Chapter 7

Low cycle fatigue behavior of AA6063 alloy using simply supported beam specimen at room temperature

7.1 Introduction

Low cycle fatigue (LCF) behavior of as received aluminum alloy AA6063 was investigated at room temperature condition using simply supported beam specimen. The influence of strain amplitude on the LCF behavior of AA6063 in the normalized condition is reported. The tests were conducted at a constant strain rate of 2*10-3 s^{-1} and at various strain amplitudes viz. 0.4%, 0.5%, 0.6%, 0.7%, 0.8% and 1%. Fatigue life was found to decrease with increase of strain amplitude and decreasing frequency.

7.2 Present work

This chapter deals with investigation of Low cycle fatigue (LCF) behaviour of aluminum alloy AA6063 at room temperature condition using simply supported beam specimen. The influence of strain amplitude on the LCF behaviour of AA6063 in the normalized condition is investigated. The tests were carried out at a constant strain rate of $2*10^{-3}$ s^{-1} and various strain amplitudes of 0.4%,0.5%,0.6%,0.7%,0.8% and 1%. The alloy shows cyclic hardening condition at 0.5%, 0.6% and 1% strain amplitude and cyclic softening condition at 0.4%, 0.7% and 0.8% strain amplitude. The strain controlled fatigue response of alloy to cyclically softening and hardening behavior was also studied. Also the effects of strain rate and strain amplitude on LCF behavior was investigated . And based on Low Cycle Fatigue test data obtained for aluminum alloy log-log stress – life, log-log strain-life and log-log stress -strain curves are is presented at different strain amplitudes.

Fatigue life was found to decrease with increase of strain amplitude and decreasing frequency.

7.3 Result

It is well established that metals with lower value of work hardening exponent (*n* < 0.15) exhibit cyclic softening. Stress response is also known to depend on the ratio of monotonic ultimate tensile stress (UTS) to 0.2% offset yield stress (YS). Metals with σ_{UTS}/σ_{YS} <1.2 undergo cyclic softening while those with σ_{UTS}/σ_{YS} > 1.4 exhibit cyclic hardening. The value of *n* and the ratio of σ_{UTS}/σ_{YS} for the present condition is presented in Table 7.1**.** It may be seen that according to the σ_{UTS}/σ_{YS} < 1.2 criteria for softening referred to above, cyclic softening may be expected in all the strain amplitude conditions [58,59]. However, according to n < 0.15 criteria it is expected to have cyclic hardening behavior.

Table 7.1 Tensile properties of the as received alloy AA6063-T6

Material Condition	Elongation %	σ_{UTS} (MPa)	σ_{YS} (MPa)	n	K (MPa)	σ_{UTS}/σ_{YS}
As received	0.242	214.8	169.67	0.25	776.2 MPa	1.265

Strain control was used in all low cycle fatigue tests, which were conducted in load control mode. For these tests, strain control was used initially to determine the stabilized load. Then load control was used for the remainder of the test. For the strain-controlled tests, the applied frequencies ranged, depending on the applied strain amplitudes of 1%, 0.8%, 0.7%, 0.6%, 0.5% and 0.4%. All tests were conducted using a triangular waveform. Test data were automatically recorded at regular intervals throughout each test, and stable stress and strain amplitude data at about midlife were used to generate the fatigue properties. In low cycle fatigue it is the plastic strain, which dominates, it is the principal cause of hysteresis loops. The area enclosed by a loop is proportional to the energy irreversibly by the material during one load cycle.

Figure 7.1 to 7.24 show cyclic stress-strain curves at 0.4%, 0.5%, 0.6%, 0.7%, 0.8% and 1% strain amplitudes, respectively, for different cycles. By looking at the movement of the cycles cyclic stress-strain behavior is concluded.

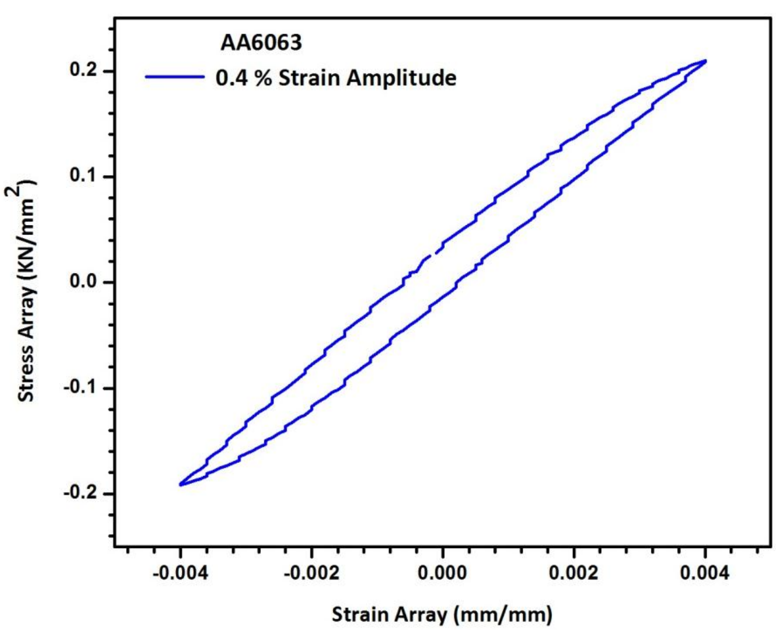

Fig. 7.1 Hysteresis Loop (One Cycle) at 0.4 % Strain Amplitude and $2*10^{-3}$ Strain Rate

It is found that only 0.5% and 0.6% strain amplitude cases show cyclic hardening while all other cases show cyclic softening behavior. Though behavior can be roughly predicted from σ_{UTS}/σ_{YS} ratio, it is heavily dependent on strain amplitudes.

The area within the loop is the energy per unit volume dissipated during one cycle.

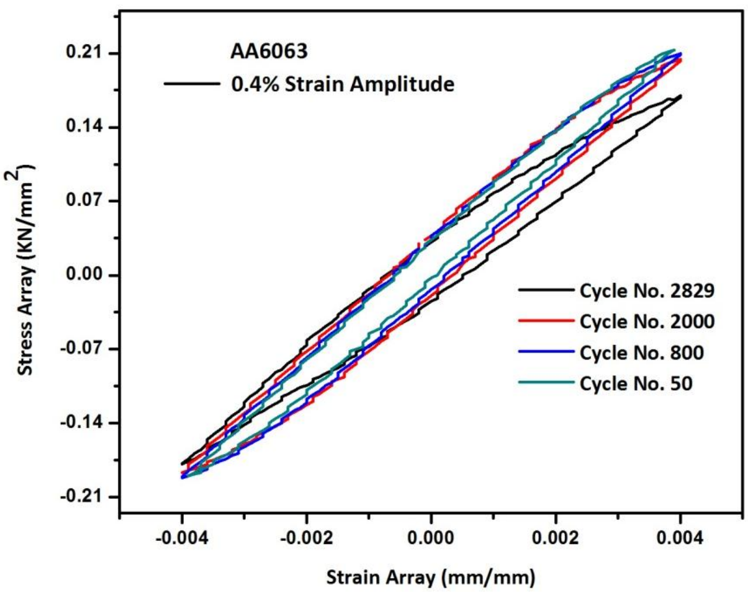

Fig. 7.2 Cyclic Stress-Strain Response at 0.4 % Strain Amplitude and 2*10^{-3} Strain rate

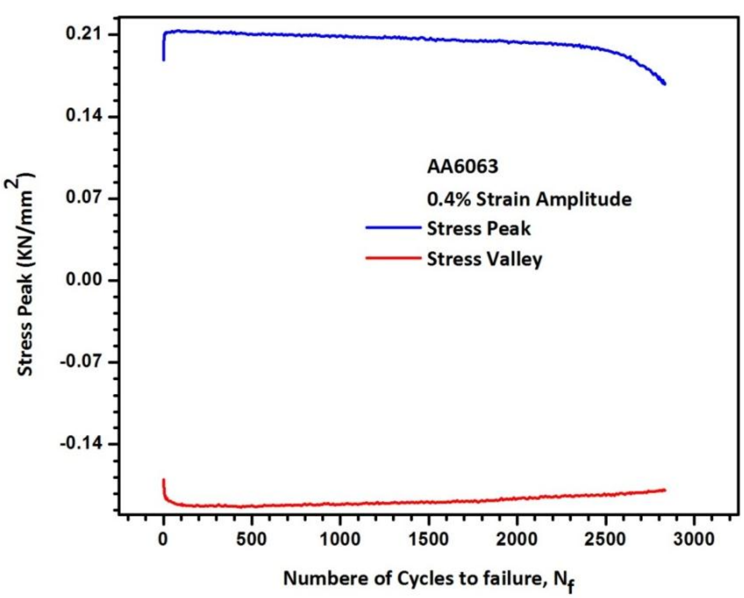

Fig. 7.3 Stress response at 0.4% strain amplitude and 2*10^{-3} Strain rate

Narrow hysteresis loop implies a small amount of dissipated energy.

