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Experimental and analytic analysis of the structure parameters

On process-induced distortions of v-shaped composite parts

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Abstract: In order tostudy the influence of structure parameters on process-induced distortions of v-shaped composite pArts,A series of experiments were performed to analysis the effect of structure parameters including part thickness,partradius,partangleand lay-up.Based on the shear lag theory and bending theory,ananalytical model

Considering the effect of structure parameters was developed to predict the spring-m of v-shaped compositeNfluence mechanism of different structure parameters on spring-m and the Modll was analyzed.The results

Show thatspring-in decreases with the increase of thethickness and maximum variation of spring-ins a bout30%whenthickness s between 1 mm and 3 mm.There s A proportion relationship whose value s about 0.014 between spring-n angles and part angle.The d ifferences of spring-n angles which result from different radius are

Less than 5%.The test pieces with Quasi-sotropic lay-up exhibit the biggest spring-in.The spring-in angles

of0 la}^up pieces decrease by.5%and90 pieces almost have nospring-n. Analysis results show that influ ence of THickness on spring-in should consider it effect on bending si i ffness and shear deformation;>mechanical

Properties and Poisson ' s effect d ifferences caused by lay.up are the main reasons for spring-in DivErsity;theMaxi Mum distortions of flange s 0. 20 which hasgreatly influences on spring-in.The comparison between emulation re

Sults and experiment verifies the accuracy of analytical model.

Keywords: Composite;spring-n;structure Parameters;shearlag analytic model

thermosetting carbon fiber reinforced resin matrix composite structure in curingcumulative residual stress after molding resulting in solidification changesform.form of a corner composite structure curing deformationmain angle rebound.angle rebound deformation can severely affect composite materialmaterial structure's molding precision,resulting in assembly difficulty.

Themain reason for the rebound deformation isthe anisotropic heat of the compositesshrink and resin chemical contraction[only].composite laminates along fiberDimension Direction of thermal expansion coefficient far less than the thermal expansion of fiber methodnumber,When the curing process is complete,hot pot temperature drops to roomtemperature,alongtheThe thickness direction is much larger than the fiber direction,This will cause the compositematerialVtype angle rebound.Thechemical contraction of the resin to the backimpactmechanism is the same as heat contraction,promotes rebound deformationgeneration[4-6].

is currently,Many scholars[next]studied the effects of composite solidificationTransform factors,research results show,The structure parameter is affecting the compositematerial rebound deformation important factors,But different structural parameters affectlaws aredifferent,And there is a certain controversy.

thickness is an important factor affecting the curing deformation of composites,DepartmentThe sub-scholar studied thickness.Albert[7]andKappeland soon[8]The results show that,with thickerLtest phaseGreaterthan,the thinnertest piece produces more rebound distortion.sati-sh[]study different thickness Utypestructure Bounce variant,test results verified,increases with thickness+,rebound deformation of test piece decreases gradually,and eventuallystabilizeset.wisnomwait(l0)and Ersoywait[one]uses a similar impersonationmethodto prove,Increase thickness

will result in smaller rebound outputthealth.The findings of thebut Zhang Jiqui, andso on [a]do not support this conclusion.There is a controversy about thickness at this time.,Controversy not onlyinclude thickness influence trend,Also includes the effect mechanism of the thickness.

Corner Radii are also important structural parameters for composite Structures.Zhang Jiquietc[[]Bounce by L on different corner radiiDeformation simulation proved that the corner radius has little shadow on Springback.ring.,&9.£;1, and so on[a]The results of the test also support this conclusion.butsalomiResearch results show,Small Corner radius test piece

to show larger springback variants.Corner radius vsVstyle reboundThe effect of the transformation is disputed,need further study.

