Experimental and analytic analysis of the structure parameters

On process-induced distortions of v-shaped composite parts

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Abstract: In order to study the influence of structure parameters on process-induced distortions of v-shaped composite parts, experiments were performed to analyse the effect of structure parameters including part thickness, partradius, partangle and lay-up. Based on the shear lag theory and bending theory, an analytical model was developed to predict the spring-m and the Modll was analyzed. The results show that spring-in decreases with the increase of thickness and maximum variation of spring-ins are about 30% when thickness 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 differences 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 of 0° lay-up decrease by 5% and almost have no spring-n. Analysis results show that influence of thickness on spring-in should consider it effect on bending stiffness and shear deformation; mechanical properties and Poisson’s effect differences caused by lay-up are the main reasons for spring-in Diversity; the Maximum Mum distortions of flange s 0.20 which has greatly influences on spring-in. The comparison between emulation results and experiment verifies the accuracy of analytical model.

Keywords: Composite; spring-n; structure Parameters; shear lag analysis model

thermosetting carbon fiber reinforced resin matrix composite structure in curing cumulative residual stress after molding resulting in solidification changes. Form of a corner composite structure curing deformation mainly rebound angle rebound deformation can seriously affect composite material structure's molding precision, resulting in assembly difficulty.

Themain reason for the rebound deformation is the anisotropic heat of the composites shrink and resin chemical contraction only. Composite laminates along fiberDimension Direction of thermal expansion coefficient far less than the thermal expansion of fiber method number, When the curing process is complete, hot pot temperature drops to room temperature, along the thick direction is much larger than the fiber direction, this will cause the composite material Vtype angle rebound. The chemical contraction of the resin to the back impact mechanism is the same as heat contraction, promotes rebound deformation generation.

is currently, Many scholars next has studied the effects of composite solidification transformation factors, research results show, The structure parameter is affecting the composite material rebound deformation important factors, But different structural parameters affect laws are different, And there is a certain controversy.

thickness is an important factor affecting the curing deformation of composites, Department The sub-scholar studied thickness. Albert and Kappeland soon They results show that, with thicker test phase greater than the thinnest test piece produces more rebound distortion, sati-sh study different thickness Utype structure, Bounce variant, test results verified, increases with thickness, rebound deformation of test piece decreases gradually, and eventually stabilizes. Wsinowwait and Ersoywait uses a similar impersonation method to prove, Increase thickness
will result in smaller rebound output health. The findings of the but the Zhang Jiqui, and so on [4] do not support this conclusion. There is a controversy about thickness at this time. Controversy not only include thickness influence trend, also includes the effect mechanism of the thickness.

Corner Radii are also important structural parameters for composite Structures. Zhang Jiqui et al. [5] Bounce by L on different corner radii Deformation simulation proved that the corner radius has little shadow on Springback ring ..., a9.c.1, and so on [6] The results of the test also support this conclusion. But Salomi Research results show, Small Corner radius test piece
to show larger springback variants. Corner radius vs V-style rebound. The effect of the transformation is disputed, need further study.

Ponger [4] The results of the show that by optimizing the overlay to achieve control of deformation, so research overlay on composite material solid. The effect of the transformation is very important. Kappelwait [7] Research results for confirm, 0 the bounce angle of the overlay is smaller than that of the multiple orientations, than 90. The ply widget rebound is larger than the abdelalwait [8] The test results for show, Overlay test piece shows maximum Springback shape, quasi-isotropic overlay second, and 90 Overlay Springback Minimum, but also reaches 1.8 ... 1 and ete [9] Research result show, quasi-isotropic overlay rebound deformation maximum, intersection level, 0 floor minimum. Current research on overlay impact reconcile contradiction.

The corner angle is also an important geometrical parameter of the composite structure, Research results currently affecting corner angles [10-12] more consistent, think the corner bounce variant increases with the corner, explains its warp mechanism as shown 1 show, and put forward rough theoretical geometry push

guided [18-2]
...1 series) (1)

type the represents the strain of the composite curing process; ft Table show structure initial corner angle; add The rebound angle of the structure form. The strain in the curing process is mainly from temperature Degree of change caused by the thermal expansion and the chemical contraction of the resin [6], so, (1) classified as down [7]

At At- ai at 1 + atat
type a There presents the thermal expansion factor; STo indicate resin during solidification Learning shrink: at Indicates the temperature difference between the cooling process after curing is completed. Actually, The formula does not contain layers and thickness parameters, at the same time the chemical shrinkage effect of resins is not a linear elasticity process, so the public the type has a certain error.

