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A REVIEW OF CERTAIN NON-STANDARD THEORETICAL AND EXPERIMENTAL INVESTIGATIONS IN FRACTURE MECHANICS

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A review of certain less known non-standard theoretical and experimental investigations in fracture mechanics is presented. It is outlined that using non-local theory of elasticity one obtains non-singular stress distributions at the crack tip. Shortly are described special non-standard experimental techniques used in crack propagation investigations: shadow optical method of caustics, determination of plastic zones at the crack tip by the recrystallization method, the infrared radiometry applications in fracture mechanics and the tomography in damage mechanics.

1. Introduction

The processes of fracture mechanics are very complex and not yet fully examined. Depending on the material properties, the rate of deformation and complexity of loading and the temperature the mechanics of fracture process may be of completely different mode. Moreover depending on the mentioned external factors the same material (we shall limit these considerations mainly to polycrystalline metals) may suffer brittle fracture for example when loaded at a very low temperature, or the fracture may be almost perfectly ductile when the temperature is high. When strain rates are high the brittle fracture may occur, while it may be ductile when strain rate is low. To a separate group belong the fracture phenomena connected with the fatigue type loadings. Specialistic monographs are devoted to these complex phenomena, for example the books by Kocańda (1978), (1990) and also the book by Kocańda and Kocańda (1989). These problems will not be discuses here.

In most practically important cases the fracture under non-fatigue type loading is of an intermediate type. It may be classified as a mixed brittle-ductile fracture. Usually final separation of the material is connected with previous large plastic deformations. Such complex processes still await more sound scientific analysis and theoretical description in spite of numerous publications referring results of various experimental studies. Recently published monographs by Thomason (1990) and by Atkins and Mai (1985) demonstrate how difficult is the formulation of a general theory of mixed brittle-ductile fracture processes and how complex are the phenomena occurring during such processes. The complexity of these processes is also demonstrates in multi-volume editions, such as for example the encyclopedic edition by Liebowitz (1971).

One can distinguish in the present fracture mechanics various specialized fields of investigations; namely, on micro, mezo and macro levels (cf Szczepiński (1994)). Two complety opposite idealized theories of fracture mechanics; namely, mechanics of perfectly brittle fracture and mechanic of perfectly ductile fracture, are also considered. In spite of the obvious fact that two extreme cases can seldom be utilized in their pure form to the analysis of real fracture processes observed in commercial metals, both can help in the better understanding of the nature of such processes.

The mechanics of perfectly brittle fracture refers with significant accuracy to such materials as for example glass in temperatures below a certain level. Let us notice, however, that glass in higher temperatures displays plastic properties and decohesion in it during extension is very close to the perfectly ductile fracture by reducing the cross-sectional area to the point. The same refers to some commercial metals, in which in low temperatures the fracture is almost perfectly brittle, while in high temperatures may be almost fully ductile. An almost brittle fracture is observed even in such materials as rubber if tested in the temperature of liquid nitrogen.

The coincidence of the perfectly brittle fracture mechanics with real behaviour of certain materials under certain conditions initiated the rapid development of the brittle fracture mechanics starting from the classic paper by Griffith (1920). Besides the obvious practical significance of this direction in the fracture mechanics, to its development contributed the fact that being based on the ideal linearly elastic model of the material it could be formulated in a rigorous mathematical manner. The mechanics of propagation of linear cracks is still attractive for researches of the mathematical attitude. Achievements of this branch of fracture mechanics are imposing. However, its practical significance is limited as stated above to brittle materials. Most commercial metals of technical significance do not belong to this group.

In most commercial metals the fracture is accompanied by both the ductile and brittle phenomena. The interaction between these two factors is complex and still not fully examined. Depending on the circumstances either brittle or ductile phenomena may dominate during the course of the fracture process. In some cases both of them play almost the same role. In extreme cases plastic phenomena may prevail and the fracture consists in reducing the area of the critical cross-section of the body almost to the point as a result of the local plastic flow. Such a local separation of the material will be referred to as the perfectly ductile fracture. It may be interpreted as an extreme contrast to the perfectly brittle fracture which is not accompanied by any plastic deformation.

In previous papers Szczepiński (1990a) and (1994) a certain attempt was undertaken to make a synthesis of up-to-date achievements of the theory of perfectly ductile fracture mechanics along with the results of experimental verifications In the present review the basic solutions of the perfectly brittle fracture mechanics are compared with the corresponding solutions of perfectly ductile mechanics. The former have been obtained under assumption of the elastic model of the material (Fig.1a), while the latter have been obtained by assuming the model of a rigid-perfectly plastic material (Fig.1b).

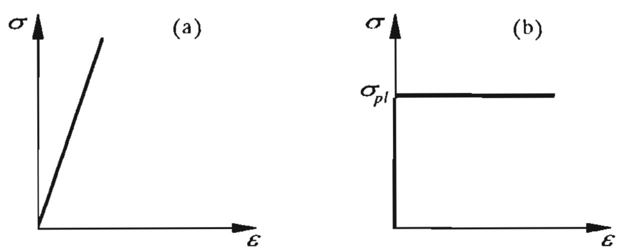

Fig. 1.

