangular portion of width 'b' and thickness 't', which is evaluated as load at failure (maximum load) divided by the projected area of the flattened portion, as $\sigma = P/(b \times t)$. The thickness of the flattened portion was assumed to be constant, whereas, the width of flat portion (b) was found using equation: $b = 2 \times \sqrt{r^2 - (r - 0.5\delta r)^2}$ in which r is the radius of test specimen and δ_r is measured radial deformation.

2.2. *Conventional tensile test*

A horizontal bench model electronic Tensometer of capacity 20 kN was used to find out the tensile strength of test

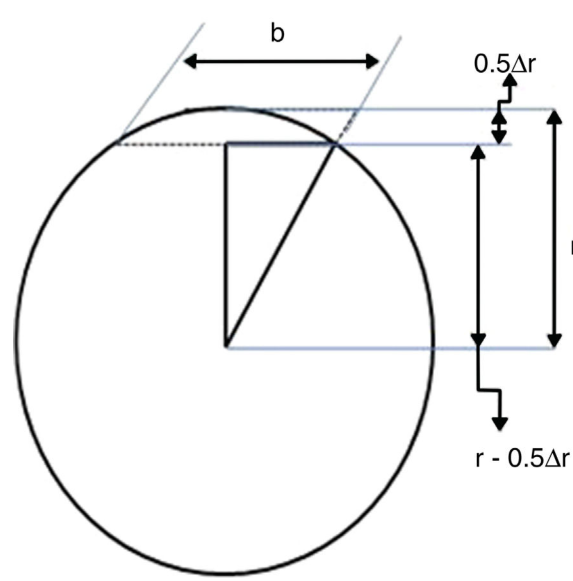

Fig. 3 – Diametral compression test specimen when deformed.

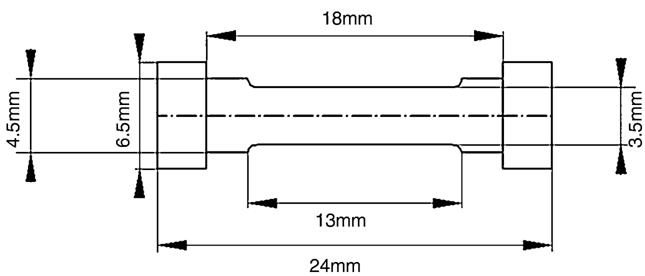

Fig. 4 – Conventional tensile test specimen.

specimens as per E8/E8M-15. A cylindrical specimen as depicted in Fig. 4 was used for conventional tensile test. This test was carried out only to verify the tensile results of specimens with respective results of diametral compression test.

3. Results and discussion

The experimental results as determined from diametral compression test and conventional tensile test of FG and SG cast iron specimens with varied *t*/*d* ratio are listed in Tables 1 and 2, respectively. Each test was carried out on five similar specimens and the average of these test values, as shown in Tables 1 and 2, is taken as the respective strength of that specimen. It was found that 8% is approximate deviation from the average values of five readings taken for each specimen, while standard deviation (SD) was not calculated due to paucity of numbers. The variation in tensile and compressive strength of FG and SG cast iron specimens determined from diameteral compression test with respective deviation is shown in Fig. 5.

The experimental results on FG cast iron specimens as depicted in Fig. 5 indicate that with the increase in *t*/*d* ratio from 0.2 to 0.6, the compressive strength is linearly increasing while the tensile strength is found to be slightly decreasing. This specifies that at lower *t*/*d* ratio, the stress state becomes biaxial and the influence of tensile stress is higher than the compressive stress. For a standardized specimen without any variation in *t*/*d* ratio, the tensile strength obtained by

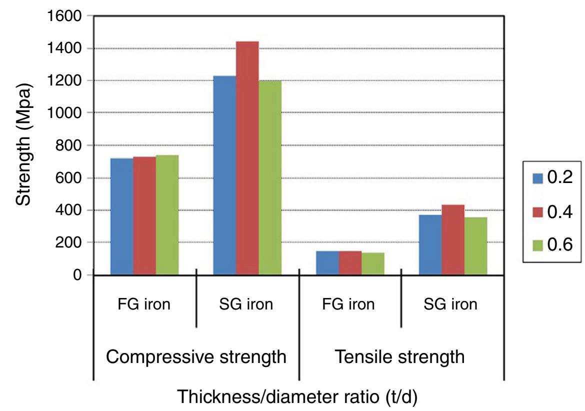

Fig. 5 – Variation of Compressive and Tensile strength of FG and SG cast iron specimens.

