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A Formulation by Finite Element Method on Large Deformation of Viscoelastic Body*

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Abstract

This paper provides a formula by the nonlinear Finite Element Method which makes it possible to analyze the mechanical behaviors of pressure sensitive adhesive tapes in contact bonding and peeling process.

Features of this method are as follows:

1) This method implemented with a generalized three dimensional linear viscoelastic model (Lodge Model) is applicable to large deformation and finite strain analysis.

2) Since incompressibility condition of the material is substantially accepted by introducing the bulk modulus, a stable solution is obtained even if the complicated geometrical shape is divided into small elements.

3) The accuracy of time approximation for finite strain is sufficient, because non-linearity derived from the tensor is considered.

4) The necessary viscoelastic constants for this analysis may be from the ones from the measurement by linear viscoelasticity.

5) The thermal stress can be included in the calculation.

As to the contact area of the adhesive tape applied onto the roughened surface, the experimental and calculated results by this work are in good agreement, which shows the formula of this method to be valid.

(Received: December 18, 1985)

Peel-strength of Composite Materials and Energy Dissipation

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Abstract

Effect of energy dissipation in adhesive layer and adherends on peel-strength is studied in the case of T-peeling of laminate type fiber-reinforced plastics bonded by viscoelastic adhesive. Steady peeling force f is given by

$$2f = \Gamma + hu' + 2w',$$

where Γ is twice surface energy of fracture surface, h is thickness of adhesive layer, u' is energy dissipation in the adhesive layer and w' is energy dissipation in the adherends per unit width and unit length during deformation and subsequent recovery of bending associated with peeling. The effect of energy dissipation of adhesive and adherends is apparently independent and additive.

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Size-effect on Ultimate Shear Stress of Adhesive-bonded Tubular Lap or Tubular Butt or Circular Scarf Butt Joint Under Twisting Load

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Abstract

The ultimate shear stress τ_u of the adhesive-bonded tubular lap or tubular butt or circular scarf butt joint with a given length of overlap l, a given thickness of adhesive layer d, a given thickness of adherend t, t_1, t_2, a given mean diameter of adhesive layer D, a given outside diameter of adherend D_o and a given scarf angle ϕ, under twisting load, can be calculated from the following formulas:

a) In the case of the adhesive-bonded tubular lap joint between different materials, $\tau_u = T_B/(D^2 l \pi/2)$,

$$\tau_{ud} = \tau_1(t_1/l)\{1 - (t_1/D)\}^2 = \tau_2(t_2/l)\{1 + (t_2/D)\}^2$$

$$\tau_{ui} = \tau_B/\alpha = (\tau_B/2.5)\sqrt{(E_2/G_a)(d/l)}$$

$$\tau_{us} = 6.25\tau_1(G_a/E_1)(t_1/d)\{1 - (t_1/D)\}^2$$

$$\tau_{ut} = \tau_B$$

b) In the case of the adhesive-bonded tubular butt joint, $\tau_u = T_B/(D^2 t \pi/2)$,

$$\tau_{ud} = \tau_1$$

$$\tau_{ui} = \tau_B/\alpha = (\tau_B/2.5)\sqrt{(E/G_a)\{d/2t)\}}$$

$$\tau_{us} = 6.25\tau_1(G_a/E)(2t/d)$$

$$\tau_{ut} = \tau_B$$

c), d) In the case of the adhesive-bonded circular scarf butt joint, $\tau_u = T_B/(D_o^2 l \pi/16)$,

$$\tau_{ud} = \tau_1 D_o/l$$

$$\tau_{ui} = \tau_B/\alpha = (\tau_B/2.5)\sqrt{(E/G_a)(d/l)}$$

$$\tau_{us} = 6.25\tau_1(G_a/E)(D_o/d)$$

$$\tau_{ut} = \tau_B$$

Here E_1 and τ_1 represent the modulus of longitudinal elasticity and the shear strength, respectively, of the adherend, and E_2 and τ_2 represent those of the another adherend ($E_1 > E_2$). G_a and τ_B represent the modulus of transverse elasticity and the shear strength, respectively of the adhesive, and α represents the stress concentration factor.

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A Study of Macroscopic Contact Process of Adhesive Tape*

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Abstract

By measuring optically the contact area between the pressure sensitive adhesive and the roughened glass, we studied the effect of the physical properties of the adhesive, the thickness of the adhesive, the surface roughness of the adherend and bonding conditions, etc.

