Expérimental Investigation of Fatigue Life Cycle Behaviour of Austenitic SS 316L

Amit kaimkuriya[1*], *Kirti* Chaware[2], *Yashwant* Singh Chandel[3], *Nitish* Kumar Singh[4], *Pankaj* Singh[5]

[1]Department of Mechanical Engineering, Bansal Institute of Research Technology and Science, Bhopal, M.P.
[2]Department of Mechanical Engineering, Mittal Institute Technology, Bhopal, M.P.
[3]Department of Basic Science, Bansal Institute of Research Technology and Science, Bhopal, M.P.
[4] School of Engineering & Technology, Vivek University, Bijnor,Uttar Pradesh
[5] Design Infinity, Bhopal, M.P.

Abstract. In this paper the fatigue life of 316L stainless steel through detailed experimental investigation has been carried out. The fatigue test performed for the mechanical testing and microstructural characterization. The rotary bending machines is used to find the cycle with a load ratio R = 0.1. The Specimens were tested under constant load, but load varied for different specimens to check the life cycle. S-N curve comparison shows the relationship between stress and number of cycle. Furthermore the fracture surfaces of the failed specimens were analysed using SEM to identify the sequence of damage evolution. It is revealed distinct zones associated with crack initiation at firstly surface voids, subsequent propagation through the microstructure, and final rupture. Overall, the experimental findings indicate that the fatigue limit of the material is approximately 140.40 MPa.

1 Introduction

Fatigue is the failure of materials due to repeated loading [1]. It has three stages i.e. crack initiation, crack growth and rupture under the stress [2]. Fatigue is a primary life limiting factor for structural components tested for varying stresses condition [3], with defects commonly arising during manufacturing, assembly, repair, or maintenance. In previous research works researcher found that the stress-life (S-N) curves to create prediction models for high cycle fatigue (HCF) [2]. Researchers found that microstructural elements like solute content, secondary phase volume, and grain size have a significant impact on HCF [3]. In the meantime, a number of studies have looked at the modes of fatigue crack initiation and propagation that cause component failure [4–6]. It was observed that failures frequently start at surface geometrical discontinuities under low cycle fatigue; with creep-fatigue-environment interactions further accelerating crack growth [7].

---

* Corresponding author: amitkaimkuriyabgi@gmail.com

When designing cylindrical components which are subjected to varying loads, life prediction of 316L stainless steel is essential. Nevertheless, compared to more straightforward plate structures, little research has been done on the fatigue mechanisms of cylindrical geometries. The purpose of this study is to describe the fatigue life of austenitic 316L stainless steel at room temperature under varying load. This paper has five sections: introduction, material, and method. The third is an experimental approach, followed by factographic characterization, results, analysis, and conclusion.

2 Materials and Method

This study utilized austenitic 316L stainless steel, with its chemical composition detailed in Table 1. The mechanical properties of the hourglass-shaped specimens are summarized in Table 2. Tubular samples were provided by Y & N metals Mumbai and manufactured in compliance with ASTM guidelines. Fatigue testing was performed in the rotary direction, and the specimen design is shown in Fig. 2.

Table 1. Chemical compositions of Type 316L stainless steel

Elements	Cu	Ni	Cr	Mn	P	S	Si	Mo	N
Composition	0.020	11.21	17.38	1.86	0.027	0.0054	0.51	2.36	0.038

3 Experiment

Fatigue tests were performed using a rotary fatigue testing machine as shown in fig.1. SS316 L Specimen as shown in fig. 2 were firmly clamped and exposed to cyclic loading under controlled conditions until failure occurred. The machine applied a constant bending stress while rotating the specimen at a consistent speed to simulate repeated load cycles. Throughout the test, critical parameters such as stress amplitude, loading frequency, and the number of cycles to failure were monitored to assess fatigue behavior. Figure shows the specimen undergoing fatigue test on rotary bending fatigue test machine.

Fig. 1 Fatigue testing machine

Fig. 2 Specimen of SS316 L for Rotary bending test

4 Experiments Results and Discussion

In this study, samples were exposed to varying repeated loads to investigate fatigue behavior. Table 2 presents the number of cycles each specimen withstood before failure. Seven different combinations of mean and alternating stress levels under tensile loading were analyzed to predict material lifespan under fluctuating conditions. Plotting alternating stress against the number of cycles to failure revealed a clear trend: higher stress levels significantly reduced the material's fatigue life compared to lower stresses.

Table 2. Stainless Steel Type 316L in term of Number of Cycles.

