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METHODS ANALYSIS TO ASSESS THE CRACK RESISTANCE OF ADHESIVE JOINTS

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Abstract:Crack resistance (impact strength) is an essential feature that shapes adhesive joints' carrying capacity and durability. The existing methods for thecrack resistance assessment do not always produce accurate figures since experimental findings can be composed of several interdependent values. Theoretical calculation of crack resistance presents another challenge.Consequently, an analytical-experimental assessment method has been proposed to improve the accuracy and reliability of crack resistanceassessment for adhesive compositions. This method translates into action through a test set-up that endures the double-bonded cantilever beam loading with equal and opposite moments.A simulator, involving only one independent variable (bending moment), has been developed to measure specific crack advancing energy. It has been established that the thickness and cross-section dimensions of the adhesive composition of test patterns have a minor impact on the spread of thecrack advancing energy values.
Keywords: crack resistance,adhesive joint, adhesive composition, crack advancing energy,carrying capacity.

Adhesivejointsareatypicalresponsetotheneedsofawiderange of industries, including mechanical engineering, automobile production, aircraft- and ship-building[1–7].
The present study aims to develop a technique that ensures higher reliability of assessing adhesive joints' crack (growth) resistance properties given their geometric dimensions and experimentally measured strengthfactor.
Insteadofservingasanindicatorofadhesivecompositionsstrength, thecarryingcapacityof structuraladhesivejointsrefers to the strain concentration following adhesion-caused technological defects, such as cavities, insertion of foreign bodies, areas of missing or weak adhesive bond.
Meanwhile, an adhesivelayer (joint) is subjected to heterogeneous stress conditions due to strength property variations of adhesive compositions and bond materials. The medium is another factor that weakens the adhesive layer unevenly.
Crackresistanceisanessentialfeaturethatshapesthecarryingcapacityofadhesivejoints.
Despitewidespreadtheoreticalandexperimentalresearchoncrackresistanceassessmentforadhesivejoints, thetopichasnotbeenstudiedthoroughly yet.Researchfindingsareoften beyondcomparisonorpartlyinvalidduetopoorplanningofexperiments, forthefindings in questioncouldincludedependent variables. Consequently, the parameter governing the deformation of adhesive components might be a dominant factor.
Three parameters are available for crackresistanceassessment:strain intensity factor, crack opening displacement, and specificcrackadvancingenergy[8, 9].
Crackresistanceassessment, to be made with the application of strainintensity factor and crack opening displacement, is a challenging task that calls for the theoreticalandexperimentalanalysis of complex stressconditions of a thin adhesive layer. Therefore, specific crack advancing energyis commonly applied as a criterion for crack resistance assessment of adhesive joints.
The authors have developed a computational and experimental technique to improve the accuracy and reliability of determining the specific energy of crack propagation.
Currently, there are many guidelines and standards for assessing the bearing capacity of adhesive joints for various types of application of loading forces, which, with certain assumptions, can be applied to assess their crack resistance[10-12].
Stress cracking resistance tests of adhesive joints were used as a generic approach involving a double-bonded cantilever beam exposed to bending load applied perpendicular to the beam. At the same time, changes in the loading are measured in parallel with the corresponding length of the crack in the adhesive joint layer. Then, the specific crack advancing energyis calculated to pass judgment on the extent of crack resistance [13, 14].
The extension of crack length significantly impacts the reliability of test results, leading to inadequate accuracy of the data received.