Ponger[a]The results of the show that,by optimizing the overlay toto achieve control of deformation,So research overlay on composite material solidThe effect of the transformation is very important.Kappelwait[[]]Research results forconfirm,0 the bounce angle of the overlay is smaller than that of the multiple orientations,than90.theply widget rebound is larger thanthe.abdelalwait[[]]The test results for show, Overlay test piece shows maximum Springbackshape,quasi-isotropic overlay second,and90 Overlay Springback Minimum,but also reaches1..^1and4etc[]-Research resultsshow,quasi-isotropic overlay rebound deformation maximum,intersection level, 0 floorminimum.Current research on overlay impactReconcile contradiction.

The corner angle is also an important geometrical parameter of the composite structure,Research results currently affecting corner angles[18-2 []more consistent,think the corner bounce variant increases with the corner,explains itswarp mechanism asshown1show,and put forward rough theoretical geometry push

guided[18-2].

...1 (series)(1)

type:the represents the strain of the composite curing process;ftTableShowstructure initial corner angle; addThe rebound angle of the structureform.The strain in the curing process is mainly from temperatureDegree of change caused by the thermal expansion and the chemical contraction of the resin[-6],so,(1)classified asdown[7]

AtAt-aiat1 +atat

type.aTherepresents the thermal expansion factor;SToindicate resin during solidificationLearning shrink:atIndicates the temperature difference between the cooling process after curing is completed.actually,The formula does not contain layers and thickness parameters,at the same timethe chemical shrinkage effect of resins is not a linear elasticity process,so the publicThe type has a certain error.

More scholars are currently focusing on the structural parameters of compositesresearch,But some of the findings are contradictory,and mostlyThe effect does not explain the corresponding factors by parsingand research.

This article withVThe type structure is the research object,Material Select carbon FiberT700/bismaleimideresinQY9611,for CompositesStructural parameter design for a series of curing deformation tests,Research thickness,,Corner angle,Corner radius and overlay to composite corner structureeffect of curing variants,analyzing the influence trend and influence of various factorsdegree,Determine the key factors that affect springback deformation.based on shear lag

theory and bending theory,derivation of composites using analytic methodVknotStructureResilience Prediction Formula,impact on different structural parametersfo reasonable analysis and explanation,In-depth research impact mechanism,andCompare tes results,Validating the accuracy of the parsing model and havingvalidity.

1. Test

1.1 Mold Contour Design

There are two types of stencils used in this article,is defined as a stencilAandB,Themold size Contour design is detailed asshown in the figure2shows.stencil toGeneral steel,stencila's Corner angle is60 Corner

radius8mmandeverymmtwo dimensions,stencilBcornerangle is$,Corner radius is8mm.Two stencils can be performed simultaneouslymale mould andmolding.

Standard test piece sizes using tooling are shown in Figure3shows,change its structural parameters based on this standardpart,Research different parametersThe effect of thenumber on its curing distortion.Standard overlay selection[45/90/-45/0]3squasi-isotropic overlay.

1.2 Test Matrix

for research thickness,Corner Radius,Corner angle and overlay toeffect of rebound deformation of composite structure,_SeriesVwidget accessThe process of overheating pressing can be solidified.,and the bounce angle is measuredQuantity.specific test matrix as table1,,molded test after[diagram4isshownin.to exclude the result of potentially interfering with structural parametersstencil factor,This article is divided into two different forms of the of the male mouldand thestencil on molding test piece.

Curing Process

before the overlay,requires gasoline and acetone on the mold surface of theOilstain and glue wash,ensure stencil surface is clean and smooth.

after cleaning,Paste a layer of release cloth on the mold surface,easy to solidifyAfter the is finished, remove the membrane,.

