IDENTIFICATION OF STATIC STRENGTH CRITERIA

O.Ol'khovik*, O.Figovsky, V.Feigin
Polyadd Ltd., P.O.B.732, Naiot, Nazareth - Illit 17106, Israel.

ABSTRACT

Up to the present time, none of static strength criteria was subject to reliable experimental verification. The original cause of such situation is not only of a methodical character, which was successfully overcomed by the authors. The fracture of polyester binder (used for production of reinforced plastics) was investigated for 18 trajectories of loading, holding away enough one from another, at triaxial stressed state. The experimental results were used for the verification of static strength criteria. It was found that the experimental fracture surface represents a rotation surface relative to hydrostatic axes and consequently, the most reliable criteria would be the models of Yagn, Kahn - Pervushin, Balandin types etc.
Ill. 2, table 3, ref. 11.
Key words: stress, triaxial stressed state, polyester polymer, criteria of strength.

INTRODUCTION

Up to now, in spite of more than 300 years of history of the science on strength, the extremely paradoxical situation has grown up in the problem of estimation of limit state for different technical objects. The problem consists of the following: the real constructions work as a rule at three-dimensional stress state. But up to now the processes of materials fracture for an arbitrary trajectory under three-dimensional stressed state were not realized in the laboratory conditions. For lack of comprehensive correct experimental data for fracture all the criteria of static strength are not yet confirmed experimentally. As long ago, as 1968 [1] B. Paul has complained " However, for lack of the data concerning the third quadrant, we can not actually verify this assumption..." Here it was implied the reliability of Coulomb - Moor criteria. But during the last 25 years little had changed.

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So in [2] it is confessed that the information about the stressed – strained state is decisive for the strength analysis of construction elements, but here too we have no information about the solution of three–dimensional problems. The testing system recommended in [3] does not permit to obtain the values of breaking stresses in all quadrants, even under two–dimensional stressed state. The established situation should be classified only as a deadlock, because it is senseless to solve the specific problem in three dimensions in order to reduce to one–dimensional introducing the permissible stress.

The present authors have carried out studies of unsaturated crossed polyester binder (used as a matrix for reinforced plastics) for 18 loading trajectories of, holding away enough one from another, using previusly developed experimental procedures and appropriate measuring equipment [4–6]. As a part of the investigation, it was rather well established, that the experimental surface of limiting resistance is the rotation surface relative to hydrostatic axes. The strength criteria associated with the rotation surfaces (Yagn, Balandin, Botkin–Mirolubov, Kahn–Pervushin), correlate satisfactorily with our experimental data.

The ensuring of reliability for different technical objects requires more complete study of the materials fracture problems at the level of elementary cube, and in particular, estimating the reliability of macroscopic fracture criteria, including the minimum necessary number of experiments. More extended estimation of the strength criteria reliability is conditioned by the growing possibilities of the stressed state determination using numerical methods [7–8]. The stressed state as a rule is three–dimensional and therefore if the strength criterion is not well–founded, the exact solution of the problem of stress field distribution has no sense.

The work is devoted to the identification of static strength criteria on the base of the experimental data on polyester binder fracture at three–dimensional stressed state.

MATERIALS AND METHODS

We have used the unsaturated nonstyrene polyester binder, contained also standard redox – system for hardening and also 1% liquid polysulphyde rubber and 1% silica powder. After mixing this material was hardened at room temperature during 72 hours with subsequent 6–hours exposure at 333 K.

Mechanical tests were carried out according the following trajectories (table 1) :

Table I.   Experimental data on fracture of polyester linder.

