ENERGY CONSUMPTION FOR DEFORMATION TO FRACTURE
OF A CIRCULAR-CLAMPED THIN PLATE
UNDER IMPACT LOADING*

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An experimental procedure for evaluating energy spent for fracture of a circular-clamped sheet structural element upon transverse flexure, induced by impact loading of a spherical head-face body, is briefly outlined. Flexure test results for two sheet metals (a 20 mild steel and a D16T aluminum alloy 1.0 and 0.75 mm thick, respectively) and a 2.0-mm PA6 shock-resistant composite are cited. Experimental data analyses and stress-strain state calculations for a plate material within the circular boundary upon flexure made it possible to establish the relation between the work of deformation and the dynamic strength and plasticity. Sheet structural element materials are comparatively evaluated by their specific energy spent for deformation under transverse static and impact loading.

Keywords: thin plate, flexure, energy consumption, impact loading, fracture, strength.

Introduction. Metals and composites are widely used for manufacturing sheet structural elements of transport facilities. Deformation of a sheet structural element under transverse dynamic loading is a complex process with the development of a nonstationary stress-strain state with time upon inelastic deformation of a material to its fracture. The choice of the optimum technology for manufacturing commercial or new materials (composites in particular) for sheet structural elements requires experimental data offering their comparison by possible absorption of energy spent for deformation (fracture) under transverse impact loading.

Different structural materials can be compared by the specific energy spent for their deformation to fracture (in the plane stress state or close to it) upon transverse flexure, using transverse flexure test data for circular-clamped thin plates. Such a procedure is applicable to static and dynamic loading tests. The identity of specimens and their loading schemes creates a reliable base for comparing energy consumption values for different materials under impact loading, if the loading time is sufficient for nonstationary processes in a plate to be neglected.

This communication summarizes flexure test results for thin plates from a 20 mild steel, a D16T aluminum alloy, and a PA6 composite with high-modulus fibers provided by the Institut für Verbundwerkstoffe, Kaiserslautern (Germany).

Tests and analyses of results were performed by procedures similar to those used earlier for studying flexure of thin plates (membranes) with different contours of clamping under short-time transverse pressure [1–3].

The influence of dynamic strength characteristics of strain-rate sensitive materials [4–6] on the energy spent for deformation of a plate in flexure were analyzed by numerical simulation results using the finite-element method.

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**Test Procedures. Impact Flexure Tests of Sheet Structural Elements.** Plates (specimens) in the form of 70×70-mm squares cut from a sheet were used for the tests. The scheme of impact loading is shown in Fig. 1. Specimen 3 was clamped between the plane surfaces of upper and lower flanges 4 and loaded by displacement of cylindrical rod 1 with a spherical head face. Impact loads on a plate were calculated by elastic strains of a dynamometer (tubular portion of support 2). Strains were recorded with wire strain gauges 6, bonded onto the outer surface of the dynamometer (support 2) that was mounted on base 5.

Static loading tests were performed on an IR 5047-50 standard testing machine with recording of load–time \((P - t)\) and longitudinal elastic dynamometer strain – time \((\varepsilon_d - t)\) diagrams.

Strain–time \((\varepsilon_d - t)\) diagrams obtained under impact loading were entered in the memory of a digital oscillograph and then processed by an EXCEL application package. The procedure of diagram processing is similar to that given earlier [5].

Flexure tests under impact loading with a velocity up to \(v_0 = 5\) m/s were performed on a vertical testing machine [4]. A plate was loaded with the impact of a free-falling heavy hammer on a rod through a damping element (copper layer about 2.0 mm thick to reduce possible rebound). In the tests at a velocity up to \(v_0 = 100\) m/s, the rod was loaded with the impact of a piston that was accelerated up to the required velocity by compressed gas pressure along a 64-mm barrel of a pneumatic testing machine. The recording scheme for \(\varepsilon_d - t\) diagrams is identical to that used in static tests.

Chosen sizes of a dynamometer from hardened steel (height of the tubular portion \(l_d = 12.5\) mm) provide a stress-strain state close to the uniform one for the time of load growth \(t_l \gg 2 \frac{l_d}{c_0} = 5\) \(\mu s\) (\(c_0\) is the velocity of longitudinal elastic wave propagation in steel). Wave processes in a 40-mm-diameter deformed part of a plate upon transverse flexure under impact loading give rise to a nonstationary stress-strain state whose deviation from the quasistatic one can be neglected if the initial time of load growth \(t_l \gg \frac{d}{c_t} = 20\) \(\mu s\) (\(c_t\) is the radial velocity of shear strain wave propagation). The propagation velocity of plastic strains in a viscoelastoplastic material decreases with an increase in strains, especially upon strain localization [4], and this in its turn increases the initial time of nonstationary deformation of the plate in flexure. The deviation of the nonstationary stress-strain state in the plate from the quasistatic one by the moment of fracture increases with the loading rate. In all the experiments, because of the long time of load growth up to a maximum value (>200 \(\mu s\)), the above deviation is insignificant and can be neglected in the analysis of experimental data.

Transverse loads \(P\) on a plate were calculated by \(\varepsilon_d - t\) diagrams using the calibration curve obtained by the results of special static loading experiments and validated by impact tests.

**Calibration-Curve Calculation.** Transverse loads \(P\) on a plate were calculated by recorded strains \(\varepsilon_d\), using the linear relation

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P = k \varepsilon_d,
\]

where \(k\) is the proportionality factor determined by the results of flexure tests under static loading.