2. Foundations of perfectly brittle fracture mechanics

The mechanics of perfectly brittle fracture is based on the assumption that inside the body in its virgin state there exsist a certain system of cracks. This hypothesis has been introduced by Griffith (1920), who analysed the strength of glass. Such an assumption was introduced in order to explain why the theoretically expected strength of material is much greater than that measured experimentally. For most materials the real strength is 100 to 1000 times smaller than that theoretically predicted.

Theoretical strength of a body without internal defects may be calculated on the basis of the theory of crystalline lattices. It can be also calculated in an elementary manner described in various textbooks (cf Hahn (1977); Knott (1973); Hellan (1984); Timoshenko (1936)). As a result of such approximate calculations one obtains the following estimate of the theoretical strength

$$\sigma^* = \sqrt{\frac{E\gamma}{d}} \tag{2.1}$$

where γ is the specific surface energy and d stands for the interatomic distance in the lattice.

For most materials the specific surface energy γ is of the order $0.01Ed$ (cf Knott (1973)). Thus we can finally write

$$\sigma^* \approx 0.1E \tag{2.2}$$

The real measured strength of such an order is observed in a very few particular cases, for example in so called whiskers or in very thin steel wires. Usually, it is many times smaller than its theoretical value (2.2).

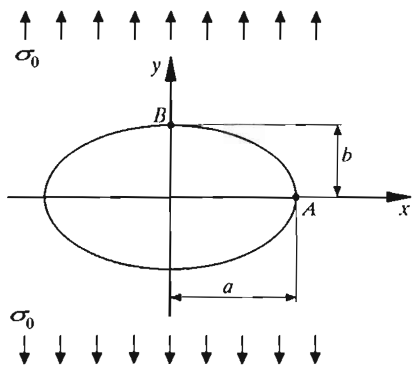

Fig. 2.

In the Griffith theory of brittle fracture it is assumed that such a discrepancy is caused by strong stress concentrations around small defects existing inside the body. The stresses there may reach locally the level equal to the theoretical strength (cf Knott (1973)). As the first approximation Griffith (1920) assumed, considering two-dimensional problems, that inside the body there exist voids of elliptic shape. If such an elliptic crack is oriented perpendicularly to the tensile stress direction (Fig.2), then according to the Inglis solution (cf Timoshenko (1936); Timoshenko and Goodier (1951)) the maximum stress appears at point A. Its value is

$$\sigma^A_{\max} = \sigma_0\Big(1 + 2\frac{a}{b}\Big) \tag{2.3}$$

Let us notice that there appears at point B a compresive stress. Its magnitude is independent of the a/b ratio and in any case takes the value

$$\sigma^B = -\sigma_0 \tag{2.4}$$

In the extreme case of a very narrow crack one can assume that the width b is equal to the interatomic distance in the crystalline lattice d. Thus one can assume in Eq (2.3) that $b = d$. Then $2a/b \gg 1$ and instead of Eq (2.3) we can write

$$\sigma^A_{\max} = 2\sigma_0\frac{a}{d} \tag{2.5}$$

Assuming as a fracture criterion the equality $\sigma^A_{\max} = \sigma^*$ we obtain the following estimate of the limit value of the external stress

$$\sigma^*_0 \approx 0.05\frac{d}{a}E \tag{2.6}$$

This approximate estimation indicates that a crack of the length $2a = 5\,000d$ (assuming $d \approx 0.2\,\text{nm}$ we obtain $2a \approx 1\ \mu\text{m}$) can decrease the strength of the body by several orders with respect to its theoretical value. The analysis of this result is given for example in the book by Knott (1973).

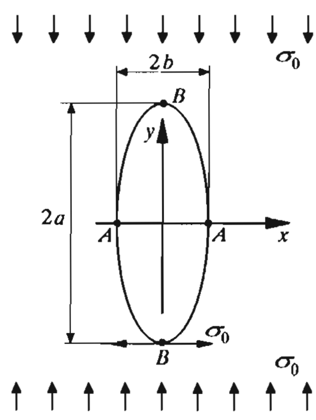

Fig. 3.

Consider now a particular case when a Griffith's crack is oriented along the direction of compressive stress (Fig.3). According to the Inglis solution we shall have at the end points of the longer axis of the ellipse tensile stresses $\sigma_x^B = \sigma_0$. It means that in the compressed specimens with Griffith defects there always appear tensile stresses in the direction perpendicular to the direction of the external compressive stresses σ_0. In such specimens made of brittle materials fracture usually takes place along the direction of the compressive force as shown in Fig.4. This may be caused by the tensile stresses discussed above.

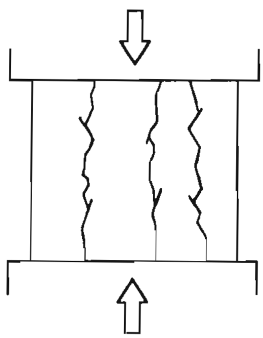

Fig. 4.

Another approach to the mechanics of brittle fracture represent studies based on the theory of linear cracks described in numerous papers and books (cf Irwin (1957), (1958); Kobayashi (1973); Matczyński (1977a,b), (1990); Rooke and Cartwright (1976); Sih (1973); Sokołowski (1974), (1977); Tada et al. (1973)). Let us notice that in all the solutions of this theory there appears singularity at the crack tip as shown in Fig.5 for the basic configuration. The distribution of σ_y stresses along the x-axis is given by the formula

$$\sigma_y = \frac{x\sigma_0}{\sqrt{x^2 - a^2}} \tag{2.7}$$

At the crack tip $(x = a,\ y = 0)$ these stresses, similarly as in the case of a Griffith crack $(b/a \to 0)$, tend to infinity even if σ_0 is very small. However, in any case the loading level may be estimated by calculating the so called stress intensity factor. For the case shown in Fig.5 such a factor is

$$K_I = \lim_{x \to a} \sigma_y(x,0)\sqrt{2\pi(x-a)} \tag{2.8}$$

and similarly for other loading modes.

