Analysis of low cycle fatigue in titanium materials 15-3-3-3

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Abstract. Microstructure changes of the properties of welded material effects the strength of the welds resulting in cracks and fractures in the weld joints. The 15-3-3-3 titanium alloy has excellent formability and is also cost effective in the fabrication process when compared to any other type materials. Low cycle fatigue is the dominant failure in titanium materials, requiring consideration of the design and analysis of material life. Low cycle fatigue test performed on tig welding of plate-shaped titanium material. Cyclic hardening causes an increase in the peak stress with the cycle, while cyclic softening results in decreasing the seek rate with the cycle. Cyclic loading which produces plastic strain is described as more complex and forms a hysteresis loop. Analysis of the hysteresis loop needs to analyze the stress distributions using the raindrop method in order to obtain a hysteresis loop pattern. The hysteresis loops consistently show the behavior of the material. Hysteresis loop were analyzed to study the LCF property. Titanium material exhibits toughness from the start of the cycle to the end of the cycle. Second before the ‘material failure’ happens, it doesn’t show any drastic decrease in quality in the term of toughness.

Keywords: LCF, hysteresis loop, titanium 15-3-3-3, stress cycle, raindrop stress distribution

1. Introduction
Recently, composite structures of dissimilar metals were gradually appreciated in national defense and civil industrial fields, such as aeronautics and astronautics, energy and electric power industry. Composite components of titanium alloy and steel can fully exert the advantages of these two materials simultaneously. Partial replacement of steel components by titanium alloy will become an important approach to reduce mass of spacecrafts [1]. The greater the stress that occurs, the lower the guarantee of safety and the greater the deflection [2]. A material when loaded repeatedly would under normal circumstances degrade its capability to support further load by breaking or reducing its static strength. This process implies that a material possesses a limit to what it can sustain. The restoration of its loss capability to resist load, however, requires the application of energy that would exceed the amount used in the strength degradation process [3].

Fatigue can cause progressive and localized structural damage that occurs when a material is cyclically loaded [4]. Failure due to fatigue is a fracture mechanism that can be identified by three processes, namely initiation crack, crack propagation and the final stage is final fracture [5] In several cases, welded connections are subject to repeated loading, which may lead to fatigue...
failure. Most fatigue failures have been documented in the high-cycle fatigue regime, associated with a large number of loading cycles [6]. However, under extreme loading conditions, large elastic–plastic strains may develop, characterized by repeated excursions in the inelastic range of the material, causing low-cycle fatigue, under a relatively low number of load cycles [7]. This study aims to see the impact of a relatively low loading on each cycle. Using experimental and numerical values, the relationship between the strain around the weld and the number of cycles corresponding to failure is determined to develop a low cycle fatigue curve, to be used for efficient fatigue assessment.

2. Methods and materials
In this study, the experiment was conducted using a specimen of a plate-shaped titanium alloy. The chemical composition of titanium 15-3-3-3 is Ti76, V15, Al3, Cr3 and Sn3. In the welding process, this material is welded using tungsten inert gas welding or so-called tig welding. Controlling the preheating temperature and the interpass temperature can ensure the quality of the welding [8].

Low cycle fatigue analysis is carried out along the axial direction of the weld. Low cycle fatigue specimens were formed according to ASTM E466-07 [9] with an hourglass shape (Figure 1). Specimens are cut from the center of the weld joint along the axial direction in order to accurately divide the weld joint. Tests were carried out with the air under fully reversed mode, control mode, total axial strain control using symmetrical triangular axial strain time waves [10]. Tests are carried out using the MTS Landmark servo hydraulic machine and the test results will be known through the MTS Test Suite software. setup parameter of maximum force 4.0 kN, minimum force of 0.4 kN, frequency of 20.0 Hz, and cycle increments of 100,000 cycles.

![Figure 1. Fatigue test specimen](image)

3. Results and discussion
The comparative variation is taken from the total cycle of testing as the independent variable in this study, where the test results are drawn at the starting middle and end points of the test where each point is taken 10 cycles each.

3.1 Cyclic stress
The basic factors which cause fatigue: stress fluctuations are large enough, the value of the maximum tensile stress is high, and the stress cycle applied is quite large[11]. Fully reversed stress cycle where the maximum and minimum stresses are the same, this graph is generally used in testing [12]. In loop hysteresis analysis, it is necessary to first analyze the stress distribution using the raindrop method to get the hysteresis loop pattern. Figure 2-4 below is the result of raindrop stress distribution modeling at three fatigue test points that have been carried out consecutively in cycle 1-10 (point 1), cycle 55810-55820 (point 2), and cycle 111605-111615 (point 3).
### 3.2 Hysteresis Loops

![Figure 1](attachment:image.png)

**Figure 1.** a) Cyclic stress, b) Raindrop distribution, c) Hysterisis loop, on cycle 1-10

Cyclic loading, which produces plastic strain, is described as more complex, forms a hysteresis loop. Each number of hysteresis curves (s vs e) (first cycle, ½ total cycles and last cycle) is used to study LCF property [13]. The stress-strain response during the cycle can change, largely depending on the initial conditions of the metal. Metals can undergo cyclic strain hardening, cyclic strain softening, or remain stable. Cyclic hardening causes an increase in the peak stress with increasing cycles, while cyclic softening results in decreasing the level of tension as the cycle increases. In general, strong metals tend to undergo cyclic softening, and low strength metals tend to undergo cyclic hardening.
Figure 2. a) Cyclic stress, b) Raindrop distribution, c) Hysterisis loop, on cycle 55810-55820
4. Conclusions

The response to the cyclic stress of the titanium material 15-3-3-3 is very stable to the end point. The stress distribution using the raindrop method is the beginning process to create a pattern in the hysteresis loop in the low cycle fatigue analysis. The hysteresis loop, which is described by points 1 (initial), 2 (middle), and 3 (end), there are some changes at the process but is not quite large. The pattern of the hysteresis loop at the end point before the failure of the material did not experience a decrease in strength in the material. These results can be stated that the 15-3-3-3 titanium material is very tough in withstanding low cycle fatigue loads.

5. References

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