No.	σ_1 MPa	σ_2 MPa	σ_3 MPa	No.	σ_1 MPa	σ_2 MPa	σ_3 MPa	No.	σ_1 MPa	σ_2 MPa	σ_3 MPa
1	46	0	0	27	3	0	-103	53	-126	0	0
2	43	0	0	28	-52	-100	-149	54	-127	0	0
3	52	0	0	29	-45	-100	-145	55	-122	0	0
4	52	0	0	30	-48	-100	-152	56	-119	0	0
5	44	0	0	31	-44	-100	-156	57	-131	0	0
6	-9	-50	-50	32	-94	-100	-206	57	-184	-50	-50
7	4	-50	-50	33	-91	-150	-209	58	-193	-50	-50
8	1	-50	-50	34	-93	-15-	-207	59	-187	-50	-50
9	12	-50	-50	35	-90	-150	-210	60	-185	-50	-50
10	8	-50	-50	36	-139	-150	-261	61	-182	-50	-50
11	-80	-150	-150	37	-143	-200	-257	62	-253	-100	-100
12	-58	-150	-150	38	-142	-200	-258	63	-260	-100	-100
13	-93	-150	-150	39	-136	-200	-264	64	-260	-100	-100
14	-75	-150	-150	40	-183	-200	-317	65	-264	-100	-100
15	-78	-150	-150	41	-185	-250	-315	66	-257	-100	-100
16	-156	-250	-250	42	-179	-250	-321	67	-326	-150	-150
17	-172	-250	-250	43	-186	-250	-314	68	-326	-150	-150
18	-182	-250	-250	44	50	25	0	69	-328	-150	-150
19	-171	-250	-250	45	54	27	0	70	-331	-150	-150
20	37	0	-37	46	55	27	0	71	-325	-150	-150
21	41	0	-41	47	52	26	0	72	-378	-200	-200
22	44	0	-44	48	52	26	0	73	-383	-200	-200
23	38	0	-38	49	0	-39	-78	74	-390	-200	-200
24	2	-50	-102	50	0	-42	-84	75	-387	-200	-200
25	-2	-50	-98	51	0	-36	-72	76	-393	-200	-200
26	0	-50	-100	52	-126	0	0	–	–	–	–

– axial tension of ring samples(working part diameter 8 mm) at
4 levels of hydrostatics pressure (trajectories 1–19);
– torsion of thin–walled tubes (outside diameter 14 mm, inside
diameter 10 mm) at 6 levels of pressure (trajectories 20–43);
– testing of thin–walled tubes at internal and external
pressure (trajectories 44–51);
– one–dimensional compression (diameter of samples – 6 mm,
height – 10 mm)by applying stiff punches under 5 levels of the
hydrostatic pressure (trajectories 52–76).

Since we have tested 76 samples by 18 trajectories, the
obtained results contain the necessary information to verify
the reliability of static strength criteria.

One of the most important problems during mechanical
testing is the choice of necessary number of loading
trajectories. The number of experiments necessary to determine
the constants in a static strength criteria must be generally
equal to the number of the constants. However if the data for
tensile and compression strength is available, it is not
correct to make the conclusion that the material conforms to
Pisarenko – Lebedev criterion, since the form and dimensions
of the surface of limiting resistance can not be determined by
only two trajectories. Therefore we must have a lot of
experimental points, sufficient enough to determine the form
and dimensions for the surface of limiting resistance in terms
of fracture or flow.

The analysis of reliability for some criteria of static
strength will be carried out in terms of coordinates R and L
[10]being expressed in the terms of main stresses:

$$R = \sqrt{\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2\right]} / \sqrt{3} \qquad (1)$$

$$L = (\sigma_1 + \sigma_2 + \sigma_3) / \sqrt{3} \qquad (2)$$

RESULTS

The preliminary analysis of experimental data of table 2
shows that it is not possible to use all trajectories from 52
to 76, describing the uniaxial compression by stiff punches for
the estimation of the reliability for all strength criteria.
There is only one reason for this: such testing do not conform
to the supposed loading trajectory, because there are friction
forces at the surfaces transmitting the load to the sample.

If at the surface σ_1 and σ_2 (fig.1) we present two points:
one–dimension compression at the normal pressure
(trajectories 52–57) and one–and–a–half–dimension compression,
which was realized by the fracture of thin–walled closed
cylindrical casing by external pressure(trajectories 49–51),
then for the realization of Druker postulate, the values of
strength under one– and two–dimension compression must be

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close. However, as it follows from the experiment, this
difference is highly essential. Consequently, the results of
testing under one-dimensional compression, even if they give
some information about the strength of materials, are
absolutely not valid for the verification of the strength
criteria reliability, the more so, as such experiments give the
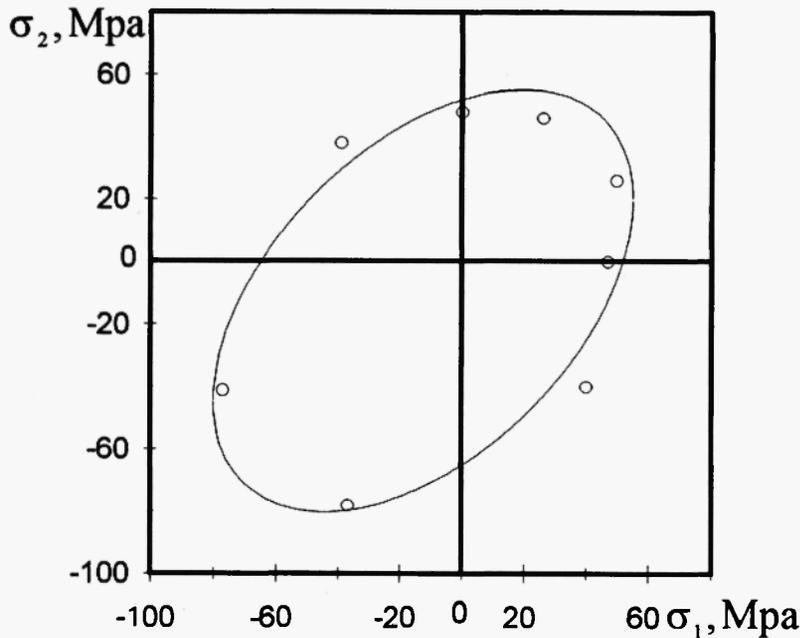excessive values for strength.

