TORQUE-RELATED LAMELLAR CARBIDE GROWTH ASSOCIATED WITH ANNEALING TWINS IN 304 STAINLESS STEEL

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DEDICATION

This thesis is dedicated to two special individuals: first, to the memory of my grandmother, Leonor Murphy Romero, for instilling the motivation and vision to pursue career opportunities which were never offered to her and the women of her generation; and to the memory of my cousin, Jeremiah Carl Gardner, who was full of life and promise but never had the chance to fulfill his dreams in the fifteen years that God had granted him on this earth.

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by

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ABSTRACT

A configurational, equilibrium theory for relative interfacial torques has been invoked to qualitatively explain growth-specific lamellar precipitation of $M_{23}C_6$ carbides in 304 stainless steel where the lamellar growth is always in the <112> directions coincident with traces of {111} planes at 90° to (110) grain surface orientations. For (112) grain surface orientation, $M_{23}C_6$ lamellar growth is always in the $[\bar{1}10]$ direction which is also coincident with traces of $(11\bar{1})$ planes at 90° to the grain surface plane. These {111} trace directions for lamellar growth are denoted T90 directions and are shown to coincide with high, relative interfacial torques (or torque configurations) resolved in coherent {111} annealing twin boundaries. For grain surface orientations containing annealing twins or twin/grain boundary geometries whose coherent {111} boundaries are not consistant with T90 directions, such as (100), there are no high-torque configurations and no significant lamellar $M_{23}C_6$ growth coincident with {111} trace directions.

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LIST OF EQUATIONS

$$DOS = \frac{\frac{Q}{A}}{5.1\times10^{-4}e^{0.35G}} \quad (1)$$

$$\sum_{i=1}^{3}\left[\gamma_i\sigma_i + (\boldsymbol{\sigma_i}\times\boldsymbol{z})\frac{\partial\gamma_i}{\partial\Omega_i}\right] = 0 \quad (2)$$

$$\begin{aligned}\gamma_{tb}+\gamma_{AB}\cos\Omega_1+\gamma_{T_AB}\cos\Omega_2+\sum M_I &= 0\\ \gamma_{tb}+\gamma_{AB}\cos\Omega_4+\gamma_{T_AB}\cos\Omega_3+\sum M_{II} &= 0\end{aligned} \quad (3)$$

$$\sum M_I = \frac{\partial\gamma_{AB}}{\partial\Omega}\sin\Omega_1 + \frac{\partial\gamma_{T_AB}}{\partial\Omega}\sin\Omega_2 \quad (4)$$

$$\sum M_{II} = \frac{\partial\gamma_{AB}}{\partial\Omega}\sin\Omega_4 + \frac{\partial\gamma_{T_AB}}{\partial\Omega}\sin\Omega_3 \quad (5)$$

$$\begin{aligned}\frac{\gamma_{tb}}{\gamma_{AB}} &= C_{AB} - \frac{1}{\gamma_{AB}}\left(\frac{\sum M_I\cos\Omega_3 - \sum M_{II}\cos\Omega_2}{\cos\Omega_3-\cos\Omega_2}\right)\\ \frac{\gamma_{tb}}{\gamma_{T_AB}} &= C_{T_AB} - \frac{1}{\gamma_{T_AB}}\left(\frac{\sum M_I\cos\Omega_4 - \sum M_{II}\cos\Omega_1}{\cos\Omega_4-\cos\Omega_1}\right)\end{aligned} \quad (6)$$

$$C_{AB}=\frac{\cos\Omega_2\cos\Omega_4-\cos\Omega_1\cos\Omega_3}{\cos\Omega_3-\cos\Omega_2} \tag{7}$$

$$C_{T_AB}=\frac{\cos\Omega_2\cos\Omega_4-\cos\Omega_1\cos\Omega_3}{\cos\Omega_1-\cos\Omega_4} \tag{8}$$

$$\frac{\gamma_{tb}}{\gamma_{gb}}=\frac{1}{2}\sum_{i=1}^{4}(-\cos\Omega_i) \tag{9}$$

$$\begin{aligned}\frac{\gamma_{tb}+\sum M}{\gamma_{AB}}&=C_{AB'}\\ \frac{\gamma_{tb}-\sum M}{\gamma_{T_AB}}&=C_{T_AB'}\end{aligned} \tag{10}$$

$$\sum M=\frac{\sum M_I\cos\Omega_3-\sum M_{II}\cos\Omega_2}{\cos\Omega_3-\cos\Omega_2}=-\frac{\sum M_I\cos\Omega_4-\sum M_{II}\cos\Omega_1}{\cos\Omega_4-\cos\Omega_1} \tag{11}$$

$$\frac{\gamma_{tb}}{\gamma_{gb}}=\frac{C_{AB}+C_{T_AB}}{2} \tag{12}$$

$$\frac{\sum M}{\gamma_{gb}}=\left|\frac{C_{AB}-C_{T_AB}}{2}\right| \tag{13}$$

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND NARRATIVE

Austenitic stainless steels (SS) are widely used for a variety of commercial applications *i.e.* piping and tubing components in nuclear reactors (especially hot water reactors) and refineries; and containers for storage and transport of nuclear and toxic waste. Thermomechanical processing, fabrication treatments, and handling along with operating conditions can produce strains and thermal conditions that initiate and accelerate microchemical and microstructural changes of the stainless steel components. In a corrosive environment, the microchemical and microstructural changes controlled by the grain boundaries present an occurring failure mechanism common in austenitic stainless steels known as stress corrosion cracking. An understanding of the vulnerability or susceptibility of the components to intergranular stress corrosion cracking is important for improvements and predictions of material reliability and performance during service.

Sensitization represents both a microstructural and a microchemical condition at an interface in stainless steels. Sensitization occurs due to the development of grain boundary or other interfacial chromium depletion (GBCD) zones. The depletion is induced by the precipitation of chromium-rich carbides on the grain boundaries or interfaces leaving the regions in and around the