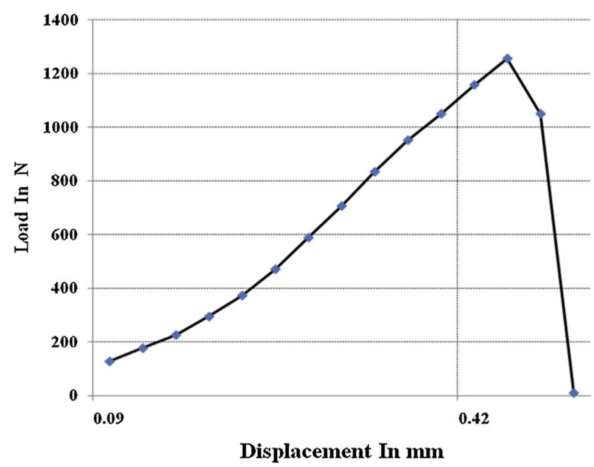

Fig. 6 – Loading Curve of SG cast iron.

conventional tensile test was found to be 203.6 MPa, which is comparatively nearer to that of diametral compression test specimen having 0.2 *t*/*d* ratio.

In case of SG cast iron specimens considered, both the compressive and tensile strength followed a trend of increase and then decrease with highest at $t/d = 0.4$. This could be the result

Table 1 – Experimental results of Flake Graphite cast iron.

t/*d* ratio	Diametral compression test		Conventional tensile test
	Compressive strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)
0.2	722.6	151.79	
0.4	733.7	148.66	203.6
0.6	741.8	138.54	

Table 2 – Experimental results of Spheroidal Graphite Cast iron.

t/*d* ratio	Diametral compression test		Conventional tensile test
	Compressive strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)
0.2	1233.1	372.3	
0.4	1446.12	437.27	644.8
0.6	1200.33	359.9	

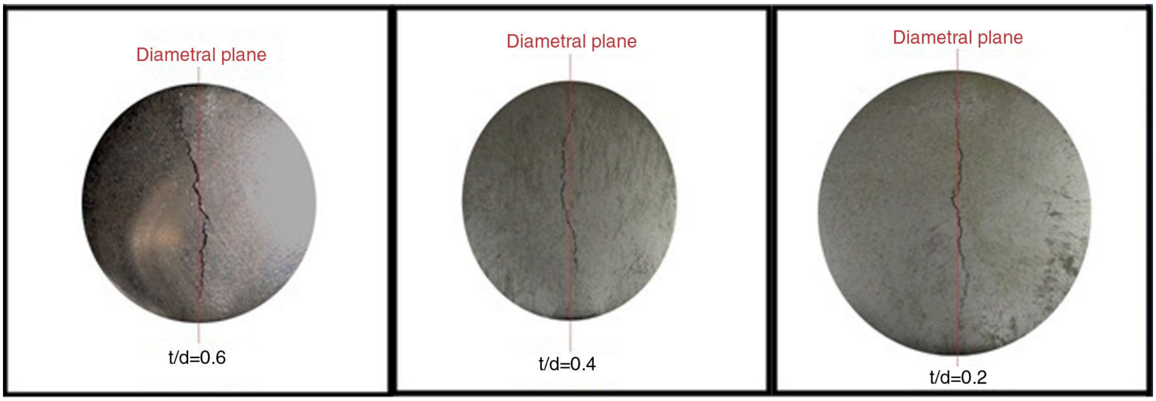

Fig. 7 – Crack developed in Flake Graphite cast iron specimens.

