LOCAL APPROACH OF FRACTURE IN GRAY CAST IRON

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Local mechanical parameters of the cast iron were determined by an indentation technique. The indentations were sectioned to allow a fractographic study of the subsurface deformation. The experimental results were used in developing stress-strain curves with the subsequent determination of the mechanical behaviour and fracture. It is shown that model may predict well the size effect on strength of cast irons fractured in a quasi-brittle manner such as shear failure. Difference in contact strength is due to the different mechanisms of the crack propagation process.

INTRODUCTION

It has long been recognized that many of the unique properties of cast irons e.g. their ability to damp vibration, excellent machinability, could be used to advantage if the limitations on structural integrity, imposed by an innate brittleness, could be circumvented. Several approaches to this problem are possible (Sedokov (1)), for example, to eliminate the most defecterious fabrication defects (inclusions, pores, etc), by improved fabrication technology. However, little attention has been devoted to enhancing the strength and crack arrest capabilities by optimizing the fracture toughness. Cast iron is a medium case compared to classically brittle materials (glass, ceramics). In the theory of plasticity the fundamental hypothesis that there is no volume change during plastic deformation is generally accepted. For cast irons there is some anisotropy of the elastic constants, the plastic deformation is heterogeneous from grain to grain, at least at yield, and this might lead to detectable effects on the yield stress at which cracking occurs is thus of major importance if one is contemplating the ductile machining of cast irons. Simple indentation can be used, based on the recognition that the indentation plasticity induces a residual stress intensity factor proposed by Lawn and Wilshaw (2). In this paper the fracture properties of the cast irons have been studied by strength measurements of controlled contact deformation and direct observation of cracks initiation and propagation under variable amount of triaxiality.

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ANALYSIS

It is a familiar observation that solids, which are normally thought of as brittle, may show ductile behaviour without cracking when indented, scribed under low loads. As a first step in attempting to predict the transition from ductile to brittle behaviour, we considered the initiation of a radial-median crack under the indenter. The compacted and sheared zone under the indentor, often refereed to as the "plastic" zone, is enclosed schematically by the dashed line in the Figure 1. Brittle fracture of failure is often thought to refer to rapid propagation of cracks without any excessive plastic deformation. In a three dimensional compression state, before a shear stress reaches a critical value to initial a crack, a hydrostatic pressure term must coexist. Once a shear crack propagates in octahedral planes, the built-in hydrostatic pressure is the main driving force of the indentation. It is observed that the metallic matrixes of gray cast irons are similar to those of eutectic steel. . Therefore, gray cast irons differ from steels in their structure only by the pressure of graphite inclusions, which distaste the properties of cast irons. A number of models for estimating void nucleation stress have been published, but the most widely used continuum model for void nucleation is due to Argon et al. (3). They argued that the interfacial stress at a cylindrical particle is approximately equal to the sum of the mean (hydrostatic) stress and the effective (von Mises) stress. The decohesion stress is defined as a critical combination of these two stresses: $\sigma_C = \sigma_H + \sigma_M$, where σ_H is the mean (hydrostatic) stress, defined as $\sigma_H = (\sigma_1 + \sigma_2 + \sigma_3) / 3$ and σ_M is given by $\sigma_M = B\,[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}$. B is a numerical constant such that when B = 1/3 then σ_M is termed the octahedral shear stress τ_{oct} and when $B = 1/\sqrt{2}$ then σ_M is known as the effective stress $\bar{\sigma}$. $\bar{\sigma}$ is the most convenient definition since in a uniaxial test σ is equal to the applied stress. For a brittle materials with constrained brittleness equivalent stresses are represented by (1).

$$\sigma_{eqv} = \lambda\,\bar{\sigma} + (1 - \lambda)\,\sigma_1 \quad \ldots\ldots (1)$$

