STRENGTH VARIATION OF PRE-STRAINED (TRANSVERSE COMPRESSIVE) ALUMINIUM ALLOY DUE TO ISOCHRONAL ANNEALING

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ABSTRACT

This thesis deals with strength variation of pre-strained (transverse compression) Al-Mg alloy sheets due to isochronal annealing which is to simulate the conditions of after paint bake cycle of Al-Mg alloy automotive Body-In-White by influenced of pre-straining. The objective of this thesis is to investigate the influences of the varied annealing heat treatment temperatures (175°C, 200°C, and 225°C) and different amount of pre-straining (transverse compression at 10%, 15%, 20% and 25%) which causes the softening behaviour of the material. The materials used in this thesis are Al-Mg alloy sheets of AA1100, AA5052 and AA5083 which are usually used to build vehicle structure. 10mm×10mm rectangular piece specimens were prepared to undergo full annealing (300°C for 1 hour) before the compression test at varied percentage and then annealed again at the different assigned temperatures. The second compression is done to obtain the results of the amount of softening at varied temperature and percentage of transverse compression. The results where the softening behaviour were characterized can also be used as guidance to improve the available facilities, thus, helpful reference for future usage in order to achieve the hypotheses result of this thesis.

ABSTRAK

Tesis ini berurusan dengan variasi kekuatan pra-tegang (mampatan melintang) kepingan Al-Mg aloi disebabkan oleh penyepuhlindapan bermasa untuk mensimulasi keadaan kitaran selepas pembakaran cat automotif *Body-In-White* Al-Mg aloi yang didorong oleh pra-tegang. Objektif tesis ini adalah untuk menyiasat pengaruh-pengaruh kepelbagaian suhu rawatan haba penyepuhlindapan (175°C, 200°C, dan 225°C) dan jumlah pra-tegang berlainan (mampatan melintang pada 10%, 15%, 20% dan 25%) yang menyebabkan sifat pelembutan bahan. Bahan-bahan yang digunakan dalam tesis ini adalah kepingan-kepingan Al-Mg aloi AA1100, AA5052 dan AA5083 yang biasanya diaplikasikan dalam pembuatan badan kenderaan pengangkutan. Spesimen- spesimen berukuran 10mm × 10mm segi empat tepat disediakan untuk menjalani penyepuhlindapan (300°C selama 1 jam) bertujuan pelembutan sebelum melalui ujian mampatan pada pelbagai peratusan dan kemudian disepuh lindap sekali lagi pada suhu berbeza yang telah ditetapkan. Mampatan kedua adalah dibuat untuk mendapatkan hasil-hasil daripada jumlah pelembutan akibat kepelbagaian suhu dan peratusan mampatan melintang. Hasil ujian yang menggambarkan sifat pelembutan juga boleh digunakan sebagai panduan untuk meningkatkan kemudahan-kemudahan yang sedia ada disamping menjadi rujukan di masa depan bagi mencapai hipotesis dalam tesis ini.

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NOMENCLATURE

Symbol Description

A	Current cross-sectional area
A_0	Initial cross-sectional area
F	Load
h_f	Final height
h_o	Initial height
S	Engineering stress
T	Temperature
T_m	Absolute melting temperature
ε	Engineering strain
σ	Engineering stress
σ_y	Yield strength

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Title

Strength Variation of Pre-strained (transverse compressive) Aluminium Alloy Due To Isochronal Annealing.

1.2 Aim

To investigate the factor of softening behaviour of annealed Al-Mg alloy sheet subjected to compressive load and suggest solution to overcome the problem.

1.3 Objectives

To investigate the effect of annealing heat treatment at 30 minutes and varies of temperatures(175 °C , 200 °C , and 225 °C) and pre-straining influence on softening behaviour during paint bake cycle after transverse direction compression.

1.4 Project Scope

i) Carry out study on heat treatment process and pre-straining of the non-heat treatable Aluminium alloy.

ii) The project is limited to the usage of wrought aluminium.

iii) The compressive strain is induced in the sheet transverse direction only.