More scholars are currently focusing on the structural parameters of composites research, But some of the findings are contradictory, and mostly The effect does not explain the corresponding factors by parsing research.

This article with V The type structure is the research object, Material Select carbon Fiber T700/bismaleimideresinQY9611, for Composites Structural parameter design for a series of curing deformation tests, Research thickness, Corner angle, Corner radius and overlay to composite corner structure effect of curing variants, analyzing the influence trend and influence of various factors degree, Determine the key factors that affect springback deformation, based on shear lag

theory and bending theory, derivation of composites using analytic method V knot Structure Resilience Prediction Formula, impact on different structural parameters for reasonable analysis and explanation, In-depth research impact mechanism, and Compare test results, Validating the accuracy of the parsing model and having validity.

1. Test
1.1 Mold Contour Design

There are two types of stencils used in this article, is defined as a stencil A and B, The mold size Contour design is detailed as shown in the figure 2 shows stencil to. General steel, stencil A's Corner angle is 60.
radius8mmandeverymmtwo dimensions, stencilBcornerangle is $\$$.Corner radius is 8mm. Two stencils can be performed simultaneously male mould and molding.

Standard test piece sizes using tooling are shown in Figure 3 shows, change its structural parameters based on this standard part. Research different parameters The effect of the number on its curing distortion. Standard overlay selection [45/90/-45/0] 3 quasi-isotropic overlay.

1.2 Test Matrix

For research thickness, Corner Radius, Corner angle and overlay to effect of rebound deformation of composite structure, Series V widget access. The process of overheating pressing can be solidified, and the bounce angle is measured. Quantity. Specific test matrix as Table 1, molded test after diagram is shown in to exclude the result of potentially interfering with structural parameters stencil factor. This article is divided into two different forms of the male mould and the stencil on molding test piece.

Curing Process

Before the overlay requires gasoline and acetone on the mold surface of the Oil stain and glue wash, ensure stencil surface is clean and smooth. After cleaning, paste a layer of release cloth on the mold surface, easy to solidify. After the is finished, remove the membrane,

(a) Mold a (b) Mold b

diagram 2 t700/qy9611 Composite V Type Component Molding tooling outline diagram

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

v-shaped Parts

Composite V test piece overlay, laying the first Layer rand every five-layer prepreg need to be applied through a vacuum bag. 0. MPa and keepmin, To ensure that the Prepreg clings to the stencil surface and drain gas from each layer of Prepreg Guaranteed Overlay Solid and molded quality. overlay, on edge of test piece Arpadrubber block curing process resin outflow. Before entering a jar lay off theremovable layer on the surface of the test piece, Glue-absorbing material, No Hole Isolation film, breathable felt and vacuum bag. As shown in Figure 5 shows. Place thermocouples on the edge of at the endof test, to monitor the curing process test piecetime temperature field changes. During the curing process, internal temperature field and pressure field in the hot-press tank such as Chart 6 show, where the curing pressure is set to 0. MPa, to ensure that the internal The sector has uniform resin distribution. The internal temperature field of the includes two thermostatic segments: page constant temperature segment to promote the internal resin flow uniformity. The Prepreg, second thermostatic segment ensure resin curing process goes smoothly, complete Final solid cross-linked reaction.

1.3 Bouncedeformation measurement

After the cure is complete, because the removable layer may affect the curing variable form, first remove removable layer, and composite material V type pieces to a uniform size, to facilitate their angle bounce test amount, after cutting test pieces like Figure 4 shows, using cursor angle ruler for composite materials, V-type widget rebound deformation measurement, Select the degree of division value 2 'cursor angle ruler, as shown in 7, to increase the angle measure Precision.

