THE MATRIX OF THE NEW COMPOSITE
IN THE EXTREME HIGH TEMPERATURE

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Abstract. The remarkable advantage of composite material is light, durative in physical-chemical environment specially in high temperature. Because of its advantages, composite material is being used in various field such as industry, transport, machine-manufacturing, medicine etc, and specially in manufacturing flying vehicle [2,3]. Many parts in flying vehicle are made from composite as they can bear the temperature of thousands C degree. However, its response to extremely high temperature is intensively complex. This article describes some new result in researching the matrix of composite in extremely high temperature.

1. Introduction

As the flying vehicle with high speed, the air nearby burns and create thermal convection flows around it. This is caused by the consequence of the brushing between the object and atmosphere. For example, the boat which retune the astronaut has Makha M coefficient in the range of 35 and zero as it reaches the atmosphere and the temperature on its surface can be up to some thousands C degree. In this case, the composite material is exploited in extremely high temperature. It is called extremely fast-thermal composite material.

Scientifically, extremely high temperature is conceived as the temperature that causes the non-reversible physical conversion in composite material.

Composite's response in high and extremely high temperature is significantly varied. In extremely high temperature, a physical non-reversible conversion occurs inside the composite include non-linear conversions which noticeably depend on temperature and heating time. Basic changes in the material are listed below:

-Composite material is being "heat eroded", a process which reduces its weight. In the matrix appear two new phases, solid phase and gas phase. The solid phase is the result of the pyrolysis process and gas phase is the result of the pyrolysis polymer holded in cavities that created in pyrolysis process on extremely high temperature.

- Heat-conducting coefficient changes irregularly.

- Increase the air absorption coefficient

- More cavities occurs (disparate to cavities which took shape in manufacturing process)

- Elastic characteristic and duration change, specially on the horizontal and length-wise direction of the reinforcing rods (fiber of composite).

Typeset by $\mathcal{AMS}$-TEX

-Heat-stretching coefficient changes irregularly and constriction can happen.

-Composite structure loses the stability.

Fiber of composite can also be heat-eroded in extremely high temperature. A solid phase, which is the product of the pyrolysis process, occurs in this condition. It is called fibre crystal phase. There is also an occurrence of replenish cavities filled with gas. This stage is called the non-fixative essential stage.

New phases and primary phases in the matrix contact to each other; under the influence of high temperature, primary solid phases change gradually into new phases.

In this articles we will deal with the initial result in researching the primarily isotropic matrix. Isotropic matrix in extremely high temperature is depicted on figure 1. It includes 3 phases; polymer matrix phase (index b), solid matrix phase, product of the pyrolysis process (index p), and gas phase in cavities (index g) . If $\varphi_b, \varphi_p, \varphi_g$ is volume of the phases, then we have:
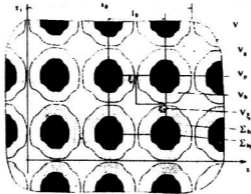
$$\varphi_b + \varphi_p + \varphi_g = 1, \tag{1}$$

Figure1: **Physical structure of the polymer matrix that have circulated structure in extremely high temperature.**

2. Model and problem for Mechanics of composite material

In order to develop the composite material problem, we suppose all cavities is in cubic form, pyrolysis of solid phase and primary polymer phase have semi-cubic shape, see fig.2a and fig.2b.

The regions' volume $V_{\xi_b}, V_{\xi_p}, V_{\xi_g}$ in the model in fig.2 is defined as below:

$$V_{\xi_g}(t) = \left\{ 0 < |\xi_k| < \frac{S_b(t)}{2} \right\},$$

$$V_{\xi_b}(t) = \left\{ \frac{S_b(t)}{2} < |\xi_k| < \frac{S_p(t)}{2} \right\},$$

$$V_{\xi_p}(t) = \left\{ \frac{S_p(t)}{2} < |\xi_k| < \frac{1}{2} \right\}, \quad k = 1, 2, 3. \tag{2}$$

These regions is changed as the boundary regions $S_b(t)$ and $S_p(t)$ change when they were burn.