(a) Mold a (b) Mold b

diagram2 t700/qy9611CompositeVType Component Molding tooling outline diagram

Fig.2Outline drawing of tools for t700/qy9611 composite

v-shaped Parts

CompositeVtest piece overlay,laying the first_Layerand every five-layer prepreg need to be applied through a vacuum bag. 0.MPaand keepmin,Toensure that the Prepreg clingsto thestencil surface and drain gas from each layer of Prepreg,Guaranteed OverlaySolid and molded quality.overlay,on edge of test pieceArpadrubber block curing process resin outflow.before entering a jarlay off theremovable layer on the surface of the test piece,Glue-absorbing material,NoHole Isolation film,breathable felt and vacuum bag,As shown infigure5shows.Place thermocoupleson theedge of at the endof test,to monitor the curing process test piecestemperature field changes.Duringthe curing process,internal temperature field and pressure field in a hot-press tank such asChart6show,where the curing pressure is set to0.MPa,ensure that the internalThe section has auniform resin distribution.theinternal temperature field of the includes two thermostatic segments:page_constant temperature segment to promote the internal resin flow uniformityof the Prepreg;secondthermostatic segment ensure resin curing process goes smoothly,complete Final solidcross-linked reaction.

1.3 bouncedeformation measurement

After the cure is complete,because the removable layer may affect the curing variableform,first remove removable layer,and composite materialVtypepieces to a uniform size,to facilitate their angle bounce testamount,after cutting test pieces like Figure4shows.using cursor angle ruler

for composite materialsv-type widget rebound deformation measurement,Select the degree of divisionvalue2 'cursor angle ruler,asshown7,,to increase the anglemeasurePrecision.

2. test Results

This article withVThe type structure is the research object,for potentially affecting duplicateto analyze the factors of material curing deformation,due to in industryproduction process,process parameters(curing temperature and curing pressure)isok,So this article is all about the tests on Bismaleimideamine resinQY9611under the curing processfor.test results such astable2theaverage bounce angle for each set of tests is given in the show,table.degree,and calculates the standard deviation of the bounce angle for each set of test pieces,Evaluateformula is as follows[13]:

type:the represents the standard deviation of the bounce angle;AGrepresents a composite materialVtype widget bounce angle.

2.1 thickness tot700/qy9611springback Impact

composite materials of different thicknesses are used in practical projectsmultiple,but thickness effects on springback and deformation of composite members

is not clear,There is more controversy now.This article is for a thickness of1mm,2mmand3mmforV-type component for solidification molding testcheck,and measure its bounce angle,results are shown in Figure8shows.can see,Regardless of the use of the yin and male mouldstencils,Vtest pieceThe angle resilience of the decreases with increasing thickness.at thickness1~3mmbetween,angular bounce Variance max in30%leftright.dueto the maximum thicknessof theVwidget for thisarticle isonly3mm,Wang Renyu etcThe results of the™show,thicknessbelow3mmwhen,effects due to uneven temperature and degree of solidificationto ignore,Thecannot explain this article by temperatureheterogeneitytest phenomenon.Albertwait[7]test got similar to this articleConclusion,But all test pieces are molded in the male mouldmold,himThe difference between the thermal expansion coefficient of the mold and the composite isThe main factor that causes the reboundangle differently,But different stencil forms cause composite material

The stress of the material member is completely reversed[a],so,ALbertResearch for

Theresults cannot explain the change of springback and deformation of the die-forming test partsreason.through a detailed analysis of the results of the experiment found,different stencil shapesThe effect of the on the back-bounce angle of the V is very small,Thecannot be usedto explain the change in bounce angleonly with the stencil effect.This article holds thatThere are two possible variations in the variation of the deformation of anegative.for:(1)the corner area of the die-forming test piece may appear rich gluephenomenon,extra resins occur in the cooling process volume contraction,therebycauses bending momentto increase,andThe bending stiffness of the V type component increases with thicknessPlus,So when thickness is minus hours,Corner angle Bounce Amountby onincrement(2)Curing procedure,Vstructural shear modulus smaller,A shear strain occurs between layers of the widget,which results in a rubber-state treeTheeffect of the lipid contraction is bound to the geometrical size of the componentDepartment,instead of just like(2)shows the situation,This relationship can bepass likewsnometc ⑽ The formula presented by represents the.preliminary view(2)should include thickness-related parameterscalculation of bounce angle.assumptions about thickness impactareanalyzed and studied in detailin this article four section.