1.5 Project Background

There is a growing demand to reduce the weight of vehicles in order to minimise energy consumption and air pollution. To accomplish this weight reduction, the "Body In White (BIW)" could be made of aluminium alloy sheet, which has a better strength to weight ratio than traditionally used low carbon steel. The formability of aluminium alloy is good relative to low carbon steel and it has good corrosion resistance.

The alloying elements increase the strength without significantly increasing the weight. Al-Mg 5XXX alloy have the highest formability. However, the yield strength decreases during the paint bake cycle which is carried out at 175°C for 30 minutes. This is due to the diffusivity of the Mg atoms, which allow easy rearrangement of dislocation accumulated during forming process. Furthermore, the high level of stored energy from the work hardening provides a large driving force for the thermal recovery and softening.

This project will investigate thoroughly the softening behaviour of pre-strained Al-Mg 5XXX alloy subjected to paint bake treatment by investigating the mechanical behaviour of these alloys using transverse compression.

1.6 Gantt Chart FYP1

PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
Meeting with supervisor	▲	▲														
Search material and equipment for training		▲														
Get equipment approval			▲													
Project title, background, and scope checked by supervisor			▲													
Submit log book			▲	▲	▲	▲	▲	▲	▲	▲	▲	▲				
Submit project title, background and scope to faculty				▲												
Experimental training and report of result			▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	
Prepare the materials to be presented internally to Supervisor			▲	▲	▲	▲										
Internal presentation							▲									
Presentation preparation			▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲			
Submit log book together with first draft												▲				
Submit 5 pages summary report												▲				
FYP1 presentation														▲	▲	▲

1.7 Gantt Chart FYP2

PROJECT ACTIVITIES	W 1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17
Preparing specimens	▲	▲	▲														
Full annealing of specimens (300°C, 1 hour)			▲														
Testing the methodology			▲														
Compression test and annealing process			▲	▲	▲	▲											
Submit log book every meeting		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲					
Discussion of results and error											▲	▲					
Rewrite of thesis							▲	▲	▲	▲	▲	▲	▲	▲	▲		
Presentation preparation															▲	▲	
Submit the full thesis																▲	
FYP2 Presentation																▲	
Correction of thesis and hard bounding																▲	▲

