CHAPTER FOUR

4.1 EXPERIMENTAL RESULTS AND DISCUSSIONS

There were two specimens for each grade of steel and two loading capacities for these various grades of steel. The specimens were tested under the same constant load capacity as tabulated below:

Table 4.1