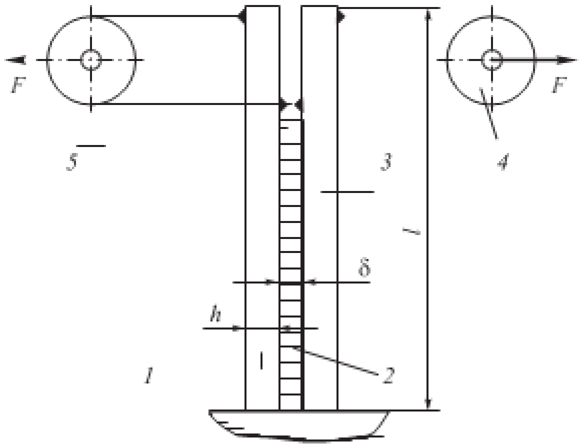

Fig.1.Testset-updesign

Description of the developed technique.Atestsample(Fig. 1) has been designed as two cantilever beams 1 and 3bonded by adhesivecomposition2.The forces F, creating a bending moment on each beam, are applied using special loading devices 4 and 5, consisting of blocks and flexible threads. The ends of each of the threads are connected to both cantilever beams, as a result of which the load is transferred to the beams in the form of equal and oppositely directed moments M (Fig. 2).Test pattern loading will eventually cause the rupture of adhesive joints to be accompanied by the corresponding crack formation and growth.

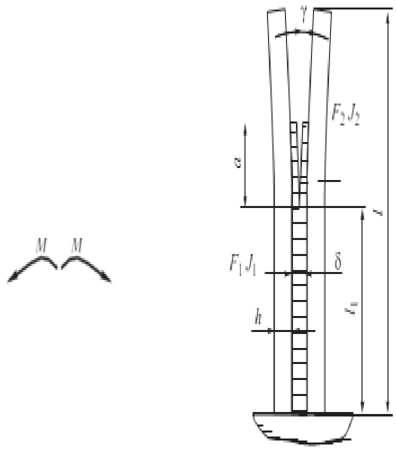

Fig.2.Designmodel for crackresistanceassessment

Higheraccuracyissupportedbyidenticalcrackformationconditionscreated by loading, which ceases to be effective once the unbroken section of the adhesive joint l1is more than four times the pattern height valueh(l1>4h).
The simulatordescribes the properties of crack resistance of an adhesive composition(Fig. 2).
Consequently, specific crack advancing energyis measured by the following formula:

$$G_1 = \frac{M^2}{2d}\frac{dC}{da} \qquad (1),$$

WhereM – bendingmoment; C –fixing compliance of cantilever beams; b –widthofa cantileverbeam (adhesivejoint); a – cracklength.
In the proposed design model, a test pattern, exposed to a bending moment load, willaccumulate the potential energy to be measured by the following formula:

$$U = \frac{1}{2}MC = M^2\left[\frac{a}{2E_1J_1} + \frac{\alpha_1}{2} + \frac{ka}{2E_2J_2} + \frac{\alpha_2}{2} + \frac{(1-k)^2(l-a)}{2(EJ)_0}\right] \qquad (2)$$

Wherek –thecoefficientdependingonthe matter propertiesandsize of cantilever beams;l–length of cantileverbeams;E1,E2–elasticity of the matter of cantilever beams;J1,J2–the moment of inertia of cantilever beamcross-section;α_1 andα2–fixingcompliance factorofcantileverbeams;(EJ)0– flexural rigidity per unit of length of a testpattern.
Solvingequations(1) and (2), we will get the following formula to measure specificcrackadvancingenergy:

$$G^1 = \frac{M^2}{2b}\left[\frac{1+k^2}{EJ} - \frac{(1-k)^2}{(EJ)_0}\right] \qquad (3)$$

Thenequation(3) worksoutonthe conditionthatatestpatternconsists of two cantileverbeamssetting the equivalent dimensions:E1=E2=E;J1=J2= J

Itis, however, assumedthatα1 = α2 = const; in all fairness, various test patterns were subjected to a measurement against their respective strain-deformedstate. Subsequently, the measurements produced the following matter elasticity values: 2.1·105MPa (carbon steel), 7·104MPa (aluminium alloys), and 2.9·103MPa (plexiglass). Theheightvalueofbeams was in the range of 2 to 12 cm (h = 2…12 cm). The tests utilized Sprut-5M, VAK-AandSprut Plus adhesive compositions setting the layer (joint) thickness δ of 0.1, 0.25, and 0.5mm, respectively.

Asummaryofthestrain (σ) dependency resultsonthelength of cantilever beams (l) is givenin the dimensionless form in Fig. 3. Thechartanalysisrevealsthatthestrain built up in the cantilever beams and adhesive composition along the length measuring more than four-fold beam height (4h) fades away to negligible levels. Therefore, the length of the section within which the beam-bending stress condition turns into the strain causing the unbroken sample part to bend will not measure more than four-fold beam height equivalent (l1≤4h).