1.8 Overall Project Flow Chart

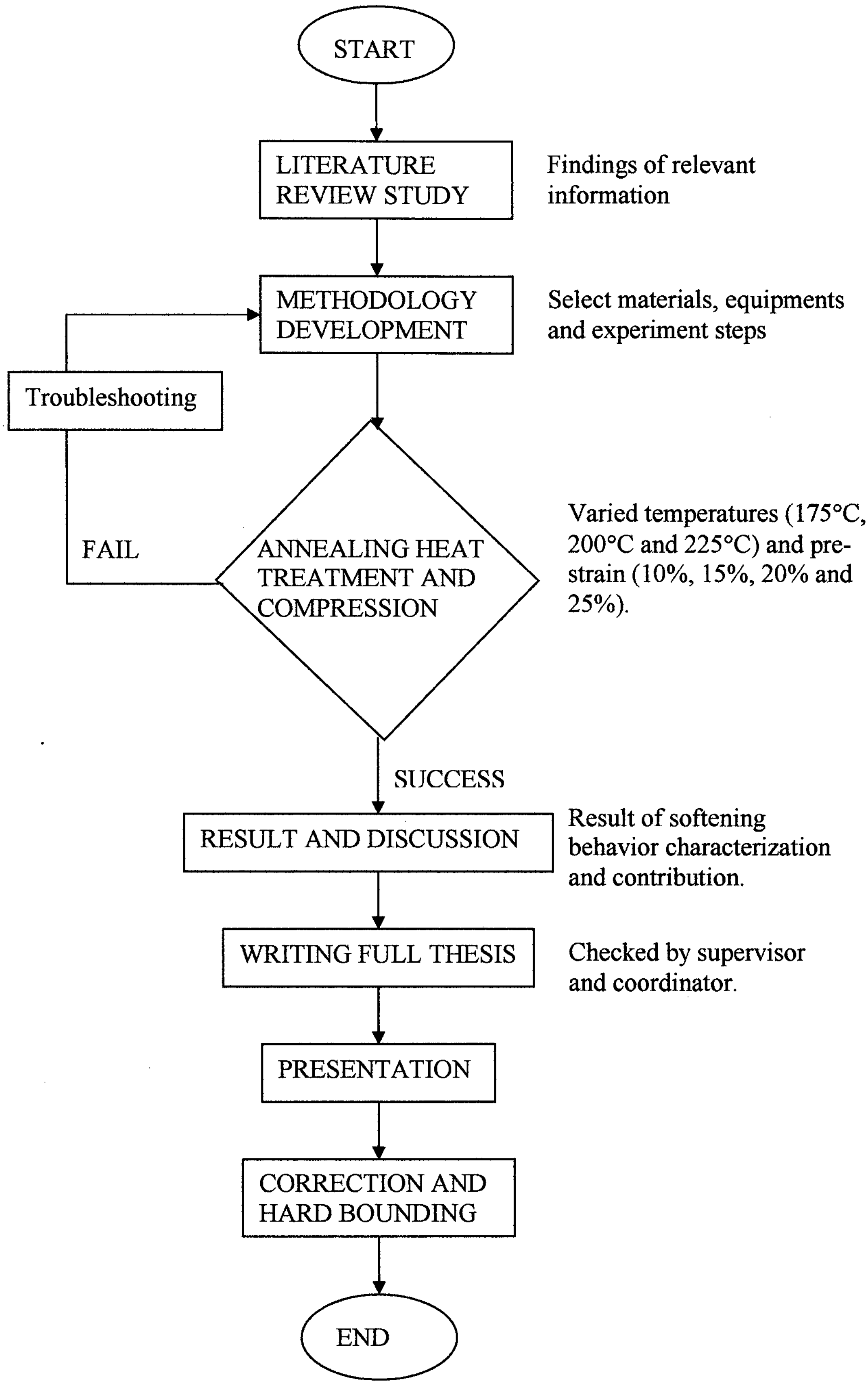

Figure 1.1 Flow chart of overall project activities.

CHAPTER 2

LITERATURE REVIEW

2.1) Aluminium Alloy

Aluminium alloys are produced in the usual flat rolled sheet and plate, in tube, rod, wire, and bar forms, as well as castings, forgings and stampings [1].

Pure aluminium is too soft to be of structural value, hence, the aluminium used in industry normally contain alloying elements. The alloying elements increase the strength without significantly increasing the weight. It also improved the machinability, weldability, surface appearance and corrosion resistance can be obtained by adding appropriate elements. The major alloying additions for aluminium are copper, silicon, magnesium, manganese and zinc [2, 3]. The composition is designated by a four digit number that indicates the principal impurities, see Table 2.1.

Table 2.1: Aluminium alloys and their principal impurities [4].

ALLOY	MAJOR ALLOYING ELEMENT
1XXX	Aluminium > 99%
2XXX	Copper
3XXX	Manganese
4XXX	Silicon
5XXX	Magnesium
6XXX	Magnesium and Silicon
7XXX	Zinc
8XXX	Other

Under normal processing conditions, the formability of aluminium sheet is lower than of deep drawing steel. This means that aluminium can withstand less deformation than deep drawing steel before failure occurs on the production process. Of all aluminium alloys, aluminium magnesium alloys (AA5XXX alloys) have the highest formability [5].

2.2 Wrought Aluminium

2.2.1 Non-Heat-Treatable

In the non-heat-treatable type, strengthening is achieved by strain hardening, which may be augmented by solid solution and dispersion hardening. Alloys of AA1XXX series have relatively low strength as the series are essentially pure aluminium with minimum 99% aluminium content by weight and can be work hardened. Alloys of AA3XXX series have the same desirable properties as those of AA1XXX series but with higher strength. Magnesium added to some alloys in this series provides additional strength, but the amount is low enough that the alloys still behave like those with manganese alone than like the stronger Al-Mg alloys of the AA5XXX series [1]. Their properties are controlled by strain hardening, solid-solution strengthening, and grain-size control. However, because the solubility of the alloying elements in aluminium is small at room temperature, the degree of solid-solution strengthening is limited [6].