2.2 Corner radius tot700/qy96Onespringback Impact

in industrial production,with different corner radiiVstructure is wideGeneric application,Research onVThe effect of the type structure resilience has heavymeaning.Current research on corner radius not much,and existsdispute,therefore,This article is for corner radii8mmandonemmVSpringbackof the type widget test,and inductive effectlaw.

diagram9Theeffect of different corner radii on curing deformation test knotfruit.can see,negative die test piece,Corner radius8mmrebound deformation of test piece is1.73 ,andOnemmThe back of the test piecebounce to1.68 Male mouldmolded8mmtest piece rebound variant

is1.81 ,andmmtest Case1.73 .with corner halfsize increase,Its rebound variant is slightly reduced,But the reduction rate is lower than5%,This shows the effect ofcorner radii on theV typestructure.very small.

found during the actual test,The increase in corner radii helpsuniform pressure distribution in curing process,Improve molding quality,reduce wasteProduct rate.so,without affecting engineering application,recommend workThe factory uses a large corner-radius structure.

Z3Corner angle toT 700/QY9611bouncedeformation effectsactual project,composite knot with different corner anglesrefactoring applies to aircraft design and manufacture,so,Study different cornersangle on composite materialThe effectof Springback deformation is heavyThe meaning of is.in this test,,to60 and90 widget reboundTheresults of the

transformation study are asfollows:, and..in the shape of thechevron60 Vtype

The widget has a rebound variant of1.73 and90 Widget has only1.21 ,2.4

reduces: 1;and the artifacts formed in the male mould also produce aphasesame effect,60 The component is deformed to1.81 ,90 Thewidget has only1.32 ,reducing27 1%.test results show,with widgetCorner angle Increase,theangle bounce amount has a decreasing trend.

theoretically,The angle rebound does have a linear with the corner anglerelationship.in this test,,corner angle defined as test piece two straightAngleangles between edges,with style(2)the corner angle of the is supplementaryangle.so,The theoretical formula should beAd=K(180 -d)

through the(4)Profiling Discovery,CompositeVknotThe angular resilience of the construct theoretically does exist with the corner angle supplementaryangleproportionalRelationship.based on the rebound deformation result of the test piece,valuesare shown inthe figureOneshows.to see,The proportions of the test piecevalues are in0.014around,But there is a difference between the different test pieces,This shows that the rebound angle is not exactly proportional to the corner angle of the supplementary angle. Relationship,This is mainly due to stencils,Fiber volume content and thicknessexternal factors affect deformation,But the overall trend of change does not occurChange,-Corner angle Greater,the smaller the bounce angle.

rebound variants of,Angular bounce amount is1.73 ,with other overlayComparedto,has the largest rebound deformation ofthe test piece.composite"V"type member has rebound deformation mainly due to thickness direction shrinkage strain largein-plane vertical contraction of the strain.for a quasi-isotropic overlay structureitem,due to vertical inside of face0 overlay,resulting incomposite fabricThe shrinkagestrain after curing is much smaller than the thickness direction of theshrink strain,Therefore, the quasi isotropic layer will cause a larger reboundtransform.ply to$[0]_2{}_4$-The angle rebound amount of the test pieceis1.32 ,The rebound strain of a quasi isotropic overlay is smallNo.7%,This is mainly due to the Poisson effect of the contraction strain along the thickness directionless than quasi-isotropic overlay, tocause its rebound deformation to decrease.and for overlay$[90]_2{}_4$widget,Hasits rebound transform to009 ,Vtypewidg*et al*most no distortion,This is the same as expected.primarilysince widgetis cured,portrait and shrink along thickness direction should be disguisedaswith,structure shrinks overall,has no shadow over the angle of the corner positionring.becauseof$[90]_2{}_4$layerVType widget has no0 Overlay,causes itsbending stiffness is low,easily bend underexternal force.