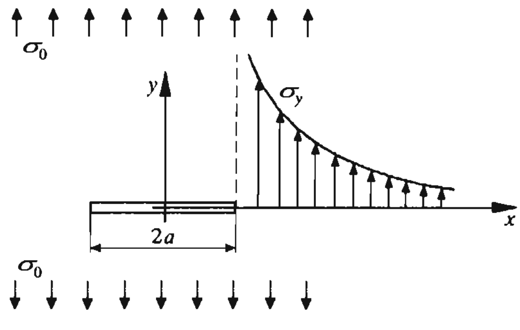

Fig. 5.

When a linear crack is oriented along the direction of uniaxial compressive stress we can notice a remarkable difference between the Griffith theory and the theory of linear cracks. It was mentioned above that even in the limit case when $b \to 0$ and an elliptic crack reduces to a linear one, at the tip of such a reduced crack still exists a tensile stress of the magnitude σ_0. The theory of linear cracks does not allow such tensile stresses to appear.

Eq (2.7) was obtained under assumption of classical Hooke's law

$$\sigma_{kl} = \lambda\delta_{kl}\varepsilon_{rr} + 2\mu\varepsilon_{kl} \tag{2.9}$$

Such an elastic model of the material is referred to as the locally elastic model, in which stresses at a given point depend on the deformations at this point only.

A significant contribution to better understanding of the theory of brittle fracture is the fact (cf Eringen et al. (1977)) that if the so called non-local theory of elasticity is used one obtains finite stresses as the tip of a linear crack. In the non-local theory of elasticity stresses at a given point depend not only on the strains at this point but also on the strains in its surrounding. Instead of the classical form (2.9) the stress-strain relation is written as

$$\sigma_{kl}(\boldsymbol{x}) = \int \Big[\lambda'(|\boldsymbol{x}' - \boldsymbol{x}|)\varepsilon_{rr}(\boldsymbol{x}')\delta_{kl} + 2\mu'(|\boldsymbol{x}' - \boldsymbol{x}|)\varepsilon_{kl}(\boldsymbol{x}')\Big]\, dV(\boldsymbol{x}') \tag{2.10}$$

where V stands for the whole volume of the body. Thus the stresses $\sigma_{kl}(\boldsymbol{x})$ at given point $\boldsymbol{x}$ depend on the strains $\varepsilon_{kl}(\boldsymbol{x}')$ at all the points $\boldsymbol{x}'$ of the volume V. The two moduli λ' and μ' are functions of the distance $|\boldsymbol{x}' - \boldsymbol{x}|$ between the reference point $\boldsymbol{x}$ and any other point $\boldsymbol{x}'$ of the body.

Not going into details of the non-local theory of elasticity and into certain its inconsistencies and uncertain reference to real materials being the subject of criticism, it should be emphasized the resulting from this theory lack of singularity in the stress distribution at the crack tip. Such a result indicates that singularities difficult to accept in classical solution are the consequence of the assumed model of local elasticity (2.9). This model may not be adequate when stress gradients are very large.

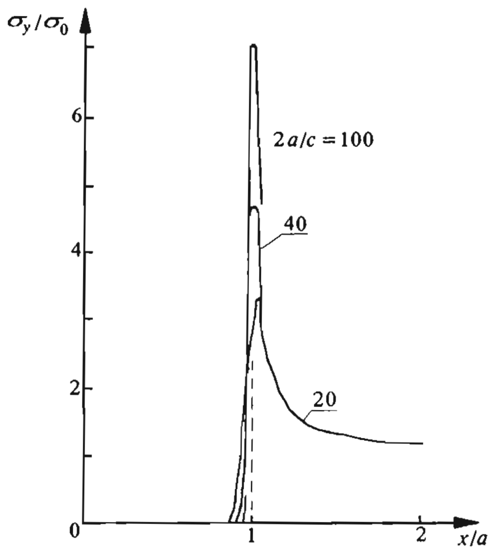

Fig. 6.

As an example of application of non-local theory in Fig.6 is shown (cf Eringen et al. (1977)) the distribution of σ_y stress component near the tip of a linear crack of a length $2a$ loaded as that in Fig.5. Now the concentration of finite stresses at the crack tip depends on the ratio $2a/c$, where c is the interatomic distance in the crystal lattice of the material. In such solutions it was assumed that the non-local interaction is limited to the interatomic distance in the lattice. Such an assumption was later strongly criticized. Nevertheless, the fact that using the non-local theory one obtains solutions without singularities induces a critical look on the applicability of local theories in cases when the singularities appear in the solutions.

Another significant factor in non-local solutions of the type shown in Fig.6 is the scale effect. Stress distribution depends on how long is the crack with respect to a certain material constant, that is to the interatomic distance in the crystalline lattice. The shorter the crack the smaller is the stress concentration.