2. test Results

This article with V The type structure is the research object, for potentially affecting duplicate to analyze the factors of material curing deformation, due to in industry production process, process parameters (curing temperature and curing pressure) is sox. So this article is all about the tests on Bismaleimide amine resin QY9611 under the curing process. For test results such as table 2 the average 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, Evaluate formula is as follows [13]:

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type: the represents the standard deviation of the bounce angle; AG represents a composite material V type.

2.1 thickness tot700/qy9611 springback Impact

Composites materials of different thicknesses are used in practical projects multiple, but thickness effects on springback and deformation of composite members is not clear. There is more controversy now. This article is for a thickness of 1 mm, 2 mm and 3 mm for V type component for solidification molding test check, and measure its bounce angle. Results are shown in Figure 8. The results show, regardless of the use of the yin and male mould stencils, V test piece The angle resilience of the decreases with increasing thickness at thickness 1 3 mm between, angular bounce Variance max in 30% left right. Due to the maximum thickness of the V widget for this article is only 3 mm, Wang Renyu et al. The results of the test show, thickness below 3 mm when effects due to uneven temperature and degree of solidification to ignore, The cannot explain this article by temperature heterogeneity test phenomenon. Albert wait(10) test got similar to this article. Conclusion, But all test pieces are molded in the male mould mold, him The difference between the thermal expansion coefficient of the mold and the composite is The main factor that causes the rebound angle differently. But different stencil forms cause composite material

The stress of the material member is completely reversed[10], so, AL bert Research for

The results cannot explain the change of springback and deformation of the die-forming test parts reason through a detailed analysis of the results of the experiment found, different stencil shapes The effect of the on the back bounce angle of the V is very small. The cannot be used to explain the change in bounce angle only with the stencil effect. This article holds that there are two possible variations in the variation of the deformation of negative. For: (1) the corner area of the die-forming test piece may appear rich glue phenomenon, extra resins occur in the cooling process volume contraction, therefore causes bending moment to increase, and The bending stiffness of the V type component increases with thickness Plus, So when thickness is minus hours, Corner angle Bounce Amont by onincrement(2) Curing procedure, V structural shear modulus smaller, A shear strain occurs between layers of the widget, which results in a rubber-state tree. The effect of the lipid contraction is bound to the geometrical size of the component Department, instead of just like (2) shows the situation. This relationship can bypass like nominet (10) The formula presented by represents the preliminary view (2) should include thickness-related parameters calculation of bounce angle. Assumptions about thickness impact are analyzed and studied in detail in this article four section.

2.2 Corner radius tot700/qy9611 springback Impact

In industrial production, with different corner radii V structure is wide. Generic application, Research on V type The effect of the type structure resilience has heavy meaning. Current research on corner radius not much, and exists dispute, therefore, This article is for corner radii 8 mm and 9 mm V Springback of the type widget test, and inductive effect law.

Diagram 9, the effect of different corner radii on curing deformation test knot fruit, can see, negative die test piece, Corner radius 8 mm rebound deformation of test piece is 1.73, and 9 mm The back of the test piece bounce to 1.68

Male mould mold 8 mm test piece rebound variant

is 1.81, and mm test Case 1.73. with corner halfsize increase, Its rebound variant is slightly reduced, But the reduction rate is lower than 5%, This shows the effect of corner radii on the V type structure, very small.

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

Z3 Corner angle to T 700/QY9611 bounced deformation effects actual project, composite knot with different corner angles re factoring applies to aircraft design and manufacture, so, Study different corners angle on composite material The effect of Springback deformation is heavy. The meaning of is in this test, to 60 and 90 widget rebound The results of the

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transformation study are as follows: and... in the shape of the chevron 60 Vtype

The widget has a rebound variant of f1.73 and 90 Widget has only 1.21 2.4

reduces: 1; and the artifacts formed in the male mould also produce a phasematching effect, 60 The component is deformed to 1.81.90 The widget has only 1.32, reducing 27 % test results show, with widget Corner angle Increase, the angle bounce amount has a decreasing trend.