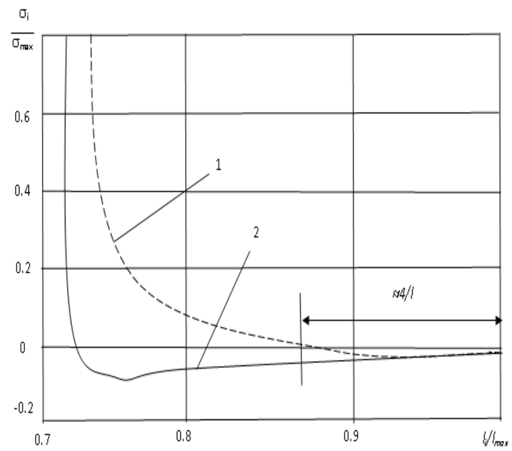

Fig.3.Straindistributionwithin the beam (1) and adhesive composition (2) along the length of a cantilever beam sample

Table: Major technologicalcharacteristicsofadhesivecompositions

Property	Adhesive composition		
	VAK-A	SprutPlus	Sprut-5M
Relativeviscosity by B3-246viscosimeter	70…80	30…60	20…35
Outdoorstrength[10],MPa,atuniform detachment/shear	10,8 10,1	8,5 9,3	8,4 7,0
Operating temperature,°C	-40…+80	–60…+100	–10…+60

Consequently, if the test leaves a sample part unbroken along the length measuring more than four-fold beam height, the stress distribution mode will remain unchanged, ensuring the compliance coefficient constancy.

Simplicityisasubstantialadvantageofequation (3) sinceitallowsforcrackresistanceassessmentthrough a single independent variable, i.e. experimentally measured bendingmomentM.

Experimentaldata. An ananalytical-experimentalassessmentofcrackresistancepropertiesofthe adhesivejointwasmade, under theproposedmethod, using atestset-up(Fig. 1) thatwasdesignedspecificallyforthestudy.

Thetestswereconductedon(carbon) steel-made rectangularbeamcross-sections bxh. Testpatternswereexposedtoloadingatauniform traversing speed of load-applying units.

BendingmomentsMand cracktip openingangles γ were measured by strain gauges. Toregistersignals emitted by strain gauges, recording equipment, precisely an XY plotter H306 was employed.

DependenceofbendingmomentMonthe steering angle γ of adhesive compositions (Sprut-5M,VAK-A, andSprut Plus) has been established in testing (See: **Table: Major technological characteristics of adhesive compositions**).Standard strength characteristics of adhesive compositions were determined according to works [15].

Theanalysisofreceivedfindings(Fig. 4) indicated the mode of steady crack growth on Sprut-5Madhesivecomposition. Meanwhile, Sprut Plusand

VAK-Aadhesive compositions experienced a slip-stock crack growth, initially high speed, recorded after crack tip opening, ebbing progressively down to zero level.Such a trend could be a consequence of over-speed crack formation.

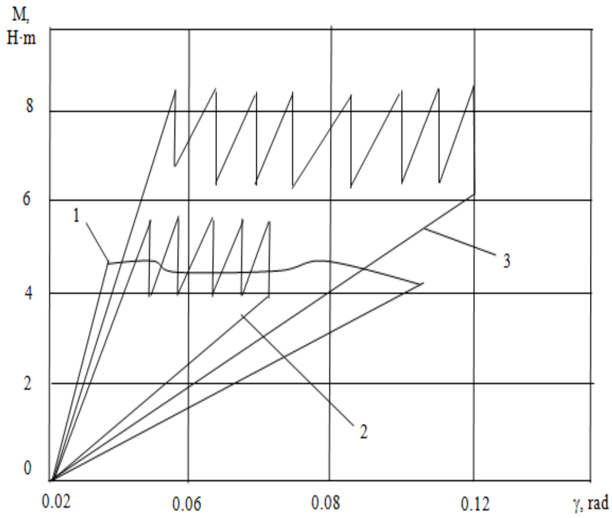

Fig. 4. Dependence of bending moment Mon the crack tip opening angle γof adhesivecompositions:

1–Sprut-5M;2–Sprut Plus; 3–VAK-A

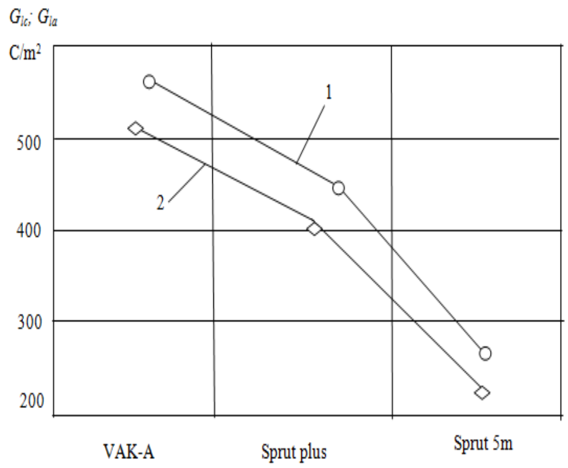

Fig.5.DependenceofthespecificcrackadvancingenergyGIc(1)and GIa(2)on the type of adhesivecomposition

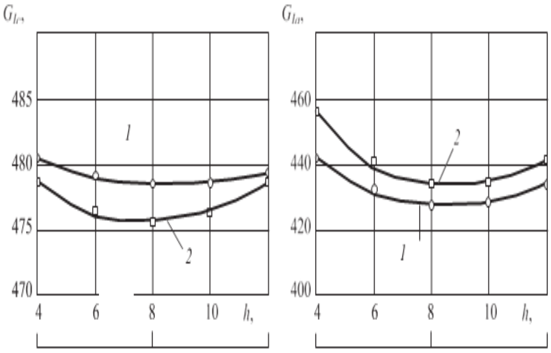

Fig. 6.Dependence of thespecific crack advancing energy GIc(a)and GIa(b)on the width b(1)and height h(2)of the cantilever beam when crack growth speed exceeds the rate of development of inelastic deformation.This phenomenon proved itself even upon the opening of the crack.

While identifying crack resistance properties of adhesive joints, two transient states are usually considered, adding notable significance to studying unstable crack growth cases. The first state, characterized by the specific crack advancing energyGIc,is reminiscent of an event involving a sudden crack jump following the maximum bending moment under the proposed method.On the contrary, the second transient state exhibits the specific crack advancing energyGIa and represents the crack growth coming to a standstill. Inthelatterevent, theenergy valuewasmeasuredby the bending moment's magnitude at the crack growth's standstill.

Assessment results.Specificcrackadvancingenergyvalues Gicand GIawere measured by the formula (3) for VAK-A, Sprut Plus,andSprut-5Madhesivecompositions. The analysis of mean values of specificcrackadvancingenergyGicand GIa(Fig. 5) showed the highest crack resistance value of the VAK-Aadhesivecomposition that was used as a cover.Therefore, furtherGic and Gia dependence calculations on other factors covered only the VAK-Aadhesivecomposition.

AsisseenfromFig. 6, atwo-foldaugmentation of the width of the cantileverbeamb, from 10up to 20mm, and a three-fold increase of the corresponding height value h, from 4up to 12mm,cause minor changes of GIc (by 0.37 and 0.65%) and GIa, by (0.84 and 1.24%).

AsisseenfromFig. 7, afive-foldaugmentationof the layer thickness of adhesivecomposition, from 0.5up to 2.5mm, leads to the maximum change in GIavalue, by 3.37and 1.98%, respectively.