Let us notice that using another non-standard theory of elasticity, namely the theory of couple stresses, we do not avoid singularities in the solutions (cf Cosserat and Cosserat (1909); Mindlin (1963); Nowacki (1986); Sokołowski (1970), (1972)).

3. On certain non-standard experimental techniques in fracture mechanics

The fracture phenomenon and its negative consequences have attracted the attention of designers and manufacturers for many years. Brittle fracture may often occur in plastic forming processes, for example in extruded rods, or in structures and machine parts.

Well known is brittle fracture in railroad rails, especially in low temperatures, fracture of steel structures – bridges, ships, containers. Brittle fracture attracted even more attention when welded structures made of high strength steel were introduced into practice. In a frosty day in 1938 collapsed a bridge over the Albert's canal in Belgium. In 1940 at the temperature minus 14°C partly fractured two other bridges over the same canal. Well known are the cases of fracture of ship hulls. In some cases the total fracture of the hull was observed.

Investigations of the causes of such catastrophes lead to the following conclusions (cf Pełczyński (1959)):

- The fracture propagates from the places with high stress concentration and three-dimensional stress state
- The fracture was almost perfectly brittle without remarkable plastic deformations
- Fracture mostly occured in large welded structures; tendency to fracture increased with the increasing thickness of metal sheets used
- The tendency to brittle fracture is higher at low temperatures
- The material of fractured structures displays low energy absorption during impact tests
- Remarkable residual stresses were observed in fractured structures.

Very important is the role of low temperatures in the brittle fracture processes in metals. For example investigations of the number of fractures in rails in the trans-Siberian railroad have shown almost perfect coincidence with the variation of the temperature. Fig.7 shows such a relation between the number of fractures in rails and the mean temperature of the month during various seasons of the year. These investigations were performed by Dabrovidov and Kuznetzov (cit. after Pełczyński (1959)).

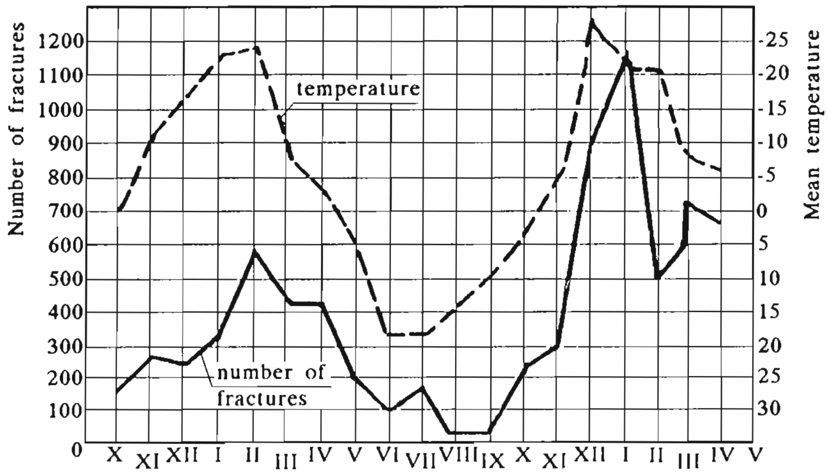

Fig. 7.

From among numerous experimental procedures concerning the fracture mechanics, many of which may be treated as routine methods, we shall mention some less known but of real scientific significance.

3.1. Shadow optical method of caustics

The shadow optical method of caustic is a new experimental technique, which proved very effective in investigations of dynamic propagation of cracks (cf Kalthoff (1987); Kalthoff et al. (1977), (1980); Manogg (1964); Theocaris (1981); Theocaris and Joakimedes (1971)). The method is sensitive to stress gradients and therefore constitutes an appropriate tool for the analysis of stress concentration problems. Principles of the method are described for example by Kalthoff (1987). We shall shortly point out its applications to the fracture processes.

The method of caustic is based on the fact that stresses in a body alter its optical properties. Tensile stresses reduce the thickness of a flat disc due to

Poisson's effect. They also reduce the refractive index of the material, since it becomes optically less dense. The reverse situation applies for compressive stresses. These changes in the optical properties are utilized in the shadow optical method of caustics to make stress distribution in solids visible (cf Kalthoff (1987)).

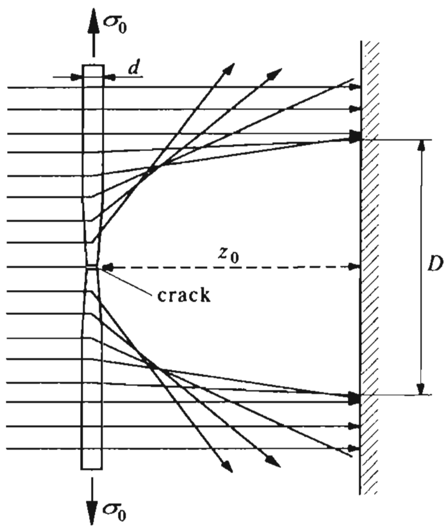

Fig. 8.

Fig.8 shows (after Mannog (1964)) the distribution of light rays in a transmission arrangement for the case of a crack under tensile (mode I) loading. The closer to the crack tip a light ray traverses the transparent specimen, the larger its deflection. The shadow optical image therefore exhibits a sharp boundary line between the area of darkness and the surrounding area of light concentration. This boundary line is called the caustic curve.