The result of the investigation has made it clear that the contact area depends on only the elastic properties of adhesive, not on the chemical components and that the viscosity has only a negligible small effect.

This result is supported by the numerical analysis made by the finite element method which was presented in the last report.

Judging from the stress and strain distribution in the adhesive layer by this measurement, we have concluded that the mechanism of contact progress is in the manner that relief pattern of the rugged surface of adherend is getting embedded into the adhesive layer.

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Studies on Adhesion and Properties of Acrylate-modified Chlorinated Polypropylene

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Abstract

Chlorinated polypropylene modified with acrylic compound (such as 2-Hydroxy Ethyl Acrylate) has been studied as the adhesive for polypropylene films and for those and aluminium foils. As for chlorinated polypropylene used here, chlorine content and molecular weight were changed for purpose of modification. Adhesive ability of this acrylate-modified chlorinated polypropylene was evaluated by a peeling strength testing method between the two oriented films and also between polypropylene film and aluminium foil.

We have obtained the following results:

About 3%-acrylate-modified chlorinated polypropylene whose chlorine content was about 30% showed remarkable improvement in the peeling strength compared with that of non-modified chlorinated polypropylene.

As results of further investigations, it has been found that this acrylate-modified chlorinated polypropylene has better properties than a non-modified chlorinated polypropylene in softening temperature, pencil hardness and solvent resistance.

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Stabilization and Atomization of Vaterite Synthesized in Methanol

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Abstract

We have investigated the effect of adding metal chlorides, surfactants and polymers in synthesizing vaterite on the stability of vaterite. Vaterite, which was synthesized under the presence of $ZnCl_2$, did not change to other crystal forms in water phase. $ZnCl_2$ is effective for stabilizing vaterite.

We have preserved vaterite synthesized under the presence of $ZnCl_2$ in methanol. This vaterite broke down to fine particles with $0.02 \mu m$ diameter in about two months. We observed acceleration of the break down phenomena of vaterite synthesized under the various additives. The break down phenomena were observed in the case of adding $ZnCl_2$, $CuCl_2$ and $AlCl_3$, and accelerated by heat treatment.

Synthesis and Applications of Poly(tetrahydrofuran) Ionene Part 3. The Effect of the Introduction of Poly(oxypropylene) Segments and the Kind of Counteranion in Quaternary Ammonium Groups on the Physical Properties of Poly(tetrahydrofuran) Ionene

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Abstract

This paper reports on the effect of the introduction of poly(oxypropylene) segments into the main chain of poly(tetrahydrofuran) ionene (PTI) or into the PTI matrix physically, and the influence of the counteranion in quaternary ammonium groups of PTI. The physical properties of block ionene (PTPI), which were prepared from dimethylamino-terminated poly(tetrahydrofuran), dimethylamino-terminated poly(oxypropylene) (AT-POP) and α, α'-dichloro-p-xylene, were found to vary remarkedly with the AT-POP content. The tensile strength of PTI was decreased with the increase of the AT-POP content. This behavior was estimated that the strain-induced crystallization of the poly(tetrahydrofuran) segments was inhibited by the introduction of poly(oxypropylene) segments into PTI main chain. By the addition of HT-PPG, which is assumed to function as a plasticizer to PTI, the peel strength of PTI was found to decrease with the increase of the HT-PPG content. This was presumed to be attributable to the plasticizing effect and the relative decrease of the cationic concentration by the dilution effect. It was attempted to change chlorine anion into fatty acid anion as the counteranion in quaternary ammonium groups of PTIs. As a result, the physical properties of PTI were found to vary by the kind of counteranion in quaternary ammonium groups of PTIs.

Adhesion of Nitrocellulose-Alkyd Resin Series Coating Films.
– Effect of Alkyd Resin Ratio and Sand Blasting for Adhesion on Each Substrates

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Abstract

In this paper, the authors studied the effects of alkyd resin ratio in nitrocellulose lacquer and sand blasting for adhesion on each substrate which are soft steel, ABS (acrylstyrenebutadiencopolymer), epoxy, 6-nylon, PE (polyethylene), PP (polypropylene) and ACT (polyacetal) plastics substrates. The results were the following:—

1. Internal stress of NC lacquer coating films influenced on adhesion of each substrate; ABS, 6-nylon and glass substrates with no sanding.

2. Adhesion of these NC lacquer coating films on each substrate; soft steel and each plastic was improved remarkably in cross cut adhesion because of sand blasting compared with no sanding.