The strongest non-heat-treatable alloys are those of the AA5XXX series, and in most products they are more economical than alloys of the AA1XXX and AA3XXX series in terms of strength per unit cost. Magnesium is one of the most soluble elements on aluminium and, when dissolved at an elevated temperature, it is largely in solution at lower temperatures, even though its equilibrium solubility is greatly exceeded [1]. As the major alloying element in the AA5xxx series of alloys, its maximum solid solubility in aluminum is 17.4%, but the magnesium content in current wrought alloys does not exceed 5.5%. The addition of magnesium markedly increases the strength of aluminum without unduly decreasing the ductility. Corrosion resistance and weldability are good [7]. It produces considerable solution hardening. Additional strength is produced by strain hardening [1].

2.2.2 Heat-Treatable

Wrought alloys that respond to strengthening by heat treatment are covered by three series AA2XXX, AA6XXX and AA7XXX series. All depend on age-hardening to develop enhanced strength properties and they can be classified into two group: those that have medium strength and are readily weldable (AA2XXX and AA7XXX series), and the high-strength alloys that have been developed primarily for aircraft construction (AA2XXX and AA7XXX series) [1]. Duralumin (also called duraluminum, duraluminium or dural) is the name of one of the earliest types of age-harden aluminium alloys. The main alloying constituents are copper, manganese and magnesium. A commonly used modern equivalent of this alloy type is AA2024, which contains (in wt.%) 4.4% copper, 1.5% magnesium and 0.6% manganese. Typical yield strength is 450 MPa, with variations depending on the composition and temper [8].

AA4XXX series are alloyed with silicon. They are also known as silumin[1] . Silumin is a series of lightweight, high-strength aluminium alloys with silicon content between 4% and 22%. Among the advantages of silumin is its high resistance to corrosion, making it useful in humid environments. The addition of silicon to aluminium also makes it more fluid when liquid, which together with its low cost (both component elements are relatively cheap to extract), makes it a very good casting alloy [9]. AA6XXX series are alloyed with magnesium and silicon, are easy to machine, and can be precipitation hardened, but not to the high strengths of that AA2XXX, AA5XXX and AA7XXX series can reach. AA7XXX series are alloyed with zinc, and can be precipitation hardened to the highest strengths of any aluminium alloys. AA8XXX series are a miscellaneous category [1].

2.3 Strength Mechanism

2.3.1 Work Hardening

During cold working, dislocations multiply and interact, leading to an increase in the strength of the metal [10]. Strain hardening (work hardening) is the reason for the elastic recovery. The reason for strain hardening is that the dislocation density increases with plastic deformation (cold work) due to multiplication. The average distance between dislocations then decreases and dislocations start blocking the motion of each one. Thus, this increases the strength of metal [11].

2.3.2 Precipitation Hardening

Precipitation hardening is a heat treatment process used to produce a mixture of uniformly distributed hard phases in a soft matrix. The precipitated phase interferes with the movement of dislocations and as a result, strengthens the alloy. Heat treatment sequences are solution heat treatment, quenching and aging. [10]