Figure 7.2 shows the hysteresis loops for different cycles. As the number of cycles increased maximum stress obtained decreased. This indicates cyclic strain softening behavior.

Variation of stress peak and stress valley with the number of cycles to failure are shown in Fig. 7.3 . This figure illustrates that, stress peak value decreasing with number of cycles to failure (N_f) while stress valley value increasing with N_f.

Figure 7.4 shows variation of average stress defined as $(\frac{stress\ peak + (-\ stress\ valley)}{2})$ with number of cycles of failure. It can be observed that the average value decreases with number of cycles of failure .

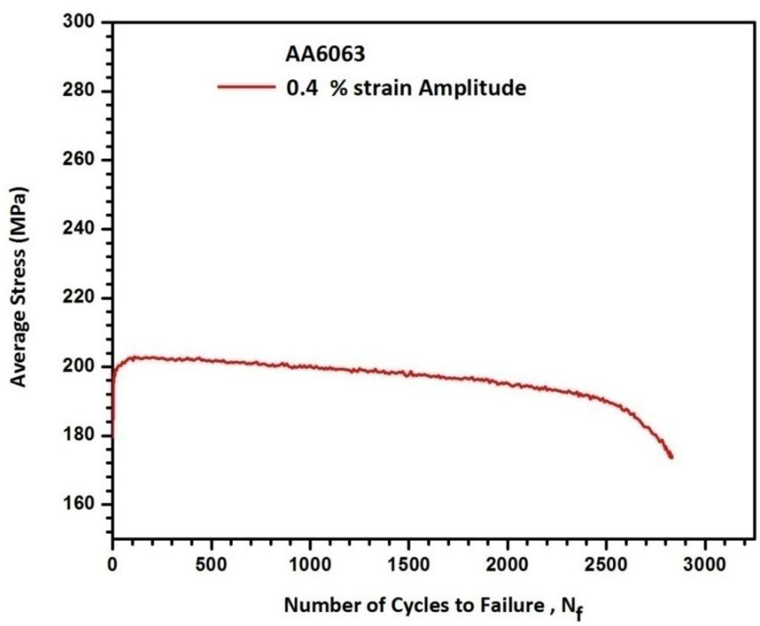

Fig. 7.4 Average stress with number of cycles to failure at 0.4% strain amplitude and $2*10^{-3}$ Strain rate

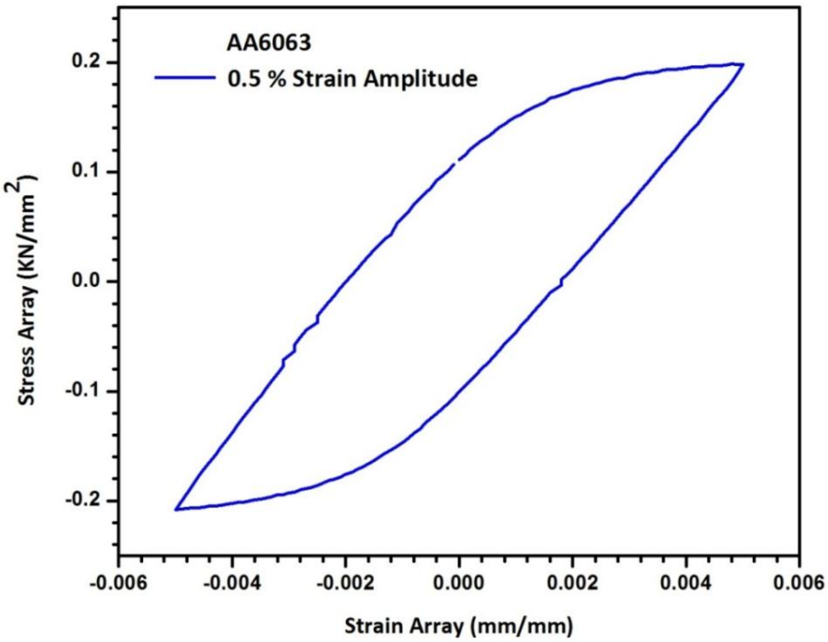

Fig. 7.5 Hysteresis Loop (One Cycle) at 0.5% Strain Amplitude and 2*10^{-3} Strain Rate

At 0.5% strain amplitude the area within the loop i.e. the energy per unit volume dissipated during one cycle is bigger than the area of the loop at 0.4% strain amplitude as explained in Fig. 7.5.

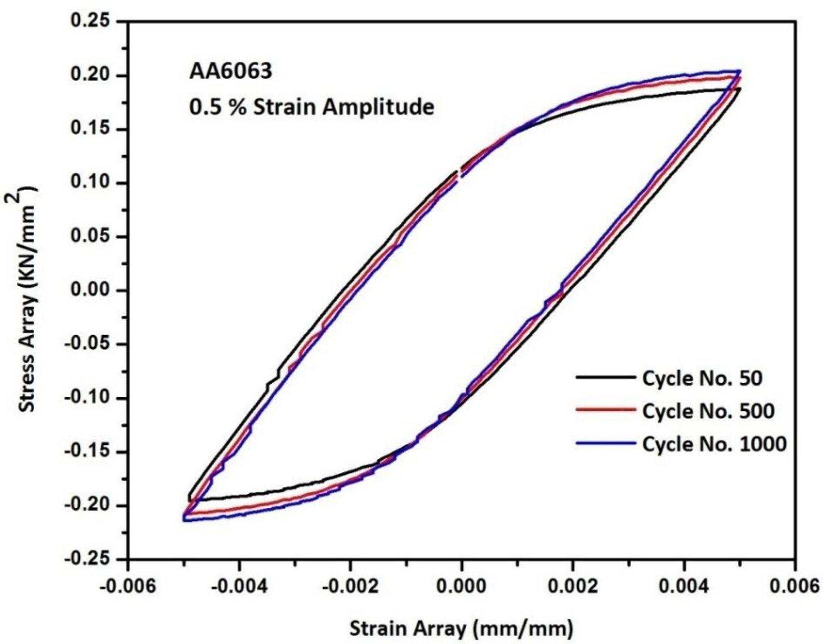

Fig. 7.6 Cyclic Stress-Strain Response at 0.5 % Strain Amplitude and 2*10^{-3} strain rate

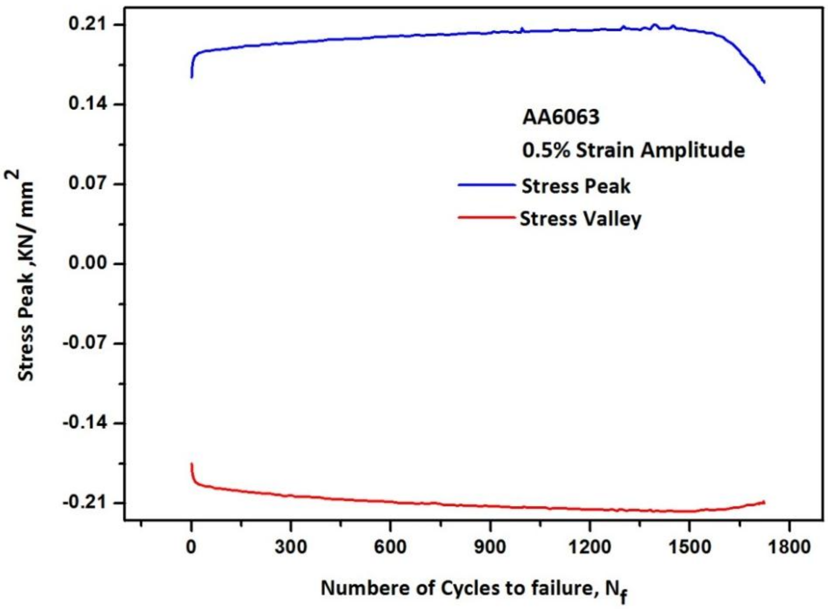

Fig. 7.7 Stress response at 0.5% strain amplitude and 2*10^{-3} Strain rate

Cyclic strain hardening behavior occurs for 0.5% strain amplitude case as can be observed from Fig. 7.6**.** Figure 7.7 also describes that the stress peak and stress valley increase with time.

