UNIVERSITI TEKNOLOGI MARA

DETERMINATION AND MODIFICATION OF UNIFIED INELASTIC CONSTITUTIVE MODEL IN PREDICTING 95.5SN-4.0AG-0.5CU SOLDER MATERIAL RESPONSE

MOHD SYAFIQ AZFAR BIN RIZAMAN

Thesis submitted in fulfilment
of the requirements for the degree of
Master of Science
(Mechanical Engineering)

College of Engineering

October 2024

ABSTRACT

Accurately forecasting the mechanical properties of materials is crucial in the field of materials science and engineering. The Anand model, a renowned constitutive model for inelasticity, has proven to be valuable in describing the intricate deformation characteristics of materials. Nevertheless, it has been observed that the parameters of the Anand model may ineffectively represent the strain rate and temperature-dependent characteristics exhibited by certain materials, leading to discrepancies between the model's predictions and experimental findings. Literature study reveals that researchers have calculated varying values for the Anand model parameters when describing different SAC solders. Using Anand's inelastic constitutive model for SAC405 (95.5Sn-4.0Ag-0.5Cu) lead-free solder, the theoretical equations for the solder's uniaxial stress-strain response were obtained in this paper. The steps to obtain the parameters of Anand model using stress-strain were also determined. Nonlinear least squares fitting was employed to optimize the Anand parameters based on the experimental data. Data on uniaxial stress and strain at various temperatures (T = 298 K (25 °C), 323 K (50 °C), 348 K (75 °C), 373 K (100 °C), and 398 K (125 °C)) and strain rates ($\dot{\varepsilon}$ = 0.001 sec^{-1}, 0.0001 sec^{-1}, and 0.00001 sec^{-1}) was used to calculate the Anand parameters. The effects of temperature and strain rate on the model's predictions were thoroughly analysed, demonstrating their significant influence on the model's accuracy. To increase the capability of the model, 4 material parameters are screened to determine if the parameters are significantly affected by temperature and strain rate. The refined Anand model's accurateness (goodness of fit) with the modified parameters was assessed by comparing the model's findings to the original model and the observed stress-strain data. The modified Anand model consistently generated good predictions of the empirical data in all cases, across a wide range of temperatures and stress-strain levels. The goodness of fit values obtained were 99.38%, 98.67% and 98.40% for strain rate 0.001 sec^{-1}, 0.0001 sec^{-1} and 0.00001 sec^{-1} respectively.

ACTKNOWLEGDEMENT

In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulillah all praises to Allah for the strengths and His blessing in completing this thesis. This success and outcome of this thesis required a lot of guidance and assistance from many people and I extremely fortunate to have got this all along with the completion of this thesis. I cannot express enough thanks to my supervisor, Dr Ahmad Sufian bin Abdullah for their continued support and encouragement. I offer my sincere appreciation for the learning opportunities provided by my supervisor. I would like to acknowledge and give my warmest thanks to my lecturer Sir Aliff Farhan bin Mohd Yamin who made this work possible. His guidance and advice carried me through all the stages of writing my research proposal.

Special thanks are due to the Ministry of Higher Education for their financial support through the Fundamental Research Grant Scheme (FRGS), which enabled me to conduct the research, attend conferences, and disseminate findings, thereby enhancing the impact and reach of this research.

My parents are also an important inspiration for me. So, with due regards I express my gratitude to them. This accomplishment would not have been possible without them. Their kindness means a lot to me. I am indebted to my family for their unconditional love, encouragement, and understanding throughout this challenging yet rewarding journey. Their unwavering support has been a constant source of strength and motivation. Thank you so much.

I also want to thank my beloved friends that always stick together and help me when I am in need. Special thanks to Muhammad Farhan Bin Bardzan who have helped me with the research and collecting the data. Also, my gratitude to Muhammad Ikmal Bin Ahmad Tarmizi who helps me by giving ideas on how to complete the research. Million thanks to all my friends because they also helped me directly or indirectly in completing the project. They always give me ideas and comments on my research so that I can improve many ways possible.

Last but not least, I express my heartfelt gratitude to all individuals, organizations, and entities who have contributed in any capacity to the completion of this thesis. Your support and encouragement have been indispensable, and I am truly grateful for the role you have played in this achievement.

TABLE OF CONTENTS

CONFIRMATION BY PANEL OF EXAMINERS	**ii**
AUTHOR'S DECLARATION	**iii**
ABSTRACT	**iv**
ACTKNOWLEGDEMENT	**v**
TABLE OF CONTENTS	**vi**
LIST OF TABLES	**ix**
LIST OF FIGURES	**xi**
CHAPTER ONE: INTRODUCTION	**1**
1.1 Project Background	1
1.2 Problem Statement	5
1.3 Research Questions	8
1.4 Objectives	8
1.5 Scope of Work	9
1.6 Expected Significant Contribution	10
CHAPTER TWO: LITERATURE REVIEW	**11**
2.1 Introduction	11
2.1.1 Anand Model	12
2.1.2 Lead Free Solder	14
2.1.3 SAC405 Solders	16
2.1.4 Creep Mechanics	18
2.2 Anand Inelastic Constitutive Model	20

CHAPTER 1
INTRODUCTION

1.1 Project Background

Elasticity is the capacity of a material to resist deformation and regain its original form after the deforming force is withdrawn. Solid objects will undergo deformation under sufficient weight. If the material is elastic, the object will return to its original shape and size upon removal [1]. Inelasticity happens when an object does not return to its original shape and remains in a deformed state [2]. The physical causes of elastic behaviours can vary significantly depending on the material. When stresses are exerted on metals, the atomic lattice undergoes changes in size and shape as energy is introduced into the system. The lattice reverts to its initial lower energy state once external stresses are removed [3].

Solder, like many solid materials, displays varying degrees of elastic behaviour. There is a maximum force and deformation range for each material within which elastic recovery can occur. The limit being referred to is the elastic limit, which signifies the greatest stress or force per unit area that a solid material can withstand before deformation begins [4]. A material will yield when subjected to stresses that are greater than its elastic limit. The elastic limit denotes the transition point between the elastic and the plastic phases. In the case of the vast majority of brittle materials, stresses in excess of the elastic limit led to fracture with almost no plastic deformation [5].

Solder, a fusible metal alloy, is utilised to create a lasting connection between metal workpieces. Solder is melted to bond and connect components after they have cooled, requiring a solder alloy with a lower melting point than the pieces being joined. The solder should possess resistance to oxidative and corrosive influences to prevent deterioration of the connection over time [6]. The solder utilised for creating electrical connections must possess favourable electrical characteristics. Soldering is the process