When models with cracks are investigated a mathematical relation between the characteristic dimension ("diameter") D of the dark region and the stress intensity factor K_I can be used for the interpretation of experimental results. The theory of such relations is given in specialistic monographs (e.g. Kalthoff (1987)).

For the mode I loading it takes the following form

$$K_I = \frac{2\sqrt{2\pi}}{3\sqrt{3.17^5} z_0 c d_{eff}} \sqrt{D^5} \tag{3.1}$$

where

c – certain optical constant
d_{eff} – effective thickness of the model.

Thus with Eq (3.1) and the measured characteristic dimension D of the caustic the stress intensity factor K_I can be experimentally determined. Thus using the method of caustics one can measure the stress intensity factor K_I and similarly the factors K_{II} and K_{III} for the two remaining loading modes.

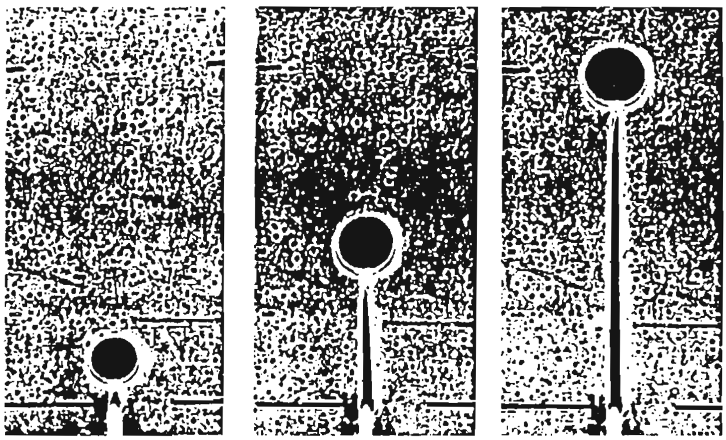
190 m/s 300 m/s 350 m/s

Fig. 9.

In Fig.9 are presented as an example three stages of the propagation of a crack in an Araldite B disc (cf Kalthoff (1987)). The pictures were photographed with a Cranz-Schardin high speed camera. The momentary crack velocity is given under each picture. The dynamic stress intensity factor K_I^{dyn} was also determined by measuring the instant characteristic dimension D of the caustic. Numerous other applications of the optical method of caustics are given by Kalthoff (1987). Among them are experimental investigations of the behaviour of arresting cracks.

Various other optical methods are used in investigations of local plastic yielding at the crack tip in ductile metals. Among them are holographic methods (cf West et al. (1971)) and methods of optical interferometry (cf e.g. Hu and Liu (1976); Ohta et al. (1977)).

3.2. Determination of plastic zones made visible by recrystallization method

Plastic deformation around a crack tip may be experimentally determined by the method of recrystallization (cf Stanzl and Faltin (1979)). Using this method one can determine plastic deformation in a small volume, almost at a given point not only on the surface of the specimen, but also inside it. Furthermore, the results are visible and therefore subjective errors may be avoided. The method of recrystallization was used by Csizmazia and Czoboly (1987) for determination of the plastic zones in compact specimens made of finegrained technically pure aluminium.

The method is based on the phenomenon that a plastically deformed metal recrystallizes if heated to an appropriate temperature. But the recrystallization begins only above a certain "critical" amount of deformation determined by the material and the heating process. In the case of a given heating procedure the size of newly developed grains depends only on the degree of deformation, being the largest at the critical value and decreasing with increasing strain (cf Csizmazia and Czoboly (1987)). This permits determining the degree of deformation.

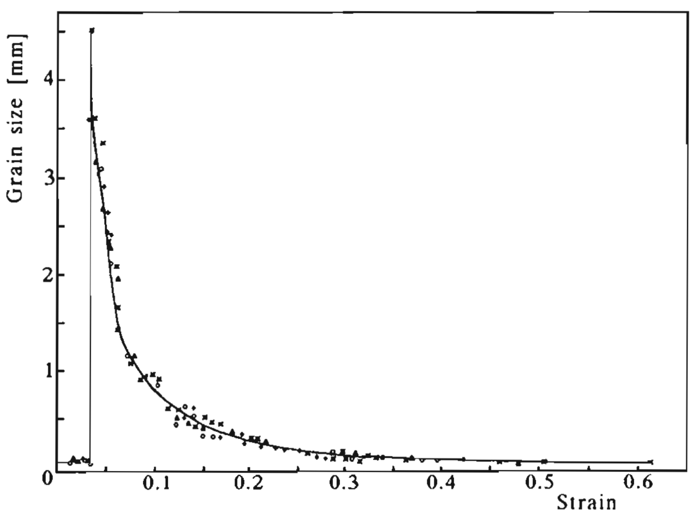

Fig. 10.

The calibrating curve for the aluminium used by Csizmazia and Czoboly (1987) is shown in Fig.10. It can be seen that the "critical" deformation is 0.04. Above 0.4 deformation the grain size is practically constant. The ratio of the diameters of the largest and smallest grains is about 45. This means that plastic deformation in a range from 4 to 40 percent can be detected and determined.