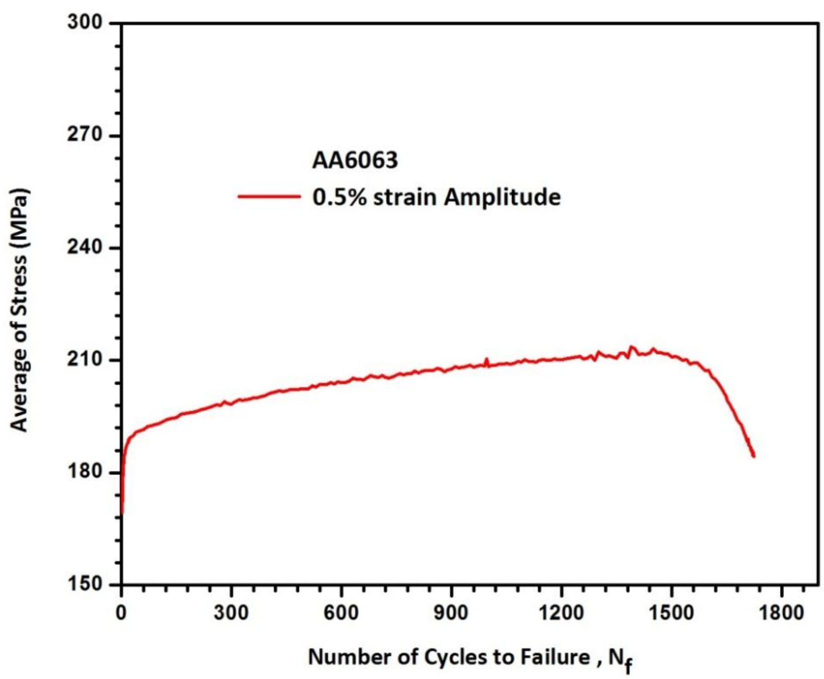

Fig. 7.8 Average stress with number of cycles to failure at 0.5% strain amplitude and 2*10^{-3} Strain rate

Additionally Fig. 7.8 shows that the average stress increases with increasing numbers of cycles to failure. It is obvious from the stress response curves that extensive hardening at room temperature takes place for 0.5% strain amplitude.

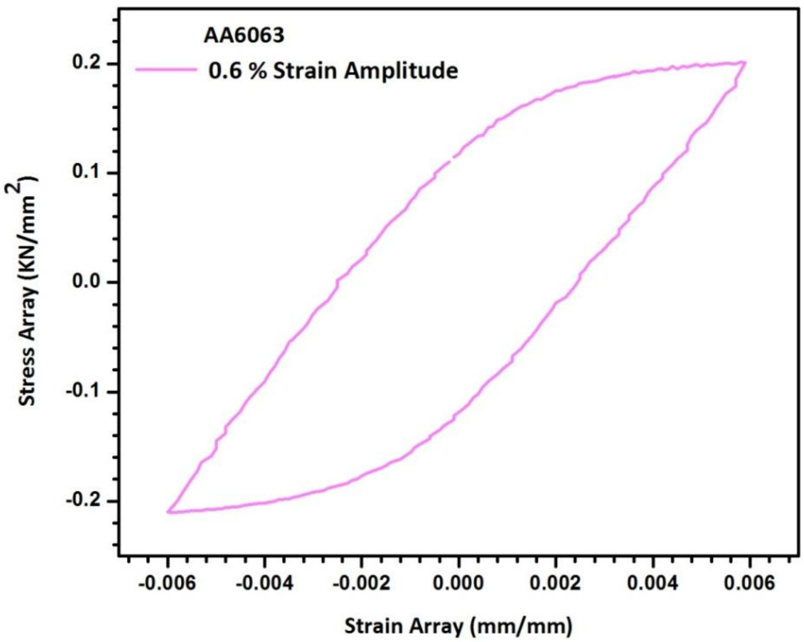

Fig. 7.9 Hysteresis Loop (One Cycle) at 0.6 % Strain Amplitude and $2*10^{-3}$ Strain Rate

Also at 0.6% strain amplitude the hysteresis loop area i.e. energy dissipated per unit volume increase compared to 0.5% and 0.4% strain amplitude as shown in Fig. 7.9.

Cyclic strain hardening behavior occurs for the 0.6% strain amplitude case, with increasing the number of cycles the stress–strain response increase for each cycle as described in Fig. 7.10**.** The stress peak and valley values increase with number of cycles of failure as shown in Fig. 7.11. Figure 7.12 shows the average stress increase with number of cycle’s failure. It may be noted that at 0.6% strain amplitude condition hardening takes place during the initial few cycles, peak hardening occurs and is followed by cyclic softening in the subsequent cycles. Though hardening is limited to the initial cycles, the degree of hardening is considerably higher than the softening in the rest of the cycles up to the failure, hardening occurs over a large fraction of the fatigue life.

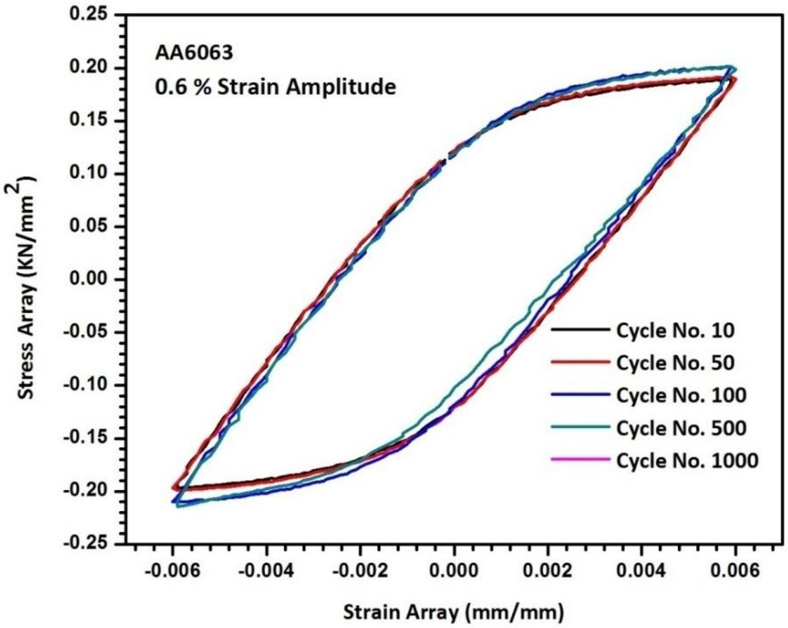

Fig. 7.10 Cyclic Stress-Strain Response at 0.6 % Strain Amplitude and 2*10^{-3} strain rate

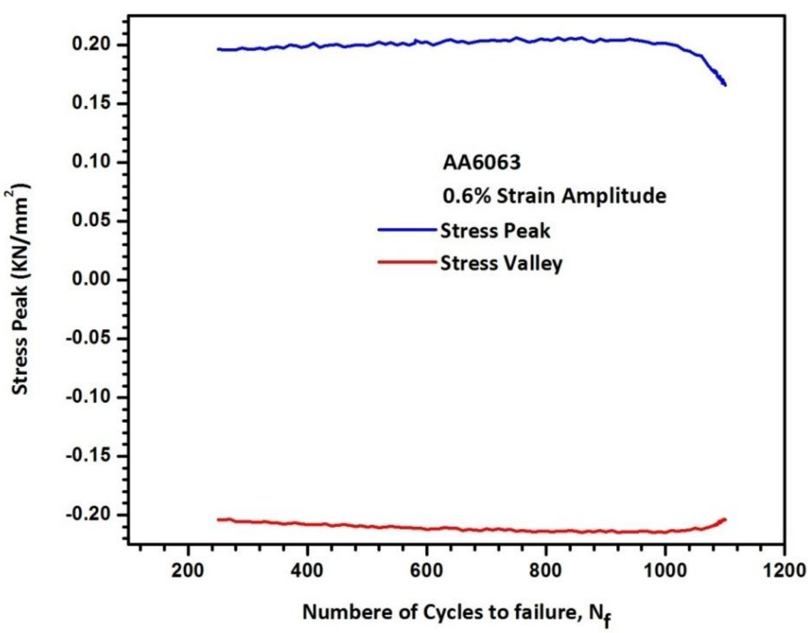

Fig. 7.11 Stress response at 0.6% strain amplitude and 2*10^{-3} strain rate

At 0.7% strain amplitude the hysteresis loop area i.e. energy dissipated per unit volume increase comparing with 0.6%, 0.5% and 0.4% strain amplitude as shown Fig. 7.13**.**

