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Investigation of residual stress in epoxy-based coatings using X-ray and FEM-ANN techniques

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Abstract:

Residual stresses play a significant role in the properties and performance of epoxy-based coatings, with their origins rooted in various factors encountered during production and application. This study focuses on quantifying residual stresses in three distinct epoxy-based coatings, commonly used as linings for crude oil storage tanks, namely, pure epoxy, Novolac epoxy, and glass-flake-reinforced epoxy. We employ X-ray diffraction to measure these residual stresses and compare them against predicted values obtained through finite element and artificial neural network methods. Our findings reveal notable differences in residual stresses among the three types of epoxy coatings. Specifically, pure epoxy coatings exhibit higher residual stresses, Novolac epoxy coatings display the lowest, and those reinforced with glass flakes fall in between. Utilising the FEM-ANN model for simulations yields results that closely align with experimental measurements obtained via the X-ray method. Test results demonstrate that the coatings cured at high temperatures have high residual stresses compared to those cured at lower temperatures. Increasing the curing temperature from 10 to 50°C will increase residual stresses by 40.81, 11.085, and 56.98% for coatings reinforced with glass-flake, Novolac, and pure epoxy-based coating, respectively.

Keywords: **curing temperature, glass-flakes, residual stress, volumetric shrinkage, X-ray method.**

Classification numbers: **2.2, 2.3**

1. Introduction

Epoxy coatings consisting of two components, a base and a hardener, are commonly employed for safeguarding crude oil storage tanks, ensuring their continued operational performance. However, a range of factors, including intrinsic characteristics, thermal influences, volumetric changes, and lattice disparities, can introduce residual stress into these epoxy coatings, potentially compromising their performance [1]. Throughout the crosslinking and curing process, volumetric transformations occur, driven by the interaction between the base and the hardener [2]. The presence of fillers, fibres, or glass flakes can exacerbate this issue as these materials often shrink at different rates compared to the resin and hardener, leading to the formation of residual stresses. Furthermore, parameters such as curing temperature and coating thickness significantly impact the initiation of residual stresses during the curing process of epoxy-based coatings [3]. Intrinsic residual stresses may also be present, stemming from defects like air bubbles and grain boundaries within the epoxy coating [4].

Various methods are employed to evaluate residual stresses, encompassing both experimental and numerical techniques [5]. The X-ray diffraction (XRD) technique is widely utilised for measuring residual stresses in diverse materials. XRD assesses strain within the crystal lattice, allowing for the calculation of residual stress based on elastic constants [6]. In contrast, numerical methods such as finite element method (FEM) and artificial neural networks (ANN) have gained popularity for predicting residual stresses. FEM entails complex non-linear analyses, influenced by boundary conditions and modelling procedures [7, 8], while ANN, as a computational model, employs artificial neurons to simulate structural organisation, predict relationships between input parameters, and model the system [9, 10].

Despite the critical implications of residual stresses, their evolution within epoxy coatings has received limited research attention. P. Kamarchik, et al. (1980) [11] reviewed the application of the X-ray technique for measuring and estimating residual stresses in coating and coating-related systems. The results indicated that less adhesion and misleading cross-linking between coating molecules can result from the residual stresses. I. Kishore (2003) [12] used finite element analysis to simulate the formation of residual stress in epoxy resins created due to the influence of dimensional constraints. The simulation results indicate that there are possible areas where delamination and cracking in epoxy

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