Note ρ_m is density of the polymer matrix when it is eroded in extremely high temperature (heat-erosion); ρ_m^0 is density of the initial polymer matrix ($t = 0$); ρ_m^∞ - density of matrix after the heat-erode process finished, thus we have [1]:

$$\rho_m = \rho_b \varphi_b + \rho_p \varphi_p; \ \rho_m^0 = \rho_b \varphi_b^0; \ \rho_m^\infty = (1 - \Gamma)\rho_m^0, \tag{3}$$

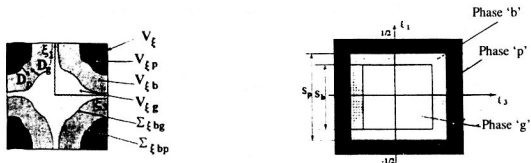Γ is gasify coefficient of the matrix.

Figure 2: a) One circulated link of chain's physical structure of polymer matrix in extremely high temperature. b) One circulated link of chain's model mechanic of polymer matrix in extremely high temperature.

Density ρ_m is defined depend on burning temperature θ and burning time t:

$$\frac{\rho_m}{\rho_m^0} = 1 - \Gamma. \exp\left(-\frac{J_0}{\rho_b}\Gamma \int_0^t \exp\left(-\frac{E_A}{R_\theta}\right) d\tau\right). \tag{4}$$

From (4) easily saw the relative change ρ_m/ρ_m^0 when material is burn depend on three constants: E_A active energy, Γ- gasify coefficient of the matrix, and J_0/ρ_b - a multiply index. The value of these three constants depends on the environment in which material is burn: inert environment (vacuum or inert gas) or oxygenated environment (air, oxygen). The local problem in the circulated link V_ξ is built below:

$$\triangle_\xi \sigma_i^0 = 0 \tag{5}$$

$$\varepsilon_i^{(0)} = \varepsilon_i^{0(0)}.\mathbf{E} + \frac{1 + \nu_i}{E_i}\sigma_i^{(0)} \frac{\nu_i}{E_i}\sigma_i^{(0)}\mathbf{E} \tag{6}$$

$$2\varepsilon_i^{(0)} = 2\varepsilon_m + \triangle_\xi \otimes \mathbf{u}_i^{(1)} + (\triangle_\xi \otimes \mathbf{u}_i^{(1)})^T, \quad \xi \in V_\xi, \tag{7}$$

$$\varepsilon_i^{0(0)} = \alpha_i(\theta - \theta_i^*) - \beta_i, \quad i = b, p \tag{8}$$

$$\sigma_i^{(0)}.\mathbf{n}^{(0)} = -p\mathbf{n}^{(0)}; \quad \xi \in \sum \tag{9}$$

$$[\sigma^{(0)}]\mathbf{n}^{(0)} = 0, \quad [\mathbf{u}^{(1)}] = 0, \quad \xi \in \sum \tag{10}$$

$$< \mathbf{u}^{(1)} >_s = 0, \tag{11}$$

where: E_i, ν_i, α_i are elastic modulus, poisson coefficient and heat-stretching coefficient of matrix; ε_i- deforming tensor; ε_m-average deforming tensor of matrix; $\mathbf{u}_i^{(1)}$- deformation of

the phase close to the average deformation of the matrix $\mathbf{u}$: $\mathbf{u}_i - \mathbf{u} = \kappa \mathbf{u}_i^{(1)}$, where: $\mathbf{u}_i$ - actual displace value of the phase, κ is random small parameter; β_i - chemical constricting index of solid phases ($\beta_b = 0$), $\sigma_i^{(0)}$ -1st invariant of stress tensor ; $\theta i*$- changing phase temperature; E-tensor unit.
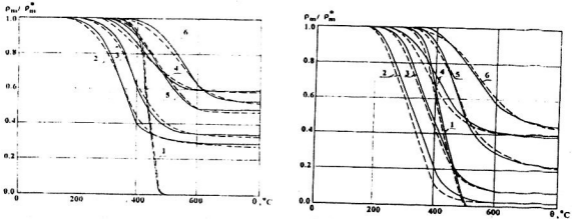
Figure 3: The density's change $\rho m / \rho 0 m$ in inert environment (fig.3a), and in the air (fig.3b), with disparate matrix: 1-polyetylen, 2-epoxy, 3-epoxyphenol, 4-phenol, 5-polyimide, 6-organic fibre. Continuous line-calculate follow the (3) equation. Dot line-practical result [1]