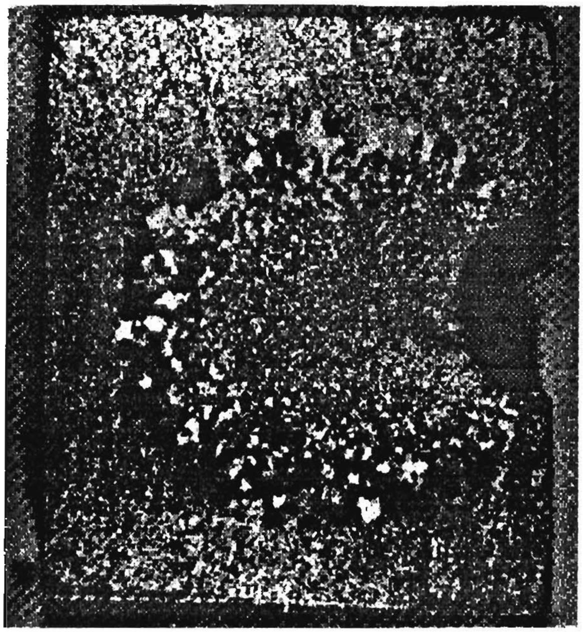

Fig. 11.

The tests were carried out using notched specimens of the configuration similar to that of the standard compact specimens used for determining the fracture toughness of metals. The specimens were loaded to the maximum tensile load, when crack nucleation could be observed in the notch root. Fig.11 shows an enlarged photograph of one of the deformed specimens. The transitory region between elastic and plastic zones is clearly visible.

In one of the series the plastic zone has been investigated as a function of the depth by cutting slices parallel to the plane of the plate after the heat treatment. The contours of plastic zones determined on the slices are shown in Fig.12. They changed from a "butterfly" shape on the surface to an elliptic shape in the mid-section. A "dog's bone" shape of the plastic region in the whole specimen is visible.

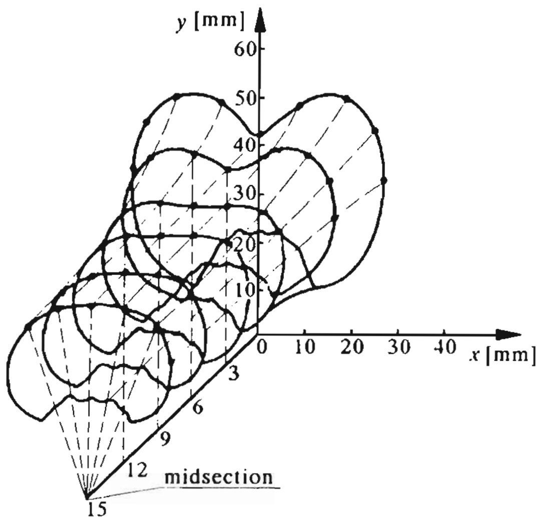

Fig. 12.

3.3. Infrared radiometry methods in fracture mechanics

The infrared radiometry method has been successfully used by Blanc and Giacometti (1981) and Nayroles et al. (1981) for the analysis of stress states around a crack tip. In an elastic medium in the case of reversible adiabatic deformation the variation of the temperature is given by the equation (cf Fung (1965))

$$\frac{\partial T}{\partial t} = -\frac{T}{\rho c_v}\beta_{ij}\frac{\partial \varepsilon_{ij}}{\partial t} \tag{3.2}$$

where

β_{ij}	–	tensor of thermal dilatancy
T	–	absolute temperature of the body
ρ	–	specific density
c_v	–	specific heat at constant volume.

Eq (3.2) constitutes the generalization of Kelvin's equation for the temperature variation in a thermically isolated body undergoing homogeneous elastic deformation.

In the case of isotropic body loaded by uniaxial tensile stresses σ, Eq (3.2) reduces to the form

$$\Delta T = -\frac{\alpha T}{\rho c_\sigma}\Delta\sigma \tag{3.3}$$

where

c_σ – specific heat under constant stress
ρ – linear thermal expansion coefficient.

It appears that tension produces a cooling of the specimen in the elastic range. It is also know that plastic deformation produces heat. Thus up to elastic limit the cooling phenomenon is governed by Eq (3.3), while beyond the yield point a rise of temperature is observed as indicated in Fig.13. For most metals it is possible to a detect in this way the conventional yield point. The cooling effect in the elastic range and heating during plastic deformation was utilized in the experimental analysis of the behaviour of more complex structures (cf Nayroles et al. (1981)).

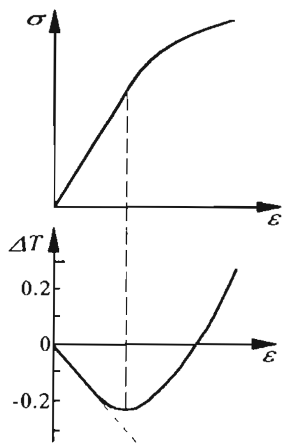

Fig. 13.

Blanc and Giacometti (1981) used the infrared stroboscopy for observing the propagation of a crack in a thin titanium sheet subjected to the cyclic (10 Hz) tensile loading. The AGA-Thermovision system was used. The thermal pictures (Fig.14a and Fig.14b) are built from the magnetic recording of the experiment. In the original paper by Blanc and Giacometti (1981) they were presented as the colour pictures. Each colour in these pictures is representative of a temperature.