λ is equal as ratio of tensile yield and strength to compressive yield and strength, $\lambda = \sigma^t_{0.2} / \sigma^c_{0.2}$ and $\lambda = \sigma^t_u / \sigma^c_u$ (index c is for compression, t – for tension). For plastic materials $\lambda = 1$ and equation (1) is von Mises $\sigma_{eqv} = \sigma_M$. Recognizing the fact that yielding in cast irons is associated with relatively volume changes, the octahedral strain which is in direction normal to the planes of the octahedron can no longer be zero. Subsequently, one must take into account the contributions of both the octahedral normal and octahedral shear stresses in order to predict the yield behaviour. A more general form of the von Mises yield criterion has been previously proposed by Mair (4) to take into account the hydrostatic pressure dependency: $\tau_{oct} + \mu\,\sigma_{oct} = K_{oct}$, where $\tau_{oct} = 1/3\,[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}$ is the octahedral shear stress, $\sigma_{oct} = 1/3\,(\sigma_1 + \sigma_2 + \sigma_3)$ is the octahedral normal stress, $K\,\sigma$ is a constant, and μ the octahedral normal stress coefficient. In the case of plastic distortion in pure shear, $\mu = 0$ and $\tau_{oct} = K_{oct}$. It is noted that this form of the von Mises yield criterion fits our experimental data and fracture may be considered (Figure 2 c) to be nucleated when a critical value of effective shear stress is attained.

In our model, the plastic zone is formed by the radial movement (by cracking, densification etc.) of that volume of material displaced by the indenter. This gives rise to an elastic-plastic strain field analogous to an internal hydrostatic force distribution (the so-called "expanding cavity" model of plasticity model proposed by (2). Expansion of this compacted zone could lead to median cracking at the base of the zone during loading (Figure 2).

TESTING AND RESULTS

The material was cast iron of the type GG-20 with lamellar graphite in pearlitic matrix. The graphite structure tended to rosette formation (IB3-3). Cast iron has a low strain-hardening coefficient, which increases markedly under pressure (10-15 % in plastic zone) (Figure 2 b). Chemical composition and mechanical properties of investigated cast iron are shown in Table 1.

TABLE 1 – Chemical composition and mechanical properties of cast iron

Cast	Chemical composition %							Mechanical properties		
iron	C	Si	Mn	S	P	Cr	Ni	σ_{ut} MPa	σ_{ub} MPa	HB
1	3.70	2.47	0.405	0.071	0.168	0.276	0.323	118	335	133
2	3.02	2.91	0.470	0.035	0.060	0.110	0.250	183	458	174
3	2.70	3.13	0.460	0.040	0.070	0.120	0.210	240	470	200

Four cylindrical disc models cut from the same cast iron casting were analysed each 10 – 30 mm in diameter with different thickness to diameter ratios (t/D) of 0.2, 0.5, 1.0 and 2.0. The strength levels in-tension ranged from 118 to 240 MPa. Our interpretation is that it is not contacted with plastic deformation in itself but has to do with the opening up of holes at the interface between the graphite flakes and the pearlitic matrix. For cast irons a phenomenon of stable crack growth complicated the measurement of k_{IC}. However using various contact geometry at initiation of cracking could be determined at various pressures. An analogy between the indentation crack and wedge-opened half-penny crack can be made because of the indentation plastic zone, in fact, acts as a wedge and is the source of the driving force for the crack as proposed by (2). For a variety of geometry of contact, experiments have shown that the plastic zones are hemispherical in shape with a relative plastic zone size that is uniquely related to the ratio of Young's modulus and hardness. Therefore, surface cracks nucleate and develop predominantly outside the plastic zones. The indenter shape (flat punch, sphere, pyramid, and cone) is likewise important, because various contact indentation angles produces various levels of contact deformation as proposed by Vasauskas and Baskutis (5) (Figure 3). Indentation of angles less than critical value (between 100 to 120 deg.) produces a cutting type of strain field.

The relation between the hemispherical plastic zone size relative to the impression volume and elastic (E, ν) and plastic (hardness, H) properties of the cast irons. By (2) $b = (E/H)^{1/2}\ r / (2\ \pi \tan\theta)^{1/3}$ .This assumption is consistent with the idea that the residual driving force for indenter cracks is derived from an elastic accommodation of the hardness impression volume. Residual crack driving force was shown by (2) to be of the form:

$P_{crit} = P\,(a/b)\,(E/H)\cot\theta$, where P is indentation load and a - the impression parameter. After the analysis of the possible fracture modes for indentation of the brittle materials was completed an experimental research effort was initiated to obtain some knowledge about modes and fracture characteristics of several cast irons alloys for manufacturing break disks for cars (Figure 4 a). The strength in circumferential direction was 220 MPa in a cracked break disk and 240 MPa in the new part, which is little below the required minimal value of 260 MPa.