theoretically, the angle rebound does have a linear with the corner angle relationship. In this test, corner angle defined as test piece two straight angles between edges, with style(2) the corner angle of the is supplementary angle. So, the theoretical formula should be: $Ad = K(180 - \theta)$

through the Profiling Discovery, Composite V knot The angular resilience of the construct theoretically does exist with the corner angle supplementary angle proportion relationship. Based on the rebound deformation result of the test piece, values are shown in the figure. One shows to see, the proportions of the test piece values are in 0.014 around, 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 thickness external factors affect deformation, But the overall trend of change does not occur change, Corner angle Greater, the smaller the bounce angle.

rebound variants of Angular bounce amount is 1.73, with other overlay Compared to, has the largest rebound deformation of the test piece. Composite "V" type member has rebound deformation mainly due to thickness direction shrinkage strain large in-plane vertical contraction of the strain, for a quasi-isotropic overlay structure item, due to vertical inside of face X overlay, resulting in composite fabric. The shrinkage strain after curing is much smaller than the thickness direction of the shrink strain. Therefore, the quasi-isotropic layer will cause a larger rebound transform ply to [0]2V. The angle rebound amount of the test pieces is 1.32, The rebound strain of a quasi isotropic overlay is small No. 7%, This is mainly due to the Poisson effect of the contraction strain along the thickness directionless than quasi-isotropic overlay, isochrony to produce rebound deformation to decrease. For overlay [90]2V widget, Hasits rebound transform to [0]09, V type widget along X, almost no distortion, This is the same as expected, primarily because widget is cured, portrait and shrink along thickness direction should be disguised as with, structure shrinks overall, has no shadow over the angle of the corner positioning because of [90]2V layer V type widget has no 0 Overlay, causes its bending stiffness is low, easily bend under external force.

male mould molded test piece, Overlay [45/90/-45/0] for V The-type widget has a rebound variant of f1.81, [0]2V, Widget's rebound transform to 1.37 and [90]2V The bounce angle of the overlay component is 0.23. The overall deformation trend of different layer members and the shape of the negative mold V-type artifacts are the same, The amount of deformation is slightly increased, This is primarily male mould the stencil promotes the deformation of the V-type widget, causes it to produce more large rebound variants. Four overlay, [0]24 Overlayer component Deformation change maximum, by 0.09 increases to 0.23. Because of 90 overlay widget missing 0 overlay, causes its flexural stiffness to drop, stencil on the tensile stress generated by the inner surface will have a greater effect. promote V The type widget further occurs with a rebound variant, causing its bounce angle increase.

F-1 and F-2 The group test piece shows a larger rebound angle Mark deviation, This is mostly about, forat0 layer widget, due to fiber dimension bending stiffness high, causes the overlay process to not fully fit the fiber stencil, Tocausethediny Some fibers in the type component appear wrinkled like, too effect rebound deformation[all]. & 2 Group Test standard deviation Reached 0.17 This also proves that the lower bending stiffness cause the test piece rebound deformation susceptible to decrasing factors such as molds and fibres The effect of dimension volume content.

3. Parsing Model

The thickness is experimentally studied, Corner Radius, Corner Corner degree and overlay to composite V effect of rebound deformation, and analyze the effect of structural parameters and the degree of influence, qualitatively the explain
why each parameter has a corresponding effect. This chapter will make a detailed analysis of the solidification process for the, based on shear lag rational theory to establish a resolution to the composite material V-type structure's bounce angle, deduce. And using this method to the existing test pieces of the deformation of the deform and Analysis, compares the results of the test with, Validation resolution method's accuracy.

wisnom, and so on[106] using the shear lag theory on the arc-junction, the rebound deformation of the construct has a formula derivation, and get bounce angle derivation formula. But it is not for a straight-edged circular structure. Line for composite corner structure Bounce Angle Prediction Formula, the contains the effects of both thermal expansion coefficients and chemical contraction. Chemical The effect of contraction generalization to the cooling process after the gel, But in the actual composite material curing process, not all chemical contraction, all cause rebound deformation, because the stiffness in the face is not 0, and the shear modulus is low at this stage, with composite corner structure along thickness direction contraction, The shear strain occurs in the face, when the clipping modulus is enough hours, The strain that occurs along the thickness makes an equivalent in the face shear strain, make structure without corresponding in-plane stress, so only there create shear strain. Serizawa See figure only, no bounce angle; when scissors, when the tangent modulus is large enough, does not produce any scissors in the composite structure face cut strain, All thickness-direction contractions are converted to the rebound angle.