In Fig.14a, obtained under a zero stress, a small light (yellow in the original picture) spot can be observed. It corresponds to the maximum temperature at the tip of the crack and is surrounded by concentric circles representative of a temperature decreasing from the centre. Fig.14b, obtained under a maximum stress, shows the lips of the crack opening. A tension induced cooling can be observed. The exact thermodynamic interpretation of such experiments has been given by Nayroles et al. (1981).

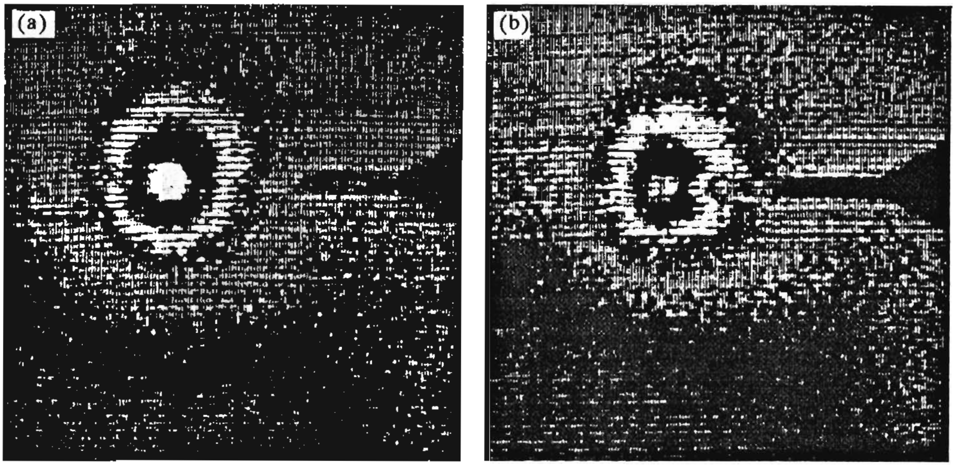

Fig. 14.

3.4. Tomography in damage mechanics

Computerized axial tomography was utilized by Cagnasso and Sawczuk (1983), (1984) to study the evolution of the internal damage growth in pure aluminium specimens subjected to large plastic deformation. Applicability of the tomography to material testing is outlined when the X-ray damping is related to the material density.

The computerized axial tomography allows one to established a local property measurable by the X-ray transition through elementary volumes in a material slice. The scanned slice is traversed by a concentrated beam of rays and their intensity is measured after a passage across the element tested. The material deterioration is usually described by a scalar parameter. The density change is associated with the voids growth, possible closing of some voids due to compressive stresses and internal cracks evolution. The material deterioration due to large straining is reflected in an increase of the standard deviation of the damping measured.

The principle of tomography is to use X-rays of known intensity I_0 and to measure the intensity of radiation I after the passage of the beam through the material tested. The fundamental relation regarding these two quantities is (cf Kaelbie (1967))

$$I = I_0 \exp(-\mu_m \rho X) \tag{3.4}$$

where μ_m denotes the attenuation constant per unit mass of the material tested, ρ stands for the volumetric density and X specifies the passage length of the radiation beam through the material. When endowing a scanner with a scale the coefficient of absorption is employed

$$\mu_m \rho = \mu \, [\mathrm{cm}^{-1}]$$

The value μ_m for an undeformed material is known. Since I_0 is known, I is measured, the density ρ can be calculated. The scale of damping is quantified in Hounsfield units H. The scale relates directly H to μ.

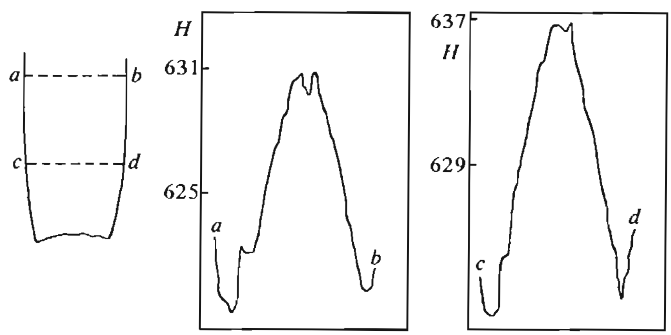

Fig. 15.

In Cagnasso and Sawczuk (1984) specimens of a pure aluminium sheet were loaded by uniaxial tension. The extension was terminated when a developed neck was visible. The undeformed and deformed specimens were subjected to tomographic scanning. In Fig.15 is shown the "density" variation across two section a–b and c–d in the fractured specimen as shown on the left side. The "density" is measured in Hounsfield units H. The distributions are seen to be non-uniform, with larger values at the axis of the specimen. Cagnasso and Sawczuk (1984) attributed such distributions presumably to the structural changes and the possible presence of compressive stresses as the stress state is no uniform deforming zone. They also conclude that their results are at present of an informative character only and that further tests are necessary to arrive at quantitative data relating to the damage evolution.

4. On the mechanics of perfectly ductile fracture

The theory of perfectly ductile fracture mechanics is based mainly on the theory of ideally plastic flow. Various aspects of this theory have been presented along with a comprehensive review of references in previous papers (cf Szczepiński ((1988), (1990a,bb), (1993)). A number of problems of perfectly ductile fracture have been analysed in these papers by using the standard slip-line technique based on the assumption of an idealized rigid-plastic model of the material (cf Fig.1b). It has been demonstrated that the plastic deformation processes leads to the local separation of the material even in such cases when a linear crack is oriented parallelly to the surface of the body under uniaxial tension. An example of such situation we shall present below. A crack of such an orientation does not play any role in the brittle fracture theory.