male mould molded testpiece,Overlay[45/90/-45/0]forVThe-type widget has a rebound variant of1.81 ,$[0]_2{}_4$Widget'sreboundtransform to1.37 and[90]24The bounce angle of the overlay component is0.23 .The overall deformation trend of different layer members and the shape of the negative moldV-type artifactsare the same,Theamount of deformation is slightly increased,This is primarily malemouldthestencilpromotes the deformation of theV--type widget,causes it to produce morelarge rebound variants.Four overlay,[0]24Overlay component Deformationchange maximum,by0.09 increases to0 23 .becauseof90 overlaywidget missing0 overlay,causes its flexural stiffnessto drop,stencil onthetensile stress generated by the inner surface will have a greater effect,promoteVThetype widget further occurs with a rebound variant,causing its bounce angleincrease.

F-1andF-2Thegroup test piece shows a larger rebound angle Markdeviation,This is mostlyabout,forat0 layer widget,due to fiberdimension bending stiffness highercauses the overlay process to not fullyfit the fiberstencil,TocausetheVSome fibers in the type component appear wrinkledlike, toaffect rebound deformation[all].&2Group Test standard deviationReached0.17 This also proves that the lower bending stiffness causesthetest piece rebound deformation susceptible to descaling factors such as molds and fibresThe effect of dimension volume content.

3. parsing Model

The thickness is experimentally studied,Corner Radius,Corner Cornerdegree and overlay to compositeVeffect of rebound deformation,and analyze the effect of structural parameters and the degree of influence,qualitativelytheexplains

why each parameter has a corresponding effect.This chapter willmake a detailed analysis of the solidification processfor the,based on shear lag rationaletheory to establish a resolution to the composite materialV-type structure's bounce angleto deduce,And using this method to the existing test pieces of the deformation oftheforecast and Analysis,compares the results of the test with,Validation resolution method's accuracy.

wisnom, and so on[ten]using the shear lag theory on the arc-junctionThe rebound deformation of the construct has a formula derivation,and get bounce angleDerivation formula.But it is not for a straight-edged circular structure.Line Research,because an arc with a straight edge is connected to a straight edgelocation with corresponding constraint,affect the shear of the structure before vitrificationstrain,so,When the rebound angle formula is deduced,need to betestedThe binding effect of the for straight edges.in this article, before the formula derivation,,have to make some reasonable assumptions,First assumes that the composite structurehasThefiber volume is evenly distributed,at the same time because of the structural thicknessof the-thin, andtheinternal temperature distribution is uniform during the curing process,and assumingWhen the composite is cured at the second thermostat, it no longer occurs.Learn shrink.

(2)for composite corner structure Bounce Angle Prediction Formula,The contains the effects of both thermal expansion coefficients and chemical contraction.ChemicalThe effectof contraction generalization to the cooling process after the gel,But in theactual composite material curing process,not all chemical contractionsallcause rebound deformation,because the stiffness in the face is not0,andTheshear modulus is low at this stage,with composite corner structure alongthickness direction contraction,The shear strain occurs inthe face,when the clipping modulusEnough hours,The strain that occurs along the thickness causes an equivalent in the faceshear strain,make structure without corresponding in-plane stress,so onlythecreate shear strain Serizawa See figureonly,no bounce angle;when scissorsWhen the tangent modulus is large enough,does not produce any scissors in the composite structure facecut strain,All thickness-direction contractions are converted to the rebound angle.

based on the bending theory[a],has a relationship:

type,FsThe represents the shear force of the unit width,Theaverage with the faceTheshear strain0and the shear modulus relationship are as follows[ten]:

when the resin takes place the gel to the final finish solidified into glassy state before,resin in rubber State,at this time the shear modulus of the composites is not0,but not large enough,As the composite occurs along the thickness directionindent,A certain shear strain will also occur.requirestheshear strain that is caused by the chemical shrinkageof the resin during the cure0to solve the,to obtain rebound deformations caused by chemical shrinkage of resins.