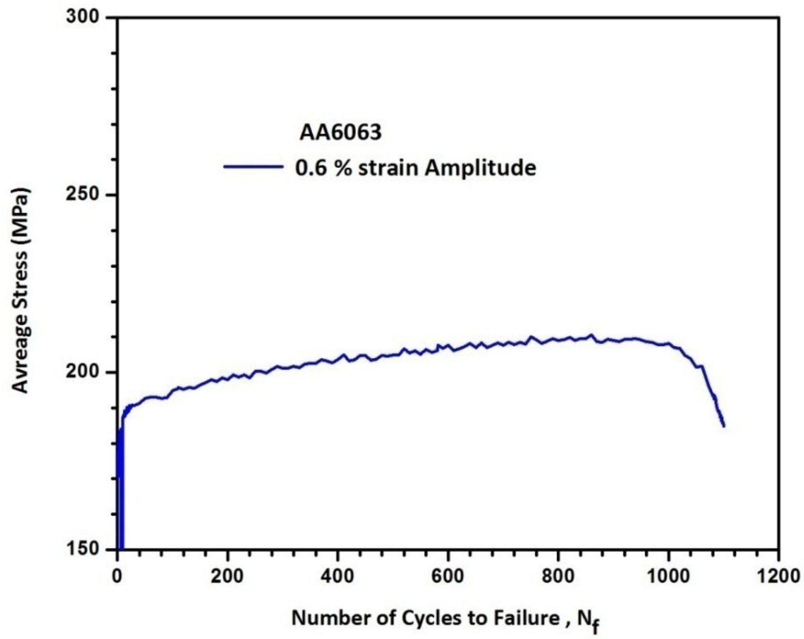

Fig. 7.12 Average stress with number of cycles to failure at 0.6% strain amplitude and $2*10^{-3}$ strain rate

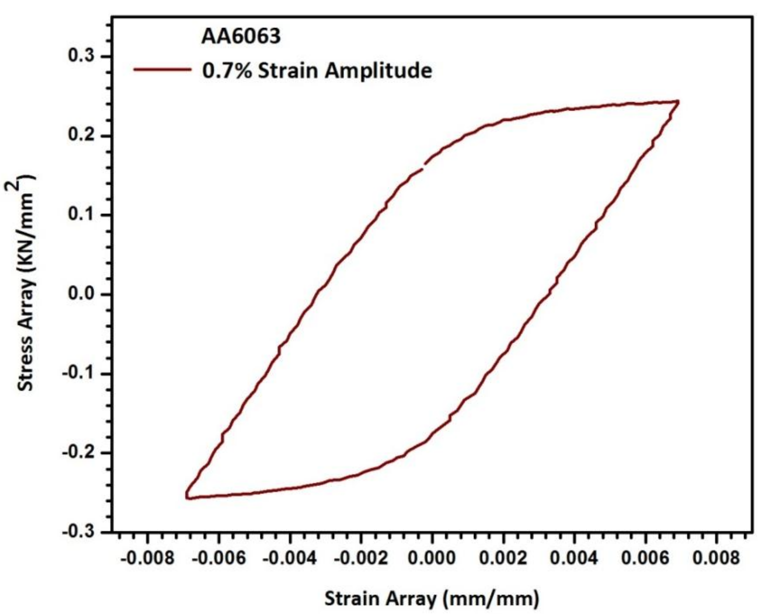

Fig. 7.13 Hysteresis loop (one cycle) at 0.7 % strain amplitude and $2*10^{-3}$ strain rate

Cyclic strain softening behavior occurs for the 0.7% strain amplitude case. With increasing the number of cycles the stress–strain response decrease for each cycle as illustrated in Fig. 7.14**.** Also it can be seen in Fig. 7.15 that stress level is decreasing with number of cycles of failure.

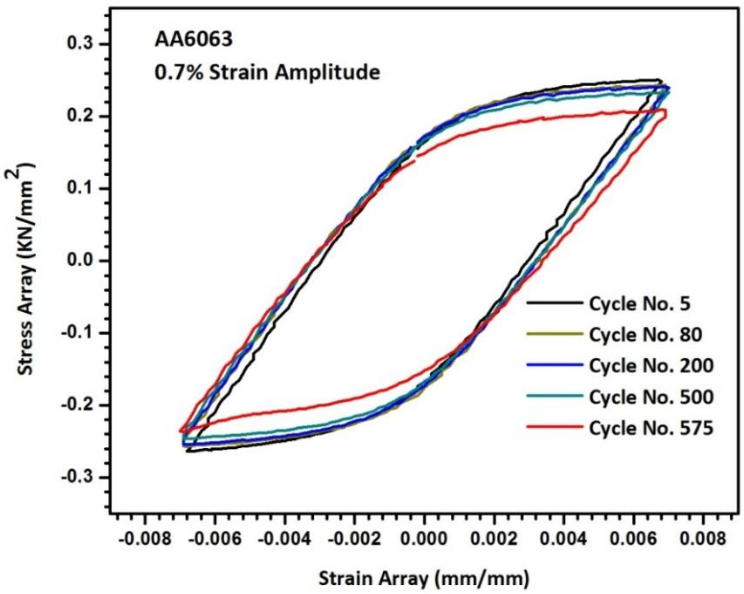

Fig. 7.14 Cyclic stress-strain response at 0.7 % strain amplitude and $2*10^{-3}$ strain rate

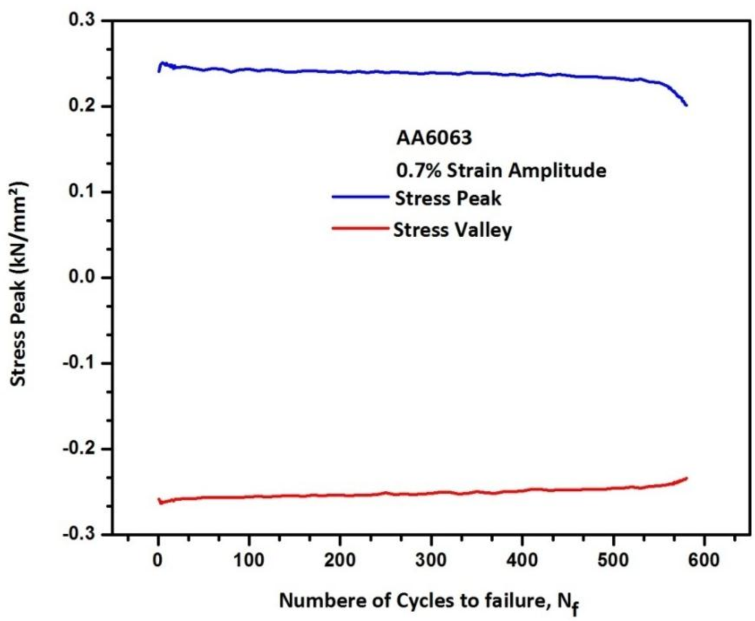

Fig. 7.15 Stress response at 0.7 % strain amplitude and $2*10^{-3}$ strain rate

The average stress also decreases with the number of cycles to failure N_f as shown in Fig. 7.16

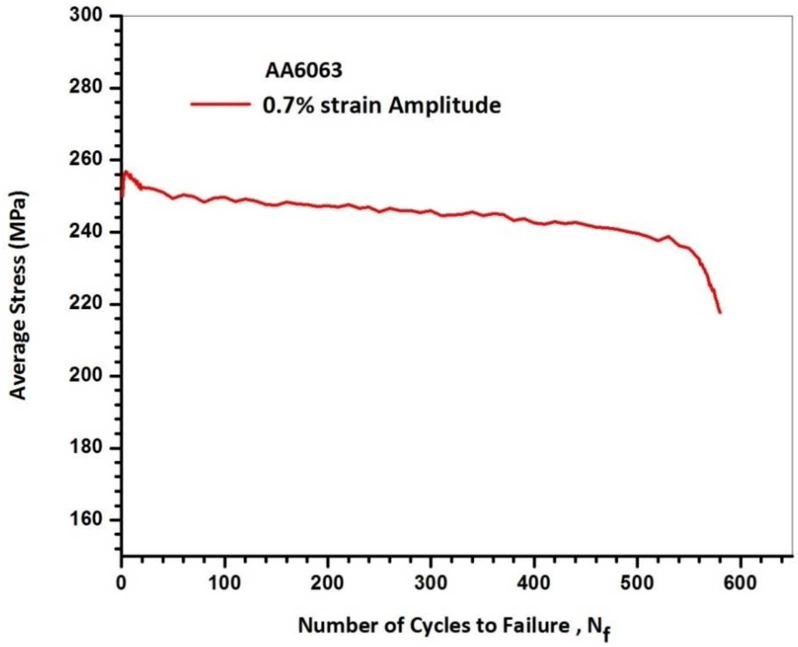

Fig. 7.16 Average stress with number of cycles to failure at 0.7% strain amplitude and $2*10^{-3}$ strain rate