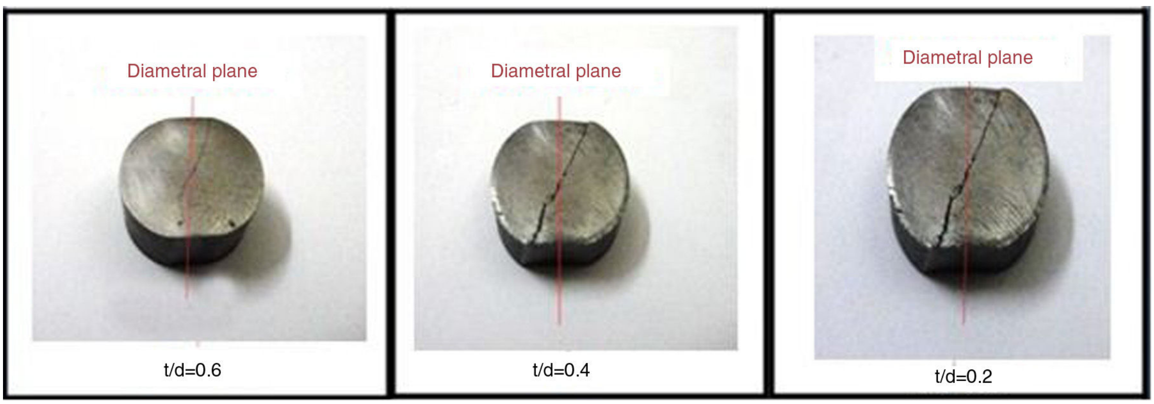

Fig. 8 – Crack developed in Spheroidal Graphite cast iron specimens.

of biaxial stress condition violation and influence of stress in z direction. Accordingly, the present work presumes that the suitability of diametral compression test for SG cast iron is only valid at lower t/d ratios. The compressive strength of SG cast iron specimen determined using conventional test was found to be distant as that of the results of diametral compression test owing to its ductile nature.

With decrease in t/d ratio, the compressive strength of FG cast iron tends to decrease while in case of SG cast iron, it was found to increase, possibly due to the structure of graphite. The presence of graphite in FG cast iron in the form of flakes interrupts the continuity and breaks at a lower load when the thickness of the specimen is lower. Whereas, spheroidal-shaped graphite in SG cast iron minimize its effect in failure. The loading curves for SG iron shown in Fig. 6 reflect the behavior of brittle material. The curve for FG is also similar showing much less ductility.

The specimens subjected to the diametral compression test were critically analyzed for its pattern of crack produced and therefore correlating with the type and mode of failure. The cracks developed in different FG cast iron specimens are shown in the Fig. 7. The failure of the material was found to be along the vertical diameter, which is primarily due to the tensile stress induced in the direction perpendicular to the direction of load. Notably, the crack formation along the diametral plane was found to be continuous and clear.

In case of $t/d = 0.6$ FG cast iron specimen, the crack slightly moved toward left of the diametral plane indicating the violation of plane stress condition and the existence of some shear. It can therefore be stated that with increase in t/d ratio, the stress state alters to biaxial state resulting in tensile failure.

In case of SG cast iron specimens, as shown in Fig. 8, the crack appeared offset from the diametral line at both the ends. This indicates that the buckling of material and crack developed in these specimens was due to shear instead of tensile stress.

4. Conclusion

The diametral compression test has been evaluated and confirmed as a simple way of measuring the tensile strength of brittle materials. The difference in test results between the diametral compression test and conventional tensile test could be decreased with improvement in t/d ratio and loading conditions. The diametral test was observed to be more suitable for less ductile material such as FG cast iron as compared to ductile SG cast iron.

By appearance of crack along the diametral plane, the failure of FG cast iron specimens was noted as due to the failure to tensile stress. While in SG cast iron specimens, the development of crack at an offset to the diametral plane depicts a shear failure owing to the presence of graphite in spheroid form which generally exhibit 10–12% ductility.

Conflicts of interest

The authors declare no conflicts of interest.

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