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Defect Analysis and Fatigue Design Basis for Ni-based Superalloy 718 manufactured by Additive Manufacturing

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Abstract

It is well known that high strength metallic materials with Vickers hardness *HV*>400 are very sensitive to small defects. This paper discusses fatigue properties of a Ni-based Superalloy 718 with *HV*=~470 which was manufactured by additive manufacturing (AM). The advantage of AM has been emphasized as the potential application to high strength or hard steels which are difficult to manufacture by traditional machining to complex shapes. However, the disadvantage or challenge of AM has been pointed out due to defects which are inevitably contained in the manufacturing process.

Defects of the material investigated in this study were mostly gas porosity and those made by lack of fusion. The √area parameter model was confirmed the successful application. Although the statistics of extremes analysis is useful for the quality control of AM, the particular surface effect on the effective value of defect size must be carefully considered. Since the orientations of defects in AM materials are random, a defect in contact with specimen surface has higher influence and has the effective larger size termed as $\sqrt{area}_{\rm eff}$ than the real size, $\sqrt{area}$, of the defect from the viewpoint of fracture mechanics. The guide for the fatigue design and development of higher quality Ni-based Superalloy 718 by AM processing based on the combination of the statistics of extremes on defects and the √area parameter model is proposed.

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1. Introduction

The advantage of AM has been emphasized as the potential application to high strength or hard steels which are difficult and costly to manufacture by traditional machining to complex shapes. However, the disadvantage or challenge of AM has been pointed out due to defects which are inevitably contained in the manufacturing process and detrimental to fatigue strength.

Many literature on fatigue properties of AM materials have been published in recent years. The review paper by Berreta, S and Roman, S (2017) gives a detailed and thorough analysis on the fundamental problems to be studied on AM materials. Günther, J. et als. (2017) carried out precise experimental observations on Ti-6Al-4V in high cycle fatigue and very high cycle fatigue and based on the observation they discussed the problem from the viewpoint of statistical scatter of defect size. They pointed out the problem raised by the interaction between defects and specimen surface.

This paper discusses fatigue properties of a Ni-based Superalloy 718 manufactured by AM in terms of the effect of defects. The guide for the fatigue design and development of high quality Ni-based Superalloy 718 by AM processing will be presented based on the combination of the statistics of extremes on defects and the √area parameter model.

2. Material, Specimen and Experimental method

The material was made by AM processes, Selective Laser Melting (SLM) method. Solution treatment is based on AMS5663. Specimens were machined from the two kind of raw plate materials, denoted by A and B, produced by AM. Specimens were cut in two directions, i.e. as-built direction (L direction) and perpendicular (T direction) to as-built direction as shown in Fig. 1 (Case for Material A and similarly for Material B). Figure 2 shows the shape and dimension of specimen. The mechanical properties were measured by using the fatigue specimens. The 0.2% proof stress ranged from 1227MPa to 1329MPa and the ultimate tensile strength ranged from 1306MPa to 1499MPa. The elongation with 8mm gauge length ranged from 13.6% to 31.8% and the reduction area from 8.6% to 30.7%. It was revealed by observation of fracture surfaces that the scatter of the mechanical properties were caused by various defects contained in specimens. Specimen surface was polished by emery paper with #600. The remaining materials of Fig.1 after cutting specimens were used to investigate the microstructure and statistical distribution of defects.

The analysis of statistics of extremes was applied to the largest defects observed on 9 sections with the observation area S_0 = 80.97mm^2 for Material A and S_0 = 116.49mm^2 for Material B. The largest defects were separately analysed on pores, linear defects and equivalent elliptical defects for interactive adjacent defects. The Vickers hardness HV (P=5kgf) was measured at 5 points. HV=465±1.7% for A-T and HV=474±1.2% for B-T. Tension compression fatigue tests were carried out with hydraulic tension-compression testing machine at 30Hz with strict specimen alignment within ±5% for the values of 4 strain gauges attached to each specimen at ±500με and ±1000με. The fatigue fracture origins were mostly at defects.

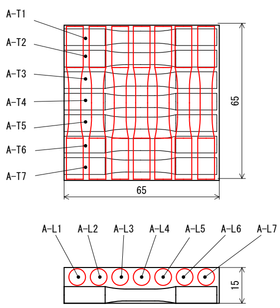

Fig. 1 Raw plate material (Material A) and cutting layout for specimens

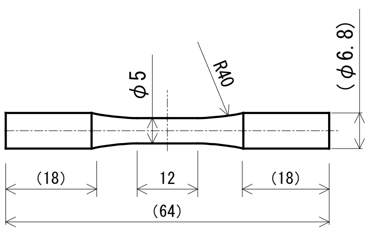

Fig. 2 Shape and dimension of tension-compression specimen