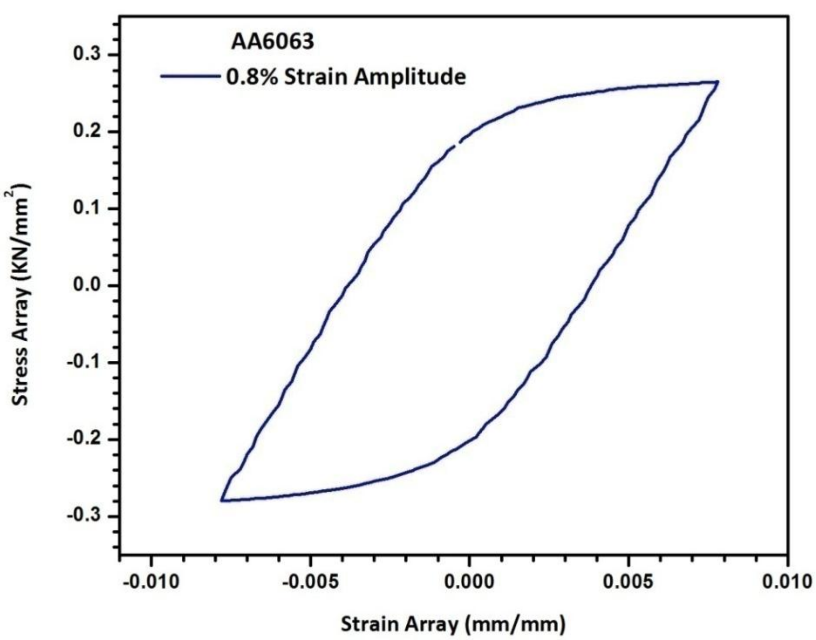

Fig. 7.17 Hysteresis loop (one cycle) at 0.8 % strain amplitude and $2*10^{-3}$ strain rate

At 0.8% strain amplitude the hysteresis loop area i.e. energy dissipated per unit volume increased comparing with the previous cases (0.7% strain amplitude) as shown in Fig. 7.17.

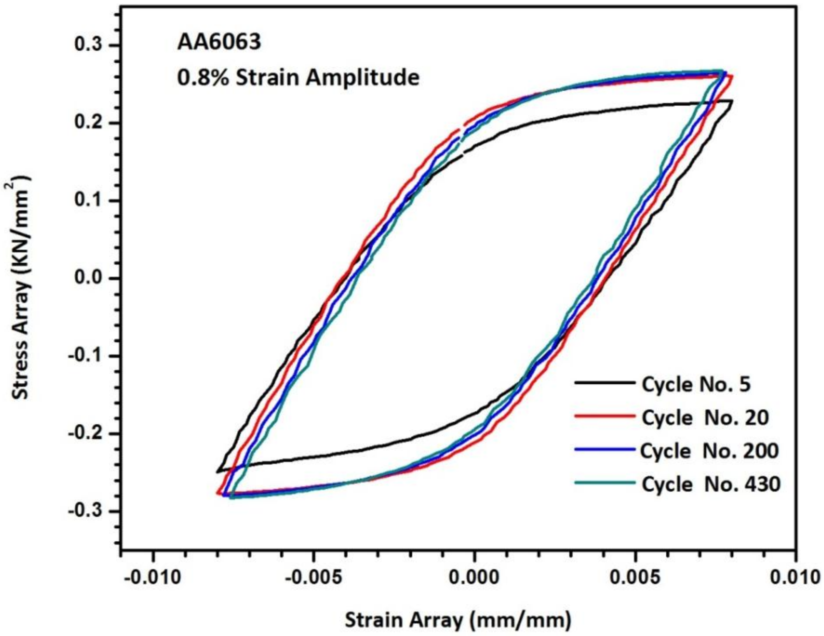

Fig. 7.18 Cyclic stress-strain response at 0.8 % strain amplitude and $2*10^{-3}$ strain rate

Figure 7.18 illustrates cyclic strain hardening behavior in 0.8% strain amplitude case. With increasing the number of cycles the stress – strain response increase for each cycle**.** Also it can be seen that as the number of cycles to failure increases stress level increases as shown in Fig. 7.19 . When the number of cycles increases the average stress also increases as illustrated in Fig. 7.20.

An analysis of the change in hysteresis loop shape during cyclic loading shows that the increase in dislocation density is responsible for an increase in effective stress. The long range internal stress (back stress), which is strongly sensitive to dislocation distribution and dislocation structure, is mainly responsible for the cyclic deformation response.

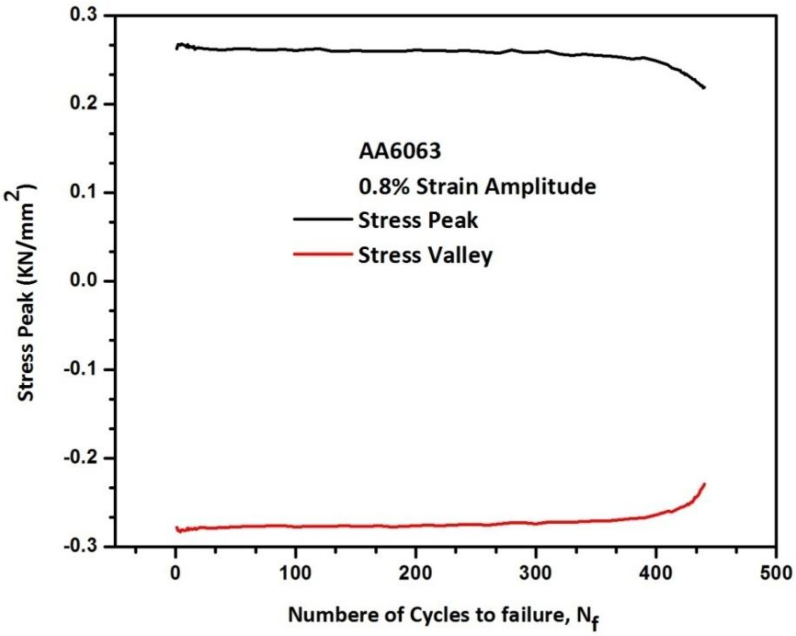

Fig. 7.19 Stress response at 0.8 % strain amplitude and $2*10^{-3}$ strain rate

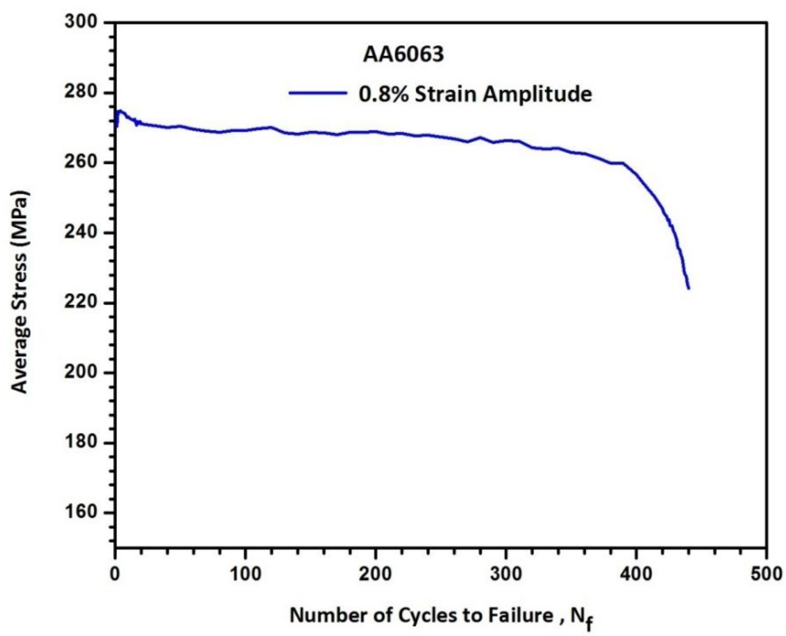

Fig. 7.20 Average stress with number of cycles to failure at 0.8% strain amplitude and $2*10^{-3}$ strain rate

Figure 7.21 illustrates a large hysteresis loop area implying a large energy dissipation per unit volume during one cycle for the test at 1% strain amplitude.