Load Ratio (R)	**Stress Amplitude (MPa),** σ_a	**Life (Cycles)** $2N_f$
0.1	280.00	3,528
	300.93	15,345
	275.20	56,488
	230.33	160,935
	210.10	440,446
	175.12	1,024,847
	165.68	4,945,385
	140.40	6,783,753

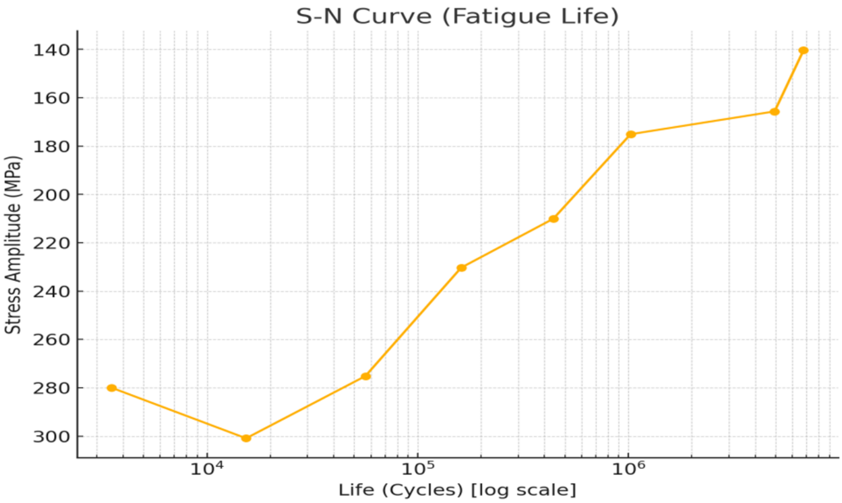

Fig. 3 S – N Curve

A data acquisition system was used to gather fatigue data at different levels of stress. Figure 3 shows these results as an S-N curve. The graph clearly shows that the fatigue life and the load are related in the opposite way: as the load increases, the number of cycles to failure goes down. These results are consistent with previous research [9], which indicated that Type 316L stainless steel demonstrates cyclic hardening behavior under repeated loading conditions.

For quantitave characterization of the fatigue response a power law model has been used. The general expression for this relationship is given by:

$$y = ax^b \quad \text{----------------(1)}$$

Specifically, the fatigue behavior was modeled using the Basquin relation:

$$S_s = S'_f (2N_f)^b \quad \text{---------------------(2)}$$

Where S_a denotes the stress amplitude, S'_f represents the fatigue strength coefficient, and b is the fatigue strength exponent. The findings demonstrate that 316L stainless steel initially experiences cyclic hardening during the initial phases of loading at ambient temperature, subsequently transitioning to softening with on-going cyclic exposure [7].

Experimental observations demonstrated that the applied stress under diverse conditions within the fatigue endurance domain results in a substantial decrease in fatigue life. The stress amplitudes in the low-cycle fatigue range, which includes cycles between 10^3 and 10^4, were between 300.93 MPa and 280.00 MPa. The fatigue lives were between 3,528 and 15,345 cycles. These short fatigue lives show how weak the material is when it is under a lot of stress, especially in dangerous or important situations.

On the other hand, the material showed high-cycle fatigue behaviour after 10^5 cycles, with fatigue lives between 56,488 and 6,783,753 cycles. This shows better durability under less stressful circumstances. In order to maintain reliability, components that endure more than a million cycles are typically scheduled for replacement. Specimens that went through more than a million cycles without failing are shown by arrows in the S-N curve.

The fatigue limit for Type 316L stainless steel was determined by analyzing the S-N curve. The material's endurance threshold under the tested conditions was confirmed when the fatigue limit was discovered to be roughly 140.40 MPa, which corresponds to a fatigue life of 6,783,753 cycles.

5 Fracture Surface Morphology and Damage Evolution

Fracture surface morphology is utilized to know the behaviour of crack propagation. Scanning electron microscope machine is utilized for fracture surface detection. Fig. 4 shows the SEM images. It represents the sequence of damage evolution during fatigue loading. The distinct regions associated with the initiation, propagation, and final rupture of the specimen.

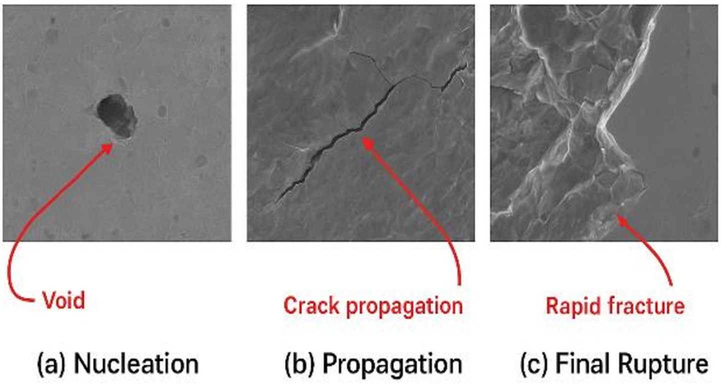

Fig. 4 Fracture Surface Morphology.

