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ORIGINAL ARTICLE

Critical thermal shock temperature prediction of alumina using improved hybrid models based on artificial neural networks and Shannon entropy

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ABSTRACT – This study investigates the potential of a simple and Hybrid artificial neural network (ANN) to predict dense alumina's critical thermal shock temperature (ΔT_c). The predictive models have been constructed using two ANNS models (M1, M2). In the first model (M1), elaboration, physical and mechanical parameters have been exploited to build three ANNs, namely generalized linear regression (M1-GLRNN), extreme learning machine (M1-ELM), and radial basis function (M1-RBFNN). The second model (M2) has been built by the three models mentioned above incorporated by the Shannon Entropy (SE) method. To compare the performance of all the developed models, coefficient of correlation (R), root mean square error (RMSE), mean absolute percentage error (MAPE), and Nash-Sutcliffe efficiency coefficient (NSE) have been considered. It is found that M2-RBFNN model with (RMSE = 4.3526, MAPE= 0.3406, NSE = 0.9921, and R= 0.9960) had superiority to the M1-RBFNN model (RMSE = 4.7030, MAPE= 0.3003, NSE = 0.9908, and R = 0.9954). More importantly, the contribution of the present work is that prediction of ΔT_c has been performed through the developed hybrid model (M2-RBFNN), which reduces the number of inputs from six to only four inputs and offers high accuracy for all the studied variables.

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INTRODUCTION

Thermal shock occurs when there is an abrupt change in the temperature of a material. The resulting temperature gradient develops gradient stresses that can locally reach the yield strength of the material and cause damage [1]. The thermal shock and thermal cycling effects are known to limit ceramics performance in many applications. Thermal shock resistance is often evaluated by measuring the resistance to fracture after the thermal shock (residual stress), making it possible to define a critical temperature range at which the material degrades.

Since the 1950s, many scientists have carried out various experimental and fundamental studies on the thermal shock resistance of ceramic materials [2-9]. Nevertheless, the crack propagation resulting from thermal shock is a speedy and complex procedure for these materials. The most commonly employed theories are the critical stress fracture theory [2] and the thermal shock damage theory [3]. It is essential to note that the thermal resistance properties of brittle materials such as alumina [4-6] and glass [7-9] have been extensively studied based on these two theories.

On the one hand, the first theory is derived from thermoelasticity and focuses on controlling the conditions of fracture nucleation. On the other hand, the second theory allows characterizing the critical temperature difference and the damage state of the material. The second theory considers the instability of pre-existing cracks according to the temperature difference.

Using the thermoelastic dynamics method, Hasselman inserted the thermal shock resistance parameter (R) to estimate the performance of a brittle ceramic material exposed to thermal shock loading. He concluded that R is correlated to the critical temperature through Eq. (1).

$$\Delta T_c = \psi^{-1}(\beta)\frac{(1-\upsilon)K_{1c}}{E\alpha Y\sqrt{\pi a_c}} \quad (1)$$

With α is the coefficient of expansion, E is Young's modulus, K_{1c} is the toughness, ΔT_c is the applied critical temperature difference, ψ is the stress reduction coefficient, β is the Biot number defining the severity of the thermal shock, υ is Poisson's ratio, ac is the crack length and Y is a geometric constant. The first parameter (R) for a hard thermal shock (β very high and $\psi \cong 1$), is expressed through Eq. (2):

$$R = \Delta T_c = \frac{\sigma_R(1-\upsilon)}{E\alpha} \quad (2)$$

where σ_R is the fracture strength.

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