3. Peel strengths of NC/GA and NC/PBA ratio have shown a maximum value at 20–40% alkyd resin ratio on each substrate; soft steel with no sanding and sand blasting, each plastic with sand blasting except ABS. This is a molecular interaction with sanding effect to substrates.

4. Adhesion of these NC lacquer coating films on PE and PP substrates which are poor adhesion essentially was improved with sand blasting.

5. Peel strengths of NC/GA and NC/PBA ratio have shown a minimum value at 40–60% alkyd resin ratio on ABS substrates with sand blasting because of mutual diffusion to interface of its substrate.

6. Generally, good adhesion of these NC lacquer coating films on each plastic substrate was obtained with sand blasting on its surface.

7. There was good correlation between peel strength and erichsen adhesion value because of its same adhesive mechanism in these NC lacquer coating films and each substrate adhesion.

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A Theory of the Contact Angle in Consideration of the Friction between Liquid Drop and Solid Surface

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Abstract

The contact angle θ of a liquid drop on a solid surface absorbed by the liquid vapor has been formulated by taking the friction into consideration as

$$\cos \theta = \frac{\gamma}{\gamma_{\mathrm{lv}}} (\gamma_s - \gamma_{sl} - \pi_e \pm \gamma_f)$$

where r is the roughness factor, γ_s stands for the surface tension of the solid in vacuum, γ_{sl} the interfacial tension at the solid-liquid interface, γ_{lv} the surface tension of the liquid in equilibrium with its saturated vapor, and π_e the equilibrium surface pressure. The last term γ_f is the frictional tension defined in this article, and that is found to be equal to the irreversible work of interfacial separation described in the previous work. The plus and the minus sign of the γ_f correspond to the receding contact angle θ_r and the advancing contact angle θ_a, respectively. This work revealed the following: The difference between θ_a and θ_r being called as the contact angle hysteresis arises from the existence of the frictional tension. Since the critical surface tension γ_c depends on contact angles applied, two kinds of the critical surface tension γ_{ca} and γ_{cr} can then be determined by means of the contact angle θ_a and θ_r, respectively. Several equations on the γ_s have been derived as a function of the γ_{ca} and the γ_{cr}. The contact angle and the friction coefficient have also been represented by the mechanical loss tangent of the solid and the liquid along with the γ_s and the γ_{lv}.

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Adhesive-bonded T-type Peel Strength
Necessary for Structural Design of Joint

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Abstract

The strength of the adhesive-bonded joint for airframe structural member, on MMM-A-132, Type 1, Class 1, is required as follows: The average ultimate shear stress of adhesive-bonded simple lap joint $\tau_u = P_B/(bl) \geqq 5000 \, \mathrm{lb/in^2} = 3.5 \, \mathrm{kg/mm^2}$. The adhesive-bonded T-type peel strength $P_B/b \geqq 50 \, \mathrm{lb/in} = 0.89 \, \mathrm{kg/mm}$. The adhesive-bonded T-type peel strength necessary for the structural design, as well as the tensile-shear strength, is decided on the maximum load P_B for the non-crack specimen. The peel strength P_B/b or the nominal maximum tensile stress $\sigma_u = (P_B/b)(3/l)$ of the adhesive-bonded T-type peel strength specimen with a given effective length of overlap l, a given thickness of adherend t, a given thickness of

adhesive layer d, and a given width of adherend b can be calculated from the following formulas:

$$(P_B/b)_d = \sigma_B t$$
$$(P_B/b)_t = (\sigma_{aB}/10.8)\sqrt{(E/G_a)ld}$$
$$(P_B/b)_s = 13\sigma_B(G_a/E)(lt/d)$$
$$(P_B/b)_t = \sigma_{aB}l/3$$
$$l = 10\sqrt{(G_a/E)(t^3/d)}$$

Here σ_B and E represent the tensile strength and the modulus of longitudinal elasticity, respectively, of the adherend, and σ_{aB} and G_a represent the tensile strength and the modulus of transverse elasticity, respectively, of the adhesive, and P_B represents the ultimate load. $(P_B/b)_d$ represents the peel strength in the case of cohesive failure in the adherend, $(P_B/b)_i$ represents that in the case of interface failure, $(P_B/b)_s$ represents that in the case of cohesive failure in the adhesive layer, and $(P_B/b)_t$ represents that in the case of tensile failure in the adhesive layer.

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