In Fig. 4(a) a single dominant void on the material's surface represents the early stage of failure. Under cyclic loading, these voids frequently act as stress concentrators and preferential locations for the nucleation of cracks. The material had not yet experienced significant plastic deformation, as evidenced by the smooth surrounding surface.

The subsequent stage, where the initiated crack starts to spread throughout the microstructure, is depicted in Fig. 4(b). Early-stage fatigue crack propagation is characterized by the relatively sharp and continuous morphology of the crack path in this area. Localized slip activity, which directs the crack along energetically advantageous paths within the material, is suggested by the surface texture.

Figure 4(c) depicts the last stage of failure, where a region of rapid and unstable crack growth is visible on the fracture surface. After the crack reaches a critical length, this zone is characterized by a rough and highly irregular morphology that suggests abrupt brittle-like separation. The material underwent a transition from stable fatigue crack growth to catastrophic failure, as confirmed by the microstructural tearing patterns.

6 Conclusion

The fatigue life cycle of SS316L tested under Rotary bending tests. From experimental results it is found that the specimens exposed to lower stresses show a noticeably longer operating life. It means that high stress increases the chances of failure. The fatigue limit of

SS316L was found to be roughly 140.40 MPa within this range, which corresponds to a life of 6,783,753 cycles.

Fracture surface analysis validate that the HCF lower the fatigue life under repetitive loading, which provided valuable insight that how material behave under HCF. SEM investigation shows the sequence of the fracture i.e. first void on the surface which shows the surface imperfection followed by crack growth or crak propagation and the final is rupture of a specimen, marked by the presence of mixed intergranular and transgranular features. This observation shows the benefits of the influence of microstructural characteristics and indicating the fatigue damage in SS316L.

The fatigue, mechanical properties and the fractographic results provide a full picture of the material behaviour under cyclic solicitation. These results corroborate that SS316L can be safely used in applications with repeated stress although microstructure quality is a key factor defining its long term fatigue reliability..

Acknowledgements

The authors gratefully acknowledge **VIT Bhopal University** for providing the necessary laboratory facilities and technical support required to conduct this research. The authors also thank their respective institutions, colleagues, and laboratory staff for their assistance and cooperation throughout the study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability Statement

All data generated or analyzed during this study are included within the article. No additional datasets were used or created.

Author Contribution Statement

Amit Kaimkuriya and Nitish Kumar Singh contributed to the writing and preparation of the manuscript. Pratima Ojha and Abhishek Badoniya assisted in the experimental work, data analysis, and review of the manuscript. All authors read and approved the final version of the paper.

References

1. Weixing Y. Stress field intensity approach for predicting fatigue life. *International Journal of Fatigue* 15, 243–246 (1993).
2. Beden S.M., Abdullah S., Ariffin A.K., Al-Asady N.A., Rahman M.M. Fatigue life assessment of different steel-based shell materials under variable amplitude loading. *European Journal of Scientific Research* 29, 157–169 (2009).
3. Landgraf R.W. Fundamentals of metal fatigue analysis. In: Meshii M. (Ed.), *Fatigue and Microstructure*, ASM, pp. 439–440 (1979).
4. Xu G., Kutsuna M., Liu Z., Yamada K. Comparison between diode laser and TIG cladding of Co-based alloys on SUS403 stainless steel. *Surface and Coatings Technology* 201, 1138–1144 (2006).

5. Kathuria Y.P. Some aspects of laser surface cladding in the turbine industry. *Surface and Coatings Technology* 132, 262–269 (2000).
6. Maeng W.Y., Kang Y.H. Creep–fatigue and fatigue crack growth properties of 316LN stainless steel at high temperature. *Transactions of the 15th International Conference on Structural Mechanics in Reactor Technology (SMiRT-15)*, Seoul, Korea, August 15–20, pp. — (1999).
7. Vogt J.-B., Foct J., Regnard C., Robert G., Dhers J. Low-temperature fatigue of 316L and 316LN austenitic stainless steel. *Metallurgical Transactions A* 22A, 2385–2392 (1991).
8. Kaimkuriya A., Sethuraman B. Optimization and experimental evaluation of Al1100 and SS202 cylindrical cups using conical die without blank holder. *AIP Advances* 14, — (2024). https://doi.org/10.1063/5.0211161