CONCLUSIONS

The results of the present paper have practical importance in understanding the deformation and fracture of materials which although basically brittle, exibit plastic or some other form of inelastic deformation, when contact loaded. Experimental results of indentation strength and fracture in cast iron have shown that the nature of the indentation fracture modes is altered by the onset of plastic deformation in the vicinity of the contact and might then be expected to lead in the lifetime calculation.

SYMBOLS USED

σ_H = mean (hydrostatic) stress

σ_M = effective (von Mises) stress

σ_1 , σ_2 and σ_3 = principal stresses

$\bar{\sigma}$ = intensitivity of the stresses

b = radius of the hemispherical plastic zone

θ = semi-contact indentation angle

REFERENCES

(1) Sedokov, L.M. “Strength of Materials to Large Plastic Strains” , TPI, Tomsk, 1966.

(2) Lawn, B.R. and Wilshaw T.R. “Indentation Fracture: Principles and Application”, J. Mater.Sci., Vol. 10(6)., 1975, pp.1049-1081.

(3) Argon, A.S. and Safoglu, R. “Cavity Formation From Inclusions in Ductile Fracture”, Metallurgical Transactions, Vol. 6A, 1975, pp. 825-837.

(4) Mair, V.M. “Fracture Criteria for Cast Iron under Biaxial Stresses “, J. of Strain Analysis, Vol.3., No. 4, 1968, pp. 254-263.

(5) Vasauskas, V.S. and Baskutis, S.V. “Static And Impact Indentation Loading Damage In Brittle Materials”, Proc. of the 9th Int. Conf. on Exp. Mechanics, Copenhagen, Denmark, Vol.1., 1990, pp. 158-167.

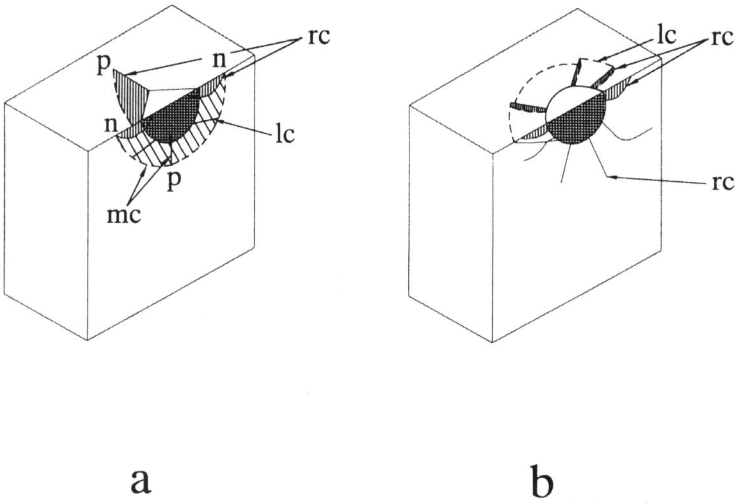

Figure 1 Schematic diagrams of cracks around sharp (a) and blunt (b) indentation: rc,mc, lc – radial, median, lateral cracks; oval-hatched zone – extent of the deformed zone

