# The Young's modulus of compression-moulded LLDPE-phlogopite composites

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To Petra

SYNOPSIS

# The Young's modulus of compression-moulded LLDPE-phlogopite composites

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Particulate reinforced polymers is a mature field and many models are available to predict the Young's modulus of such composites. However, all the existing models have a common flaw; they all predict that the composite modulus equals that of the reinforcing agent when the polymer content approaches zero. This implies, in this limit, a monolithic reinforcement whereas, in fact, it is composed of discrete particles with very little interaction. This is a serious drawback and therefore this study focussed on:

- finding the composition and processing variables that contribute most to the Young's modulus of a LLDPE / phlogopite composite and
- deriving an improved model for the Young's modulus in the plane of the reinforcement.

The Taguchi method was used to separately investigate the effects of composition and processing variables on the mechanical properties of compression moulded sheets. The composition variables considered were: particle size, polymer content and type of polymer modification. With respect to main effects (Young's Modulus) the factors particle size and polymer content were found to be the most important. It should, however, be noted that the modulus showed a broad maximum in the range of polymer content investigated. This could have masked the true effect of binder content.

The processing variables considered were: holding pressure, mould temperature, moulding time and the amount of material moulded per unit area. Concerning the preparation variables, pressure contributed the most towards the Young's modulus, although the contribution was small. The experimental results for the flexural modulus confirmed that pressure was the most important preparation variable. Particle shape will ultimately influence the ability for good packing of particles in the composite. Poor packing will result in a high voidage, especially when the polymer content is low. Using a high holding pressure helps to reduce this voidage.

The voidage of the present samples were correlated with the volume fraction binder and the maximum packing density of the pure reinforcement. A theoretical model was derived along the lines of the Padawer-and-Beecher-modified-Cox model. However, it included the effect of composite voidage on the composite's mechanical properties. In contrast to other available models, it correctly predicts the loss of material stiffness and strength in the limit of zero binder content.

Keywords:

Polyethylene, phlogopite, Young's modulus, voidage, packing platelet, reinforcing agent, binder, aspect ratio, model

SINOPSIS

# Young se modulus vir persgietgevormde LLDPE-flogopiet samestellings

deur

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Partikel-versterkte polimere is 'n gevestigde veld en verskeie modelle is beskikbaar om Young se modulus te voorspel. Al die bestaande modelle het egter een gemeenskaplike nadeel; dit is dat hierdie modelle voorspel dat Young se modulus gelyk is aan die partikel materiaal-modulus wanneer die polimeerinhoud neig na nul. Dit impliseer, in hierdie limiet, dat die versterker kontinu is, terwyl dit egter uit diskrete partikels bestaan met baie min interaksie. Dit is 'n ernstige nadeel en hierdie studie het daarom gefokus op:

- die bepaling van die samestelling- en prosesseringsveranderlikkes wat die meeste bydra tot Young se modulus van sulke materiale
- die afleiding van 'n verbeterde model om Young se modulus te voorspel in die vlak van oriëntasie van die versterker.

Die Taguchi metode is gebruik om onderskeidelik die invloed van die samestellingveranderlikes en prosesseringsveranderlikes te bepaal op die meganiese eienskappe van persgietgevormde velle. Die samestellingsveranderlikes ondersoek was: partikel grootte, polimeerinhoud en tipe polimeer modifikasie. Met betrekking tot die hoof effek (Young se modulus) is daar gevind dat partikkel groote en polimeerinhoud die belangrikste faktore was. Daar moet egter in gedagte gehou word dat die modulus 'n breë maksimum toon in die gebied van polimeerinhoud wat ondersoek is. Dit kon dalk die ware effek van polimeerinhoud verskuil.

Die prosesseringsveranderlikkes ondersoek was: prosseseringsdruk, vormingstyd, en die hoeveelheid materiaal gebruik per eenheidsarea. Met betrekking tot die prosesseringsveranderlikkes dra prosseseringsdruk die meeste by tot Young se modulus, maar, die effek is klein in vergelyking met die foutterm. Die eksperimentele resultate vir buigmodulus het egter bevestig dat prosesseringsdruk die belangrikste prosseseringsveranderlikke is. Verder, beïnvloed partikelvorm ook die vermoë van die partikels om dig te pak. Swak pakking veroorsaak 'n hoë porositeit in die materiaal, veral as daar min polimeer teenwoordig is. Toepassing van 'n hoë prosseseringsdruk verlaag die porositeit.