Problem $\{(5)\text{-}(11)\}$ on the matrix's circulated links of chain is essentially 6 disparate problems, correlative with six independent components of the deforming tensor $(\varepsilon_m)_{kl}$. Where deforming tensor $(\varepsilon_m)_{kl}$ relate to vector of displacement on the Cosi equation:

$$2\varepsilon_m = \triangle_x \otimes \mathbf{u} + (\triangle_x \otimes \mathbf{u})^T. \tag{12}$$

3. Consider the particular situation in resolving the problem that defines ε_{m33}

We found:

$$\varepsilon_{m33} = \frac{\sigma_{m33}}{E_m} + f_m \cdot p + \varepsilon_m^0. \tag{13}$$

Where: σ_{m33} is the normal stress component of the average stress tensor $(\sigma_m)_{kl}$; E_m- elastic modulus; f_m-phases reciprocal coefficient; ε_m^0-effective thermal displacement.

These components are found by:

$$E_m = E_b^0 \tilde{a}_1, \tag{14}$$

$$\tilde{a}_1 = \left(\frac{S_b}{a^{(0)}(S_b^2 - S_p^2) + m_p(1 - S_p^2)} + \frac{S_p - S_b}{a^{(0)}S_p^2 + m_p(1 - S_p^2)} + \frac{1 - S_p}{m_p} \right)^1, \tag{15}$$

$$f_m = \frac{\varphi g}{E_p^0} \left(\frac{1}{a^{(0)}(S_b^2 - S_p^2) + m_p(1 - S_p^2)} - \frac{1}{\tilde{a}_1} \right), \tag{16}$$

$$\varepsilon_m^0 = \alpha_b \varphi_b (\theta - \theta_0) + \alpha_p \int_0^t (\theta(t) - \theta(\tau)) \dot{\varphi}_p d\tau - \beta_p \varphi_p, \tag{17}$$

with $m_p = E_p/E_b$; elastic modulus ratio among phases; S_b; S_p-specific function of the phases' geometry dimension;

Easily get the equation that define the average stress and displacement of the heat-eroding matrix as:

Thus, after averaged, heat-eroding matrix is conceived as a homogeneous environment.

Figure 4 perform the dependence of a1 to the burning temperature *theta* with various polymer matrices.Fig.4 a) is the air; fig.4 b) is the inert gas; the continuous curve-is formed by calculating; doted curve- practical result [1];The heat increase speed $\bar{\theta}$ is 0.1 K/s.
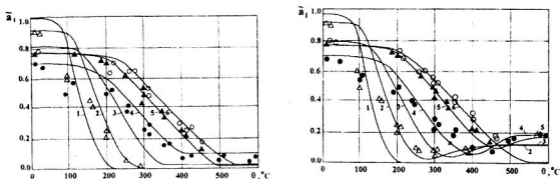

Figure 4: a) and fig. 4 b) : 1-polyester matrix; 2-epoxy matrix; 3-epoxyphenol matrix; 4-phenol matrix; 5-polyimide matrix; 6-organic matrix.

From the practical and theorical result, we can conclude that the transformation of matrix's physical characteristic depend greatly on the environment in which material is heated., specially notice to the epoxy, polyimide and phenol matrix (the curve 2, 4, 5 of figure 4.b): Coefficient $\tilde{a}_1$ increases (which means elastic modulus E_m also increases) in the temperature range from 500^0C to 600^0C. This is the same as practical test. It is because when temperature is in the range from 350^0C too 500^0C the hardiness of polymer matrix is inconsiderable and the ratio φ_p is not great enough, the pyrolysis process is just beginning. When temperature is from 500^0C to 600^0C, a thermal-disintegrating process happens rapidly in the polymer matrix. And φ_p ratio reach the maximum, and lead to the increase of modulus E. This happens only in the inert environment. In oxygenized environment, when temperature increases, reduce significantly hence, φ_p increases, therefore modulus E of polymer matrix does not increase (figure 4.a).

References

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