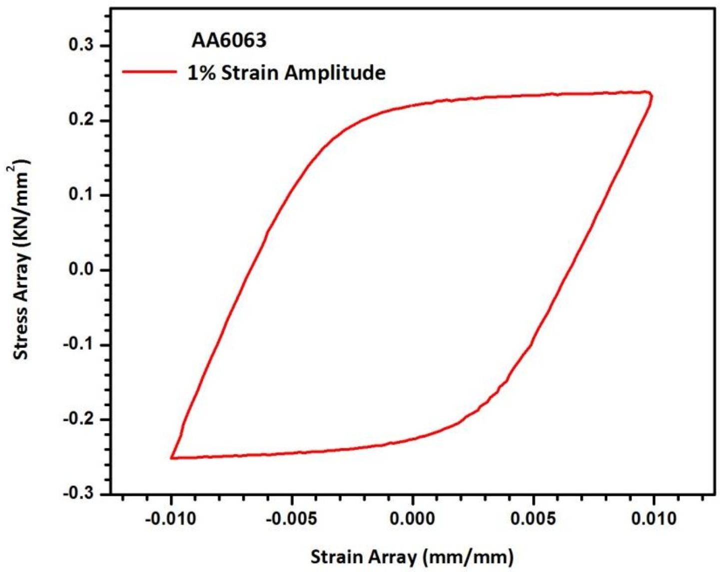

Fig. 7.21 Hysteresis Loop (One Cycle) at 1 % Strain Amplitude and $2*10^{-3}$ Strain Rate

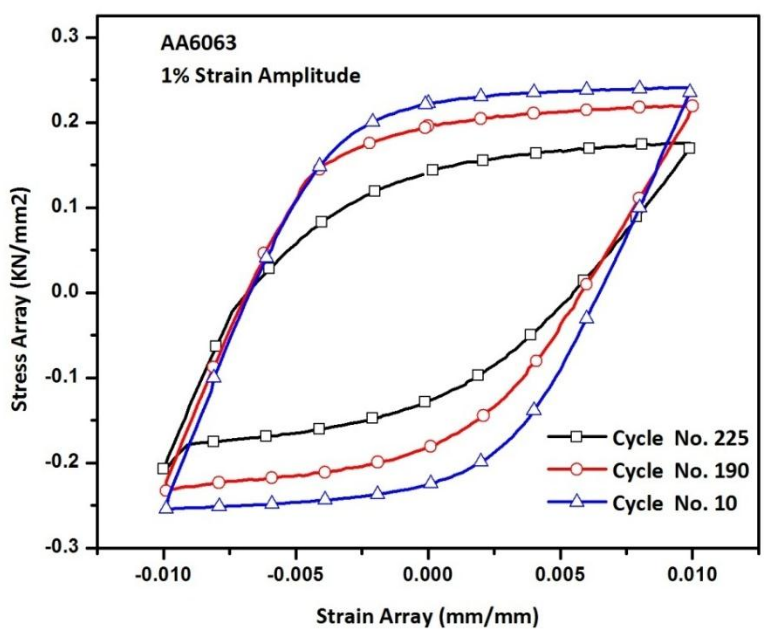

Fig. 7.22 Cyclic stress-strain response at 1% strain amplitude and $2*10^{-3}$ strain rate

Figure 7.22 shows the hysteresis loop for the different cycles for 1% strain amplitude. As the number of cycles increases the maximum stress obtained increase resulting in the cyclic strain softening behavior.

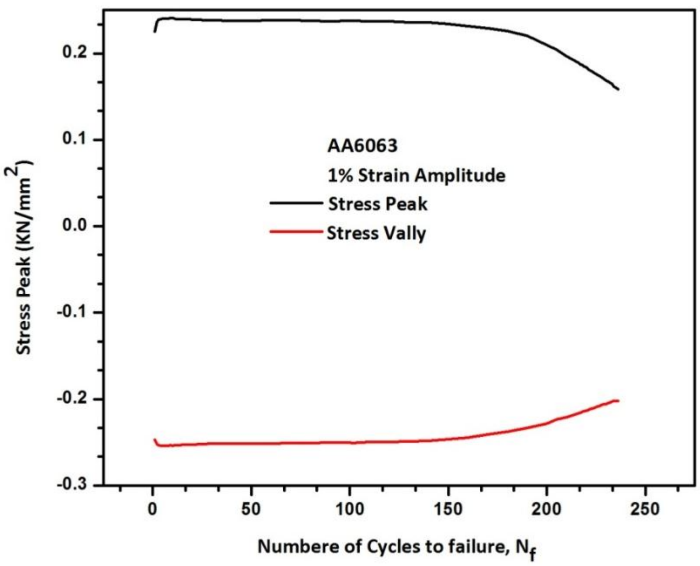

Fig. 7.23 Stress response at 1% strain amplitude and 2*10^{-3} strain rate

Figure 7.23 shows the stress response of a material loaded in strain control, the stress peak and stress valley decreasing with increasing the number of cycles to failure for 1% strain amplitude. The average of stress decrease when the number of cycles to failure N_f at 1% strain amplitude increase as shown in Fig. 7.24 .

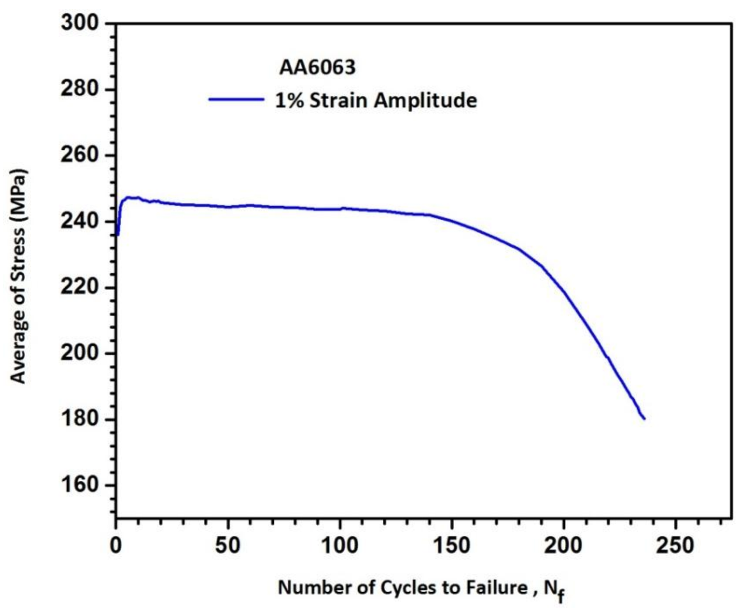

Fig. 7.24 Average stress with number of cycles to failure at 1% strain amplitude and 2*10^{-3} strain rate

Cyclic hysteresis loop stress-strain curves are plotted at different strain amplitude of 0.4%, 0.5%, 0.6%, 0.7%, 0.8% and 1% and shown in Fig. 7.25. It can be observed that when the strain amplitude increases the hysteresis loop area increases implying large energy dissipation per unit volume.

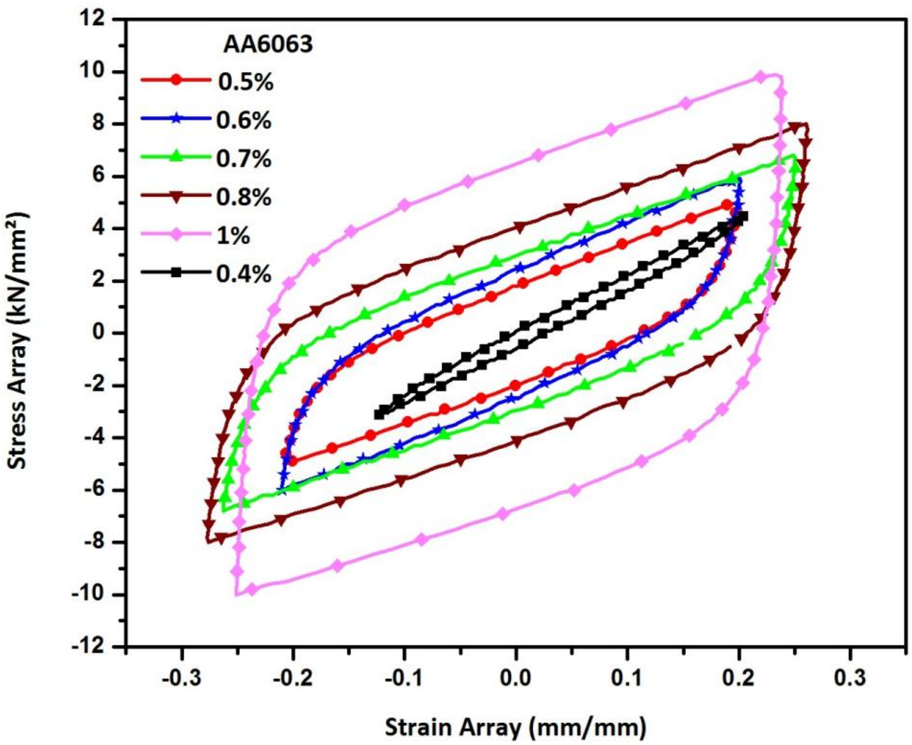

Fig. 7.25 Cyclic hysteresis loop stress-strain curves plotted at different cycles numbers at different strain amplitude and $2*10^{-3}$ strain rate

The cyclic stress response of the alloy at different strain amplitude conditions is presented in Fig. 7.26. This plot of tensile stress (peak stress) with the number of cycles to failure Nf, illustrates that stress response decreases with increase in strain amplitudes. Figure 7.27 shows Plastic strain amplitude decreases as number of cycles to failure increases.