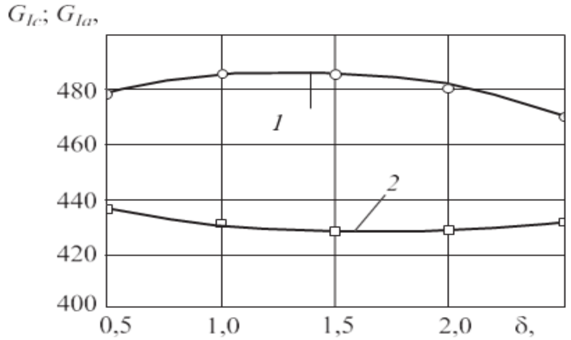

Fig.7. Dependence of specificcrackadvancingenergyGIc(1)and GIa(2)on the layer thickness of theadhesivecomposition.

Conclusions

A scheme has been proposed to test a double-bonded cantilever beam sample by subjecting it to loading with equal and opposite moments to guarantee identical conditions of crack formation throughout the adhesive composition.

Ithasbeenestablishedthat the values of specificcrackadvancingenergyexperience minor variations following a change of geometricparameters of cantileverbeamsand the thickness of adhesivecomposition. Consequently, the changes of cross-section parameters, precisely, a two-fold augmentation of the width and a three-fold increase of the height values, produce the outcome range of 0.37 to 1.24%. Meanwhile, a five-fold augmentation of the layer thickness of adhesive composition widens the corresponding spread from 1.98 to 3.37%.

Finally, it has been found that the VAK-Aadhesive composition has the highest crack resistance value, up 19.9and 53.3%versus Sprut Plus and Sprut-5Madhesive compositions, respectively.

References

1. Croccolo D. (2014) “Adhesives: Mechanical properties, technologies and economic importance” // NewYork,NovaSciencePublishersInc.,153.
2. LeesW.A. (2013) “Adhesives in engineeringdesign” //Berlin,SpringerScience&BusinessMedia,147.
3. Weitzenböck J.R. (2012) “Adhesives in Marine Engineering” // Oxford–New Delhi, Woodhead PublishingLimited,218.
4. Scattina A., Roncato D., Belingardi G., Martino G. (2015) “Investigation of creep phenomenon oncompositematerialforboltconnections” //CompositeStructures, Vol.134,378–383.
5. MatlinM.M.,KablovV.F.,KeibalN.A. (2011) “Modernadhesivesandgluejointsinvehicles” //Volgograd,VSTUpubl.,111.
6. Bobovich B.B. (2009) “Nonmetallic structural materials” // Moscow,Moscow State Universityofmechanicalengineering(MAMI)publ.,383.
7. KonoplinA.Iu.,BaurovaN.I.(2015) “Features of applying the adhesive welding technology during repair works” // Puti I putevoe khozyaistvoNo. 6,30–32.
8. KudrinaA.V.,Kleevye I. (2014) “Adhesive and sealing materials used in aircraft industryandengineeringindustry” // Entsiklopediiainzhenera-khimika No.6,28–30.
9. Terekhin A.V.,Rusin M.Iu.,Nepovinnykh V.I.,Dumanskii A.M. (2015) “Serviceabilityofelastomericadhesivejointsofaircraftstructuresunderextendedthermalload-bearingeffects” // Mekhanikakompozitsionnykh materialov i konstruktsii,Vol.21, No.4,599–609.
10. Koriagin S.I. (1996) “Bearing capacity ofcompositematerials” // Kaliningrad, Yantarny Skaz,301.
11. Cherepanov G.P. (1983) “Fracture mechanicsofcompositematerials” // Moscow,Nauka Publ.,296.
12. Finogenov G.N. (2007) “TestMethod of adhesive metal compounds on crack” // Klei. Germetiki. Tekhnologii, No.5,24–26.
13. OsipovN.L.,PirozhkovV.A.,ChabuninI.S.(2014) “Strength of polymer composites used inautomotive industry” // Proceedings of the Moscow State Technical University MAMI, Vol. 1, No. 2(20),45–47.
14. GiftM.D.M.,SelvakumarJ.,AlexisS.J.(2015) “Fracturestudiesofanadhesivejointinvolvingcomposition alteration” // Journal of Chemical and Pharmaceutical Sciences, Vol. 2015, April,269–273.
15. Chai H., Fox J. (2012) “On delamination growth from channel cracks in thin-film coatings” // InternationalJournalofSolidsandStructures,Vol.49,Issue22,3142–3147.