Die porositeit van die materiaal hier tersprake, is gekorreleer met die volumefraksie polimeer en die maksimum pakkingsdigtheid van die suiwer versterkingsmateriaal. 'n Teoretiese model, gebasseer op die van Cox, soos gemodifiseer deur Padawer en Beecher, is afgelei om Young se modulus te voorpel. Die nuwe model sluit egter die effek van porositeit, op die meganiese eienskappe van die materiaal, in. In kontras met die ander modelle voorspel hierdie materiaal die verlies in materiaal styfheid en sterkte, die korrekte gedrag by die limiet geval van geen polimeer teenwoordig.

**Sleutelwoorde:**

Poliëtileen, flogopiet, Young se modulus, porositeit, pakking, plaatjie, versterkingsmateriaal, binder, aspekverhouding, model

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# Contents

# List of Symbols

| | |
|---|---|
| $A_c$ | Area of the composite over which the tensile force acts |
| $A_f$ | Area of a particle |
| $A_p$ | Area of the polymer over which the tensile force acts |
| $A_{pa}$ | Particle area |
| $A_v$ | Void area |
| D | Particle length |
| $E_c$ | Young's modulus of the composite in the plane of orientation |
| $E_m$ | Young's modulus of the reinforcement (mica) |
| $E_p$ | Young's modulus of the polymer |
| $F_c$ | Tensile force acting on the composite |
| $F_m$ | Average tensile force acting on the platelet |
| $F_p$ | Tensile force acting on polymer |
| $G_p$ | Shear modulus of the polymer |
| MRF | Modulus reduction factor |
| S | Spacing between plates |
| t | Plate thickness (m) |
| u | Displacement of the particle at distance x from the edge |
| v | Displacement of the polymer at distance x, form the edge of the particle when no particles are present |
| $V_{apparent}$ | Apparent volume of one particle ($m^3$) |
| $v_f$ | Volume fraction reinforcement, associated with zero voidage |
| $v'_f$ | True volume fraction reinforcement |
| $v_{f,max}$ | Maximum true volume fraction filler |

| | |
|---|---|
| $v_p$ | Volume fraction polymer, associated with zero voidage |
| $v'_p$ | True volume fraction polymer |
| $V_{particle}$ | Volume of one particle ($m^3$) |
| W | Width of the plates |
| $x_m$ | Mass fraction filler |
| $x_p$ | Mass fraction polymer |
| y | Constant used in the Hirsch model to determine the contribution of the different mixing rules (Equation 2). |
| $\alpha$ | Flake aspect ratio |
| $\gamma$ | Shear strain |
| $\rho_{composite}$ | Measured density of the composite ($kg/m^3$) |
| $\rho_m$ | Filler density |
| $\rho_p$ | Polymer density |
| $\rho_{theoretical}$ | Density of the composite based on zero voidage ($kg/m^3$) |
| $\sigma_c$ | Tensile stress in the composite |
| $\sigma_f(x)$ | The tensile stress in the particle as a function on the position along the particle |
| $\sigma_p$ | Tensile stress in the polymer |
| $\tau$ | Shear stress |
| $\phi$ | Voidage |
| $\phi_d$ | Voidage caused by debonding |
| $\phi_m$ | Fraction void volume per cubic metre particles |
| $\phi_{m,max}$ | Maximum void volume based on 1 $m^3$ when no polymer is present ($m^3$) |
| $\chi$ | Modified voidage (Voidage relative to polymer phase) |
| $\nu_{ps}$ | Poison's ratio of the polymer |
| $\omega$ | Restricted displacement of the polymer due to the filler |
| $\varepsilon$ | Strain in the composite |

Definitions:

| | |
|---|---|
| ANOVA | Analysis of variance. Used to investigate the relative contribution of various factors on the main effect. |
| Binder | Polymer phase in the composite. If the volume fraction binder becomes more significant it is also referred to as the matrix |
| LLDPE | Linear low density polyethylene |

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