Figure 7.28 illustrates variation of average stress with number of cycles of failure for different strain amplitude cases for as received AA6063 alloy.

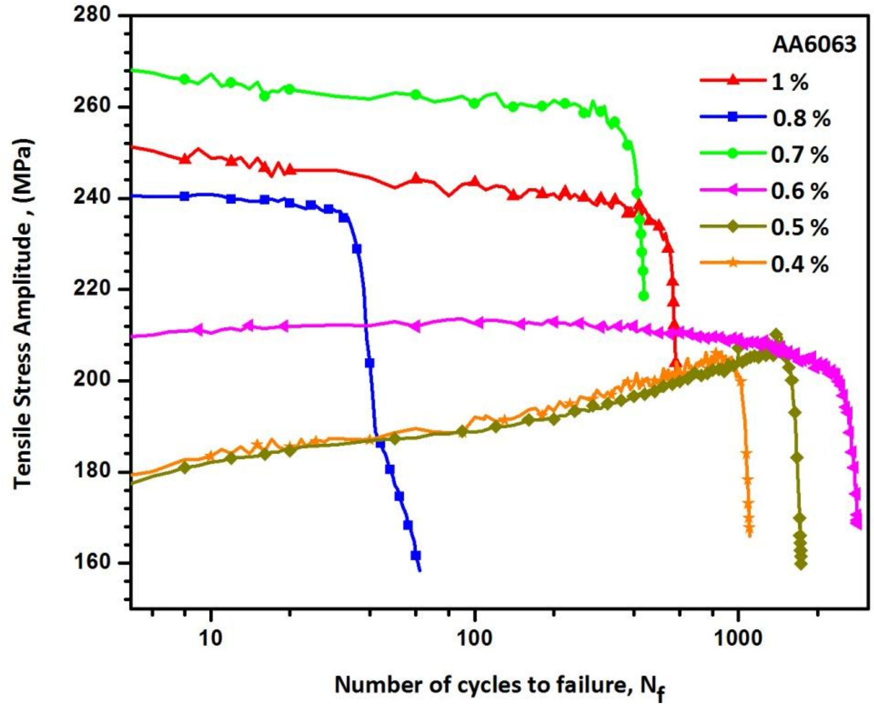

Fig. 7.26 Cyclic Tensile Amplitude stress response VS Number of cycles N_f with different strain amplitudes and $2*10^{-3}$ strain rate

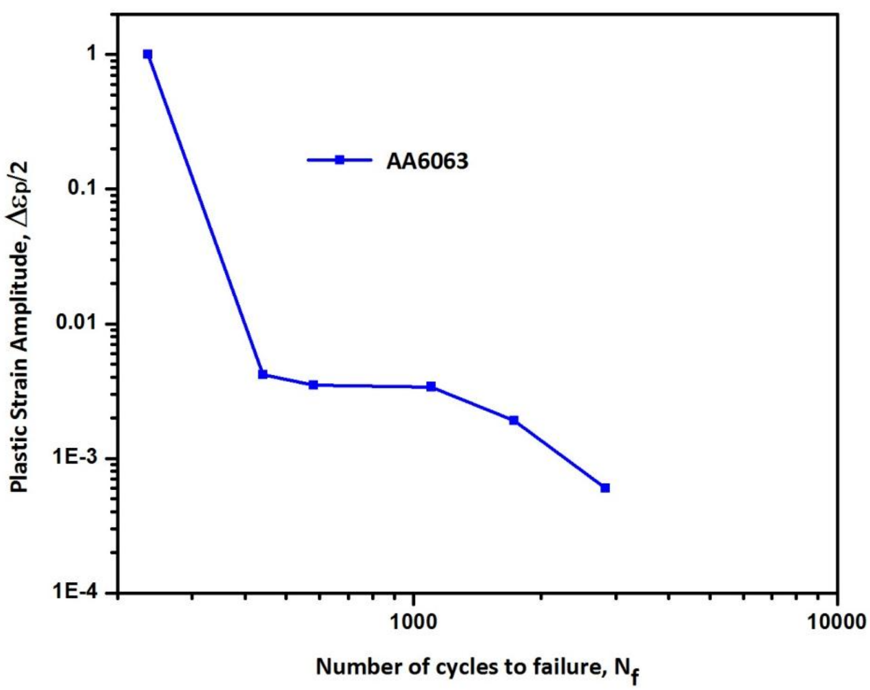

Fig. 7.27 Plastic Strain Amplitude various with Number of cycles N_f to failure

Figure 7.29 shows that frequency increases as the number of cycles to failure increases. The total average stress amplitude decreases with number of cycles of failure as illustrated in Fig. 7.30.

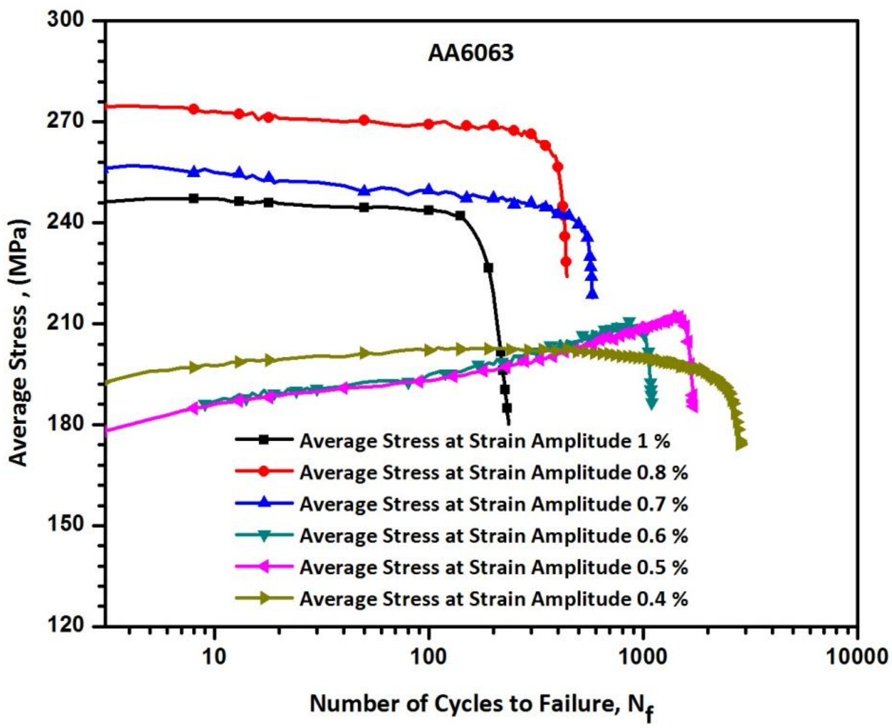

Fig. 7.28 Variation of Average cyclic stress with Number of cycles N_f to failure of AA 6063 as received

Table 7.2 reported the variation of number of reversals to failure (2Nf) with different components of strain amplitude at the room temperature for the alloyAA6063 at fracture point of each sample

Figure 7.31 demonstrates that with the increase in frequency, the strain amplitude decreases. The plastic strain amplitude decrease with the number of cycles to failure as shown in Fig. 7.32.