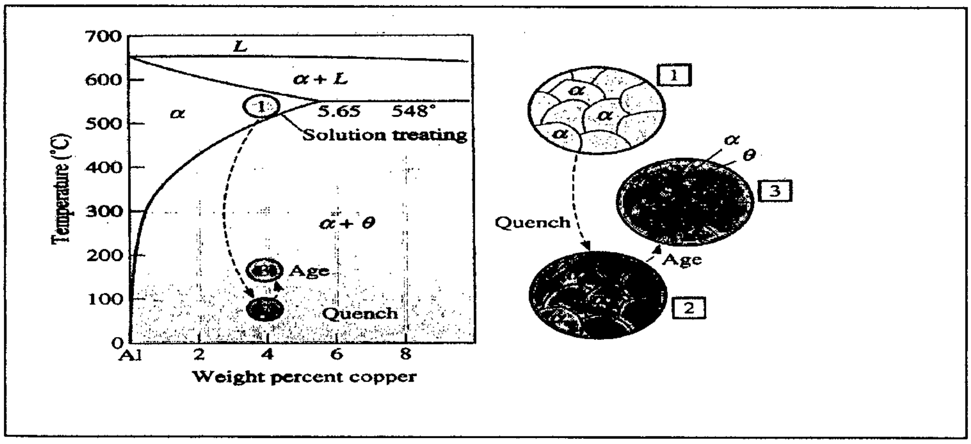

Figure 2.1: The aluminium rich end of the aluminium-copper phase diagram showing the three steps in the age hardening heat treatment and the microstructures that are produced [6].

2.3.3 Solid-Solution Strengthening

Another method of strengthening a metal is by addition of one or more elements to a metal which can strengthen it by the formation of solid solution. The impurity atoms cause lattice strain which can prevent dislocations from moving through a metal lattice when the atoms are different in size and electrical characteristics, as is the case with solid solutions [6]. This occurs when the strain caused by the alloying element compensates that of the dislocation, thus achieving a state of low potential energy. It costs strain energy for the dislocation to move away from this state (which is like a potential well). The scarcity of energy at low temperatures is why slip is hindered [11].

2.4 Material Selection

For training purpose, the specimens we are using are AA1100-H14 aluminium alloy sheet, a half hardened. It has low strength but very workable alloy with excellent corrosion resistance. It is not heat treatable. It is easily welded, however it is soft, and spalls or chipped off when machined. For actual experiment we are provided with AA5083-H32 and AA5052-H32 aluminium alloy sheets. For comparison, AA1100-H14 is also used.

2.4.1 Alloy AA5052 [12]

Classified as wrought aluminium alloy; strong, not heat treatable, easily welded, with excellent corrosion characteristics.

a) **AA5052-O**: Annealed (or "soft", bendable condition)
b) **AA5052-H32**: Strain-hardened and stabilized

2.4.2 Alloy AA5083 [12]

Aluminium AA5083 is known for exceptional performance in extreme environments. AA5083 is highly resistant to attack by both seawater and industrial chemical environments and commonly used for pressure vessels and road transport application below 65°C, shipbuilding, mining man cages and ore skips [13]. Alloy 5083 also retains exceptional strength after welding. It has the highest strength of the non-heat treatable alloys but is not recommended for use in temperatures in excess of 65°C. Alloy AA5083 is generally supplied as a flat rolled product in plate form. The most common tempers for AA5083 aluminium are:

a) 0 – Annealed wrought alloy
b) H111 – Some work hardening imparted by shaping processes but less than required for a H11 temper.
c) H32 –The first suffix digit with number 3 indicates that the alloy is cold-worked and stabilized. The second suffix digit indicates it is stabilized with a quarter hard tempers.

2.4.3 Chemical Composition

As we can see from the Table 2.2, AA1100 only contain copper as its alloying element. The effects of copper addition can be reviewed from the next table, Table 2.3 which explaining the effects of adding any of other alloying elements in aluminium. For AA5052 and AA5083, the highest alloying element is Mg and it is less than 5.5%.

Table 2.2: Typical chemical composition for aluminium alloys AA5052, AA5083 and AA1100.

Alloying elements	AA5052[14]	AA5083[15]	AA1100[16]
Si	0.25%	0.4%	-
Fe	0.4%	0.4%	-
Cu	0.1%	0.1%	0.05%-0.20%
Mn	0.1%	0.4%-1.0%	-
Mg	2.2%-2.8%	4.0%-4.9%	-
Zn	0.1%	0.25%	-
Ti	-	0.15%	-
Cr	0.25%	0.05%-0.25%	-