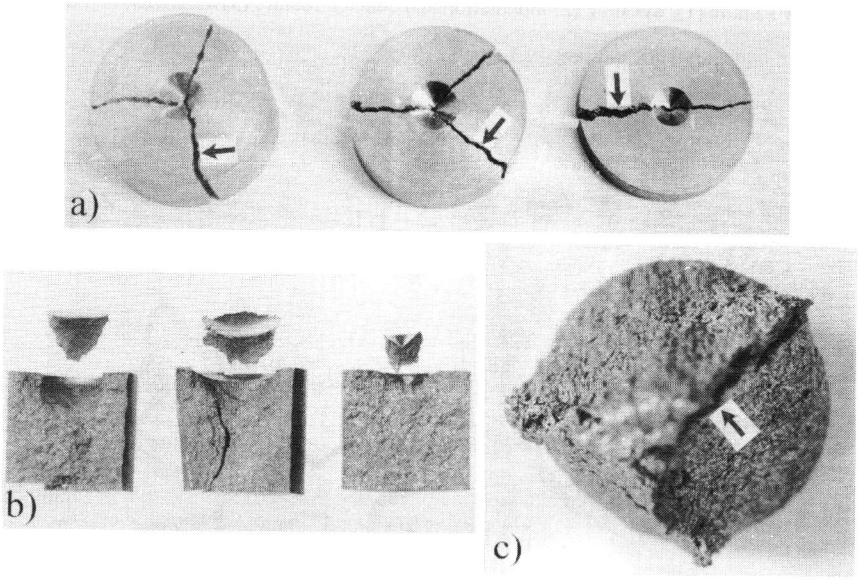

Figure 2 Fracture modes of cast iron (a), deformed volumes for various indentation angles(b) , octahedral fracture planes ($2\theta > 120$ deg.) (c)

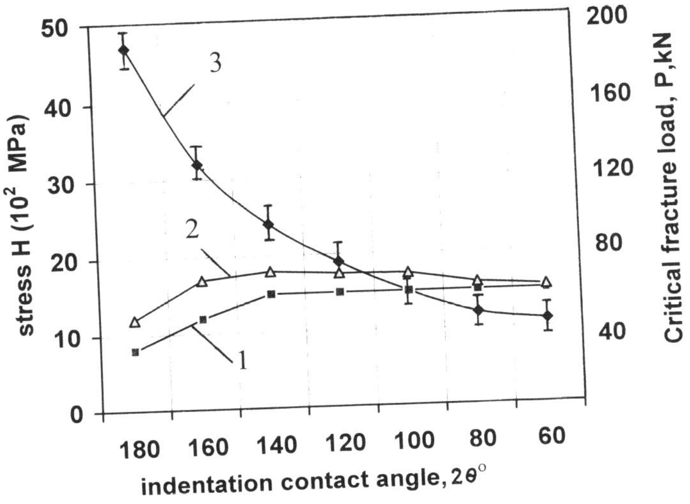

Figure 3 Static (1), dynamic (2) indentation and contact fracture (3) diagrams

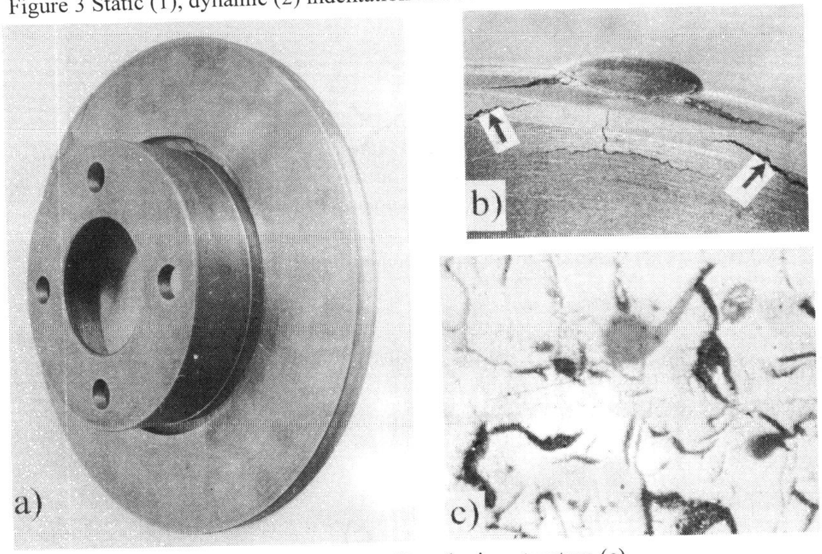

Figure 4 Break disk (a), fracture cracks (b) and microstructure (c)