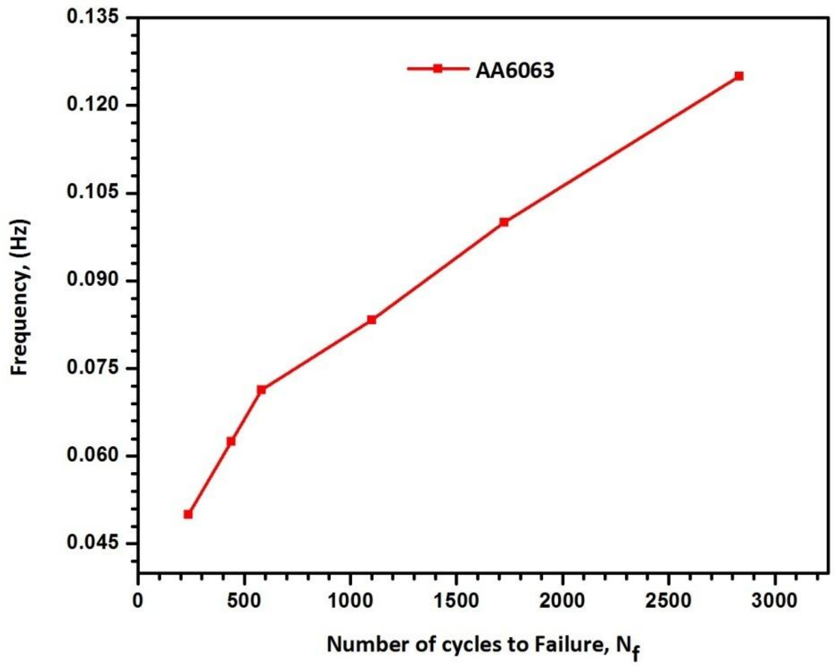

Fig. 7.29 Frequency various with Number of cycles N_f to failure

Table 7.2 Variation of number of reversals to failure (2Nf) with different components of strain amplitude at RT for the alloyAA6063 at fracture point of each sample

Strain Amplitude %	Strain Rate	Frequency Hz	Time Duration (hour)	Stress peak (KN/mm) at fracture	Stress Valley (KN/mm2) at fracture	Stress Amplitude (GPa), $\Delta\sigma/2$ at fracture	Reversals to failure ($2N_f$) at fracture	Strain Max. (mm/mm) at fracture	Strain Min. (mm/mm) at fracture	Strain Amplitude $\Delta\varepsilon/2$ at fracture
1	$2*10^{-3}$	0.05	1:18 min	0.1584	0.2021	0.18025	236	0.0069	0.0069	1
0.8	$2*10^{-3}$	0.0625	1:57 min	0.2192	0.2291	0.22415	440	0.0043	0.0041	0.0042
0.7	$2*10^{-3}$	0.0714	2:15 min	0.2017	0.2338	0.21775	580	0.0037	0.0033	0.0035
0.6	$2*10^{-3}$	0.08333	3:40 min	0.1659	0.2039	0.1849	1100	0.0037	0.0031	0.0034
0.5	$2*10^{-3}$	0.1	4.59 min	0.1599	0.209	0.18445	1724	0.002	0.0018	0.0019
0.4	$2*10^{-3}$	0.125	6:18 min	0.0040	0.0040	0.001	2834	0.0005	0.0007	0.0006

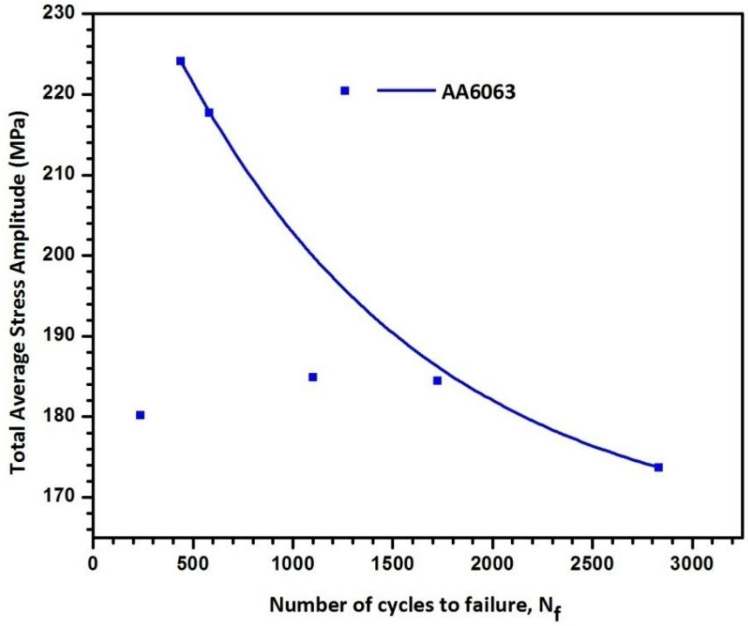

Fig. 7.30 Total Average stress amplitude various with number of cycles to failure

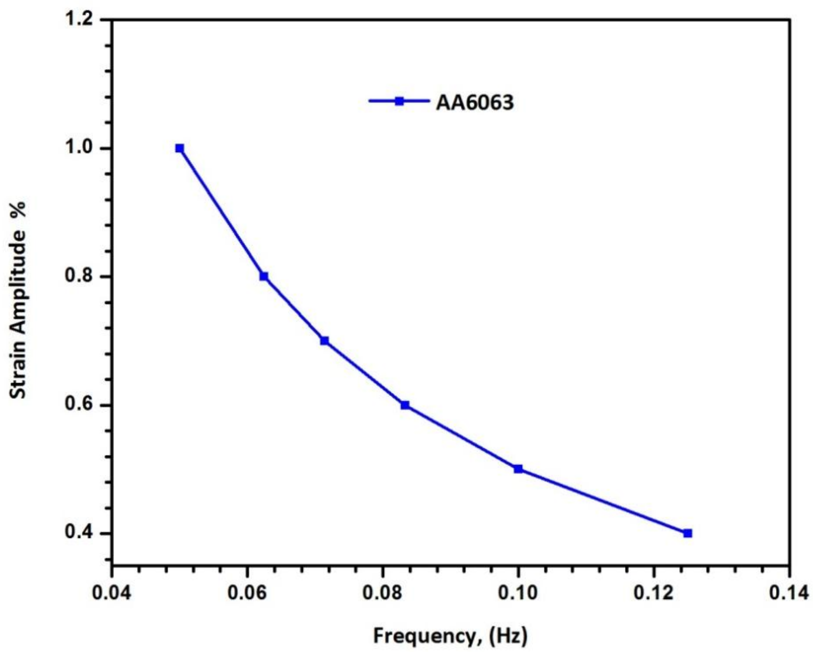

Fig. 7.31 Strain amplitude various with Frequency

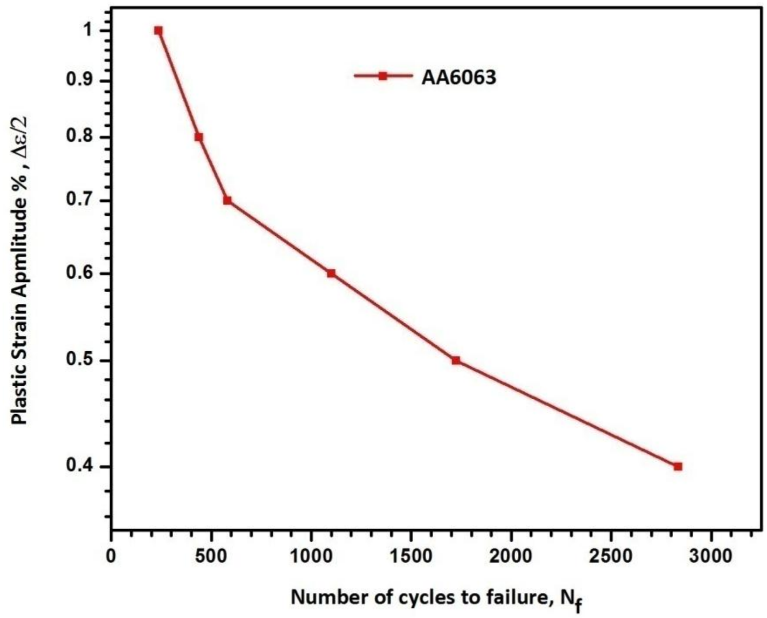

Fig. 7.32 Plastic strain amplitude various with number of cycles to failure

7.4 Conclusions

Low cycle fatigue behavior of as received AA6063-T6 at room temperature is investigated using simply supported specimens. Cyclic hardening was exhibited at higher strain amplitudes ($\Delta\varepsilon'_{f/2} > 0.6\%$). Further, there was secondary cyclic hardening during the later stage of cycling at all the strain amplitudes and constant strain rates. The area within the loop (the energy per unit volume) dissipated during one cycle increased with increase the strain amplitude at same strain rate $2*10^{-3}$.