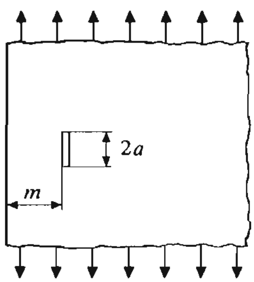

Fig. 16.

Let us analyse a particular case when a short linear crack of the length $2a < m$ is parallel to the stress-free surface of a half-space subjected to uniaxial tension (Fig.16). The simplest mechanism of plastic deformation consists in uniform extension connected with the progressive reduction of the width in the lateral direction. The tensile stresses applied at both ends of the body must be equal to the yield stress, as required by the assumed model of the material. Since the width of the body decreases due to the lateral contraction the total pulling force also decreases as shown schematically in Fig.17 – curve A.

However, another deformation mechanism is more significant. This mechanism consisting of rigid blocks motion is shown in Fig.18. Initial configuration of slip-lines constituting simultaneously the lines of velocity discontinuity is shown by dashed lines. Continuous lines present an advanced stage of deformation when the well-known perfectly plastic necking in the ligament between the crack and the external surface has led finally to the local separation of the material.

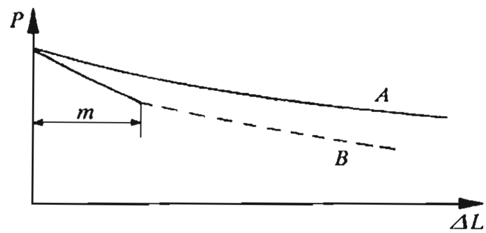

Fig. 17.

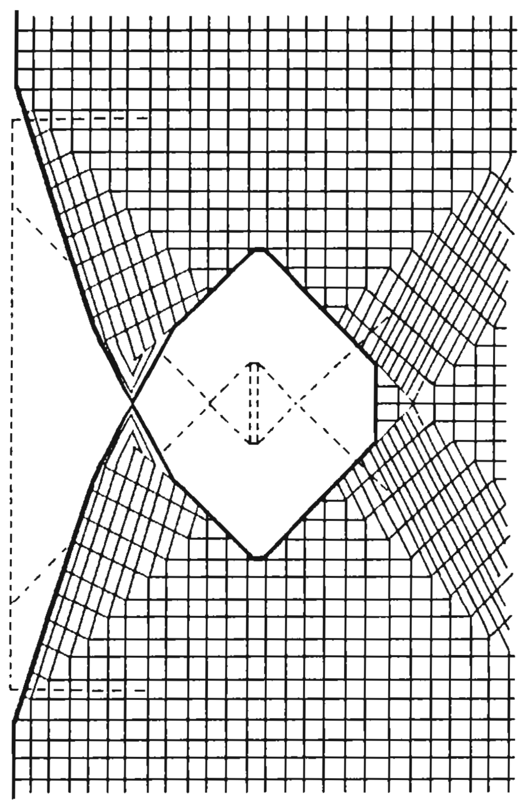

Fig. 18.

The relation between the pulling force and the elongation resulting from this solution is represented in Fig.17 by the curve B. It is seen that the force in the advanced stages of deformation is smaller than that in the case of uniform deformation. More discussion of such local solutions is given by Szczepiński (1993).

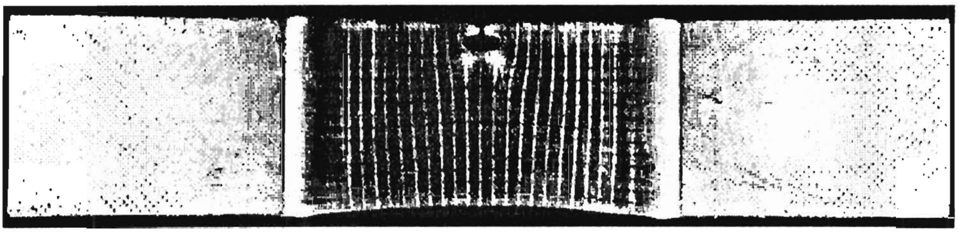

Fig. 19.

Similar solution for a circular defect located near the external surface is also given by Szczepiński (1993). The mechanism of plastic deformation is similar to that presented above. Such a mechanism leads also in this case to local separation of the material. The experimental result shown in Fig.19 substantiates the theoretical solution.

Such deformation mechanism may cause during plastic forming operations defects in drawn or forged pieces.

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Przegląd niektórych niestandardowych teoretycznych i doświadczalnych badań w mechanice pękania

Streszczenie

Przedstawiono przegląd niektórych mniej znanych nie standardowych teoretycznych i doświadczalnych badań w mechanice pękania. Podkreślono, że stosując nielokalną teorię sprężystości otrzymuje się rowiązania bez osobliwości przy czole szczeliny. Krótko przedstawiono specjalne niestandardowe metody doświadczalne stosowane przy badaniach propagacji szczelin, w tym: optyczną metodę kaustyk, określanie zasięgu strefy plastycznej przed czolem szczeliny przy użyciu metody rekrystalizacji, zastosowania metody termografii w podczerwieni oraz metodę tomografii komputerowej do badania rozwoju uszkodzeń w metalach odkształconych plastycznie. Podano również niektóre problemy mechaniki pękania ciągliwego.

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