Fig. 1. The curve of limited strength for polyester crossed
polymer at the two – dimensional stressed state. The continuous
curve conforms to Yagn criterion.

So for the identification of the strength criteria we
choose 12 trajectories (fig 2).

The analysis was carried out for the criteria, their
limiting resistance surfaces being rotation surfaces. These
criteria in the terms of coordinates R and L are:

$$R = A + BL + CL^2$$ Kahn – Pervushin   (3)

$$R = A + BL$$ Botkin – Mirolubov   (4)

$$R = \sqrt{R = A + BL + CL^2}$$ Yagn   (5)
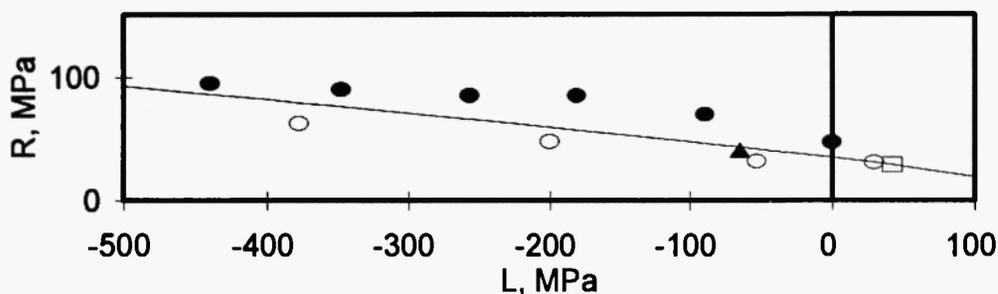
$$R = \sqrt{A + BL}$$ Balandin   (6)

Fig. 2. Surface of limited strength at the triaxial stressed state(● – torsion, ○ – tension, □ – two–dimensional tension, ▲ – two–dimensional compression).The continuous curve conforms to Yagn criterion.

The solution of the overfilled systems of equations with dimension 3×51 for Kahn–Pervushin and Yagn criteria and dimension 2×51 for Botkin–Mirolubov and Balandin criteria by the method of least squares results in the values of constants coefficients for the considered criteria. The results of the implemented calculations are given in the table 2.

As it follows from the table 2 the four considered criteria describe the experimental surface of the limited resistance for crossed polyester polymer with the practically equal accuracy .

Table 2. Analysis of strength criteria reliability

Criterion	Constant coefficient			Error, %
	A	B	C	
Kahn–Pervushin	44.6	$-14.6 \cdot 10^{-2}$	$-14.0 \cdot 10^{-5}$	15.0
Botkin–Mirolubov	47.7	$4.8 \cdot 10^{-3}$	–	16.5
Yagn	23.0	-15.0	$-78.4 \cdot 10^{-4}$	15.2
Balandin	23.6	-12.2	–	16.2

DISCUSSION

The obtained experimental data and its analysis show that the surface of limited resistance for the particular tested material represents a rotation surface relative to hydrostatic axis, and the spherical tensor of pressures essentially affects the strength.

The analogous results were also obtained earlier for gray iron magnesium and alloys [6], filled epoxy crossed polymers [11] and reinforced plastics [12].

The obtained information make the essential change in the calculations of strength. For three—dimensional and even for two—dimensional stressed states such values as equivalent or permissible stresses almost always have no sense in view of the following. All criteria of static strength may be divided into one—, two— or three—parametrical, depending on the number of constants. The typical representative of one—parametrical criterion is the Guber — Myzes mathematical model, containing only one constant. For this strength criterion the critical situation for any kind of stressed state is determined unequivocally by the value of segment connecting the point, at the hydrostatics axis with the point at the surface of limited It follows that only for this theory it is justified to talk about equivalent or permissible stresses. For all other strength criteria the critical length of the loading trajectory can not be expressed by only one number, since the loading trajectory length generally depends on the kind of the stressed state.

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