Assuming that thecomposite does not occur with shear distortion,Resin Chemical receiptThe bounce angle for the indent is0T,Gel thickness Direction response toST,The rebound angle caused by the resin shrinkage is shown in the following example:

type:&represents internal shrinkage in composite material;^represents the composite materialThe initial corner angle of the material structure.(5)convert to

type,^represents a correction factor for shear stress.in Bend theoryderivation procedure,Bending shear stress for the unit width of a rectangular profilefabricto parabola distribution[A],specificshows,in realcalculation,usually introduced^value,to cut the parabola in the formShear Stress value is constant form,Mimiko belongs to empirical factor,General takevalue range1~1.2.discovery of the,Mimiko valuein the post-Solver processThe effect of thevalue on rebound deformation is not obvious,here Mimiko value is1.2then.

The overlay of this test piece includes the[0],[#]and the quasi-to same level$[45/90/-45/0]_{3s}$,Composite material with different paving layerThemechanical parameters of the material test are different.,takes advantage of different parametersfor springback prediction.Use classic laminated theory tosolve the mechanical parametersof different overlays.due to Poisson effect,to eachthermal expansion coefficients and along thickness shrinkage of same-level layer members with[]is not the same,can be inferred from the finite element method,The material parameters for this model are asfollows table5show.

4. Discussion

uses the parsing method established in this article to separate the different structural parametersback-bounce angle prediction,and test results tomore accurate than validation model,as shownisshownin.simulatesdifferent structural parameters to composite materials by simulating a combination oftestsVeffect of rebound deformation,The warping deformation of theComposite Straight Edge section is also studied.

from Diagramto see,The predicted results of this model and the testTestResults fit well,Different structural parameters of composite materialmaterial rebound deformation trends in the results of this article also obtainedwell embodied.simulation results slightly less than test results,but maximumerror No more than15%,comparison results show the model'saccuracy.because the model does not consider the mold contact effect and the composite materialfiberVolume content difference effect, so thesimulation results are better than the test knot

Small Fruit.

thickness to compositeVEffects of the-type structural rebound deformation inTheparsing solutionhas been proven,This article forecast results and test results Exhibitnow has the same effect trend,This paper analyzes the formula to prove the thickness of the backThe impact of elastic deformation is not exactly the mold and uneven temperature field, etc.Results of external effects,different thickness structure occurrence of shear deformation notand,to cause the final rebound variant to be different,increases with thicknessplus,The greater the cut deformation,to cause the widget to take a smaller backElastic variant.In this paper, the simulation results of the thickness effect and the test results have acertain error,because the test piece is thicker than an hour,its curved justLower,affectedby mold and fiber volume content greater, andthereforecause a large rebound variant,Corner radius8mmandallmmThe results of the springback deformation of the test piecesare1.64 and1.65 This is exactly the same as the effect of the test results.simulationresults and test results show corner radius toVback of the type structureThe impact of theelastic deformation is smaller.There are corner radius parameters number in solution,But its effect on the result of the formula will be offset or reduced by each other,Final Forecast results display,Corner radius affects rebound deformationsmaller.

The effect of thecorner angle on rebound deformations is also obtained in the modelprove,60 and90 V1rebound variants are.64 and1.21 ,fit well with the test results.through parsing publicparsing discovery,thecorner angle is the most directly affected parameter in a formulanumber,But because the shear strain is not proportional to the corner angle,becauseof theThis,VThe supplementary angle of the type structure rebound angle and its corner angle are notcompletea linearly growingrelationship,But its influence trend is still the same(4)securityconsistent,withV-structure corner angle increase,its bounce angleThe degree has a significantly reduced trend.

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