Based on the bending theory [3], has a relationship:

\[
type, \text{Fs} \text{The represents the shear force of the unit width, The average with the face, The shear strain} 0 \text{and the shear modulus relationship are as follows}[106]:
\]

when the resin takes place the gel to the final finish solidified into a glassy state before, resin in rubber State, at this time the shear modulus of the composites is not 0, but not large enough, As the composite occurs along the thickness direction indent, A certain shear strain will also occur, require the shear strain that is caused by the chemical shrinkage of the resin during the cure 0 to solve the to obtain rebound deformations caused by chemical shrinkage of resins.

Assuming that the composite does not occur with shear distortion, Resin Chemical receipt: The bounce angle for the indent is 0, Gel thickness Direction response to ST, The rebound angle caused by the resin shrinkage is shown in the following example:

\[
type, \text{represents internal shrinkage in composite material, } ^* \text{represents the composite material The initial corner angle of the material structure.}(5) \text{convert to}
\]

type, \text{represents a correction factor for shear stress. In Bend theory derivation procedure, Bending shear stress for the unit width of a rectangular profile fabric to parabola distribution}[46], specific shows, in real calculation, usually introduced \text{value}, to cut the parabola in the form, Shear Stress value is constant form, Mimiko belongs to empirical factor, General take value range 1~1.2, discovery of the Mimiko value in the post-Solver process, The effect of the value on rebound deformation is not obvious, here Mimiko value is 1.2 then.

The overlay of this test piece includes the [0], [1] and the quasi-to same level [45/90/-45/0], Composite material with different paving layer. The mechanical parameters of the material test are different, takes advantage of different parameters for springback prediction. Use classic laminated theory to solve the mechanical parameters, different overlays, due to Poisson effect, to each thermal expansion coefficients and along thickness shrinkage of same-level layer members with [6] is not the same, can be inferred from the finite element method, The material parameters for this model are as follows: table 5 show.
4. Discussion

uses the parsing method established in this article to separate the different structural parameters back-bounce angle prediction, and test results to more accurate than validation model, as shown in this paper. Simulates different structural parameters to composite materials by simulating a combination of tests of the rebound deformation, the warping deformation of the composite straight edge section is also studied.

from Diagram to see, the predicted results of this model and the test results fit well, different structural parameters of composite material, rebound deformation trend in the results of this article also obtained well embodied. Simulation results slightly less than test results, but maximum error. No more than 15%, comparison results show the model's accuracy. because the model does not consider the mold contact effect and the composite material fiber volume content difference effect, so the simulation results are better than the test knot.

Small Fruit.

thickness to composite V effects of the type structural rebound deformation in the parsing solution has been proven. This article forecast results and test results Exhibit now has the same effect trend, This paper analyzes the formula to prove the thickness of the back. The 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 not and, to cause the final rebound variant to be different, increases with thickness plus, The greater the cut deformation, to cause the widget to take a smaller back. Elastic variant. In this paper, the simulation results of the thickness effect and the test results have certain error, because the test piece is thicker than an hour, its curved just lower, affected by mold and fiber volume content greater, and therefore cause a large rebound variant, Corner radius 8mm and all mm. The results of the springback deformation of the test pieces are 1.64 and 1.65. This is exactly the same as the effect of the test results, simulation results and test results show corner radius to V back of the type structure. The impact of the elastic 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 deformations smaller.

The effect of the corner angle on rebound deformations is also obtained in the model prove, 60 and 90 V 1 rebound variants are 6.4 and 1.21, fit well with the test results. Through parsing public parsing discovery, the corner angle is the most directly affected parameter in a formula number. But because the shear strain is not proportional to the corner angle, because of the This V, The supplementary angle of the type structure rebound angle and its corner angle are not completea linearly growing relationship, But its influence trend is still the same (4) security consistent, with V-structure corner angle increase, its bounce angle, The degree has a significantly reduced trend.

References

2. Li Guoxian, Wang Tao, Sherhairong, hu