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ABSTRACT

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2.2. Surface operations and projections

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, $\boldsymbol{E}$ $\boldsymbol{W}$ -

$$\boldsymbol{E} \quad \frac{1}{2} \quad u \quad u)^{T}) \qquad \boldsymbol{W} \quad \frac{1}{2} \quad u] \quad u)^{T}), \qquad 12)$$

T , . - , -

3.1.3. Relationship between macroscopic and microscopic interface strains

$\tilde{\boldsymbol{\chi}} = \partial\tilde{u}/\partial\boldsymbol{\xi}$ $\tilde{u}(\xi_n, \xi_s, \xi_t)$

$\tilde{\boldsymbol{\chi}}(\xi_n, \xi_s, \xi_t)$

n,

$$\tilde{\boldsymbol{\chi}}(\xi_n, \xi_t, \xi_s) = \langle\tilde{\boldsymbol{\chi}}\rangle(\xi_t, \xi_s) + \langle\langle\tilde{\boldsymbol{\chi}}\rangle\rangle(\xi_t, \xi_s)\,\xi_n + O(\xi_n^2) \quad (22)$$

$\langle\tilde{\boldsymbol{\chi}}\rangle$ $\langle\langle\tilde{\boldsymbol{\chi}}\rangle\rangle$

μ Γ

$\zeta_s^\perp$] μ[/h. 3)

, 1/h .

, $\boldsymbol{\upsilon}_s^\perp$ (1),

] μ .

$$\tilde{q}\ (\xi_n, \xi_t, \xi_s) = q_s^{\|} + q_s^{\perp} n\ (\xi_t, \xi_s) + q_m\ (\xi_t, \xi_s)\frac{\xi_n}{h} + O(\xi_n^2), \qquad (4\ )$$

( ) ( )

4. Mass conservation

$$\rho^f = \phi\rho_t^f \qquad \rho^s = 1]\ \ \phi)\rho_t^s, \qquad (4\ )$$

t

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$\bar{\rho}^\alpha$ $\bar{\bar{\rho}}^\alpha$

α (α s,f)

$$\bar{\rho}^\alpha = h\langle\tilde{\rho}^\alpha\rangle, \quad \bar{\bar{\rho}}^\alpha = h^2\langle\langle\tilde{\rho}^\alpha\rangle\rangle \qquad (4\ )$$

$\tilde{\rho}^f = \tilde{\phi}\tilde{\rho}_t^f \quad \tilde{\rho}^s = 1]\ \ \tilde{\phi})\tilde{\rho}_t^s$ $\tilde{\rho}_t^\alpha$

α.

h

Upc5 0 Tcombin.1(s)-27F7 46.7(o)0(n)-2ar

(.)

$\tilde{\rho}^\alpha\ \xi_n, \xi_t, \xi_s) = \langle\tilde{\rho}^\alpha\rangle\ \xi_t, \xi_s) + \langle\langle\tilde{\rho}^\alpha\rangle\rangle\ \xi_t, \xi\upsilon$

$\cdot \tilde{\mathbf{v}} = \dot{\bar{e}}^{v}$

(2) (1)

$$\frac{D\bar{\rho}^s}{Dt} + \bar{\rho}^s \dot{e}_s^v + \bar{\bar{\rho}}^s I \dot{e}_m^v = 0$$

$$\frac{D\bar{\bar{\rho}}^s}{Dt} + \bar{\bar{\rho}}^s \dot{e}_s^v + \bar{\rho}^s \dot{e}_m^v = 0,$$

I

$$I = \frac{1}{h^3}\int_{-h/2}^{h/2} \xi_n^2 \, d\xi^n = \frac{1}{12}.$$

( ) $\bar{\rho}^s$

∂

$$\delta E_{int} = \int_{\Omega} \mathrm{div}\,T \cdot \delta u\, dV + \int_{\Gamma} \boldsymbol{t}_s \cdot \delta u \;\; \mathrm{div}^{\parallel} T_s \cdot \delta\{u\}$$
$$\mathrm{div}^{\parallel} T_m \cdot \delta u\, dS \;\; \int_{\Gamma} T \cdot n \cdot \delta u\, dS + \int_{\partial\Omega} T \cdot \bar{n} \cdot \delta u\, dS$$
$$+ \int_{\ell_i} T_s \cdot m \cdot \delta u\, d\ell + \int_{\ell_e} T_s \cdot m \cdot \delta\{u\} + T_m \cdot m \cdot \delta u\, d\ell \quad (4)$$

$\bar{n}$ $\partial\Omega$ m

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($\partial\Omega$). ,

u 0 $\{u\}$ u ℓ_i. ,

,

$$T \cdot n \cdot \delta u = T \cdot n \cdot \{\delta u\} + \{T \cdot n\} \cdot \delta u$$

$$\int_{\ell_i} T_s \cdot m \cdot \delta u\, d\ell = \int_{\Omega} T_s \cdot m\, \delta(x - x_{\ell_i}) \cdot \delta u\, dV$$

$\delta(x - x_{\ell_i})$, δE_{int}

$$\delta E_{int} = \int_{\Omega} (\mathrm{div}\,T + T_s \cdot m\, \delta(x - x_{\ell_i})) \cdot \delta u\, dV$$
$$+ \int_{\Gamma} \boldsymbol{t}_s \;\; \mathrm{div}^{\parallel} T_m \;\; \{T \cdot n\} \cdot \delta u + \mathrm{div}^{\parallel} T_s$$
$$T \cdot n \cdot \delta\{u\}\, dS + \int_{\partial\Omega} T \cdot n \cdot \delta u\, dS$$
$$+ \int_{\ell_e} T_s \cdot m \cdot \delta\langle u\rangle + T_m \cdot m \cdot \delta u\, d\ell.$$

( ) (3) (2)

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δu, $\{\delta u\}$ δu

$\delta u = 0$ $\partial\Omega^u$, $\delta u = 0$ ℓ_e^u $\delta\{u\} = 0$ ℓ_e^u,

$\mathrm{div}\,T + b \;\; T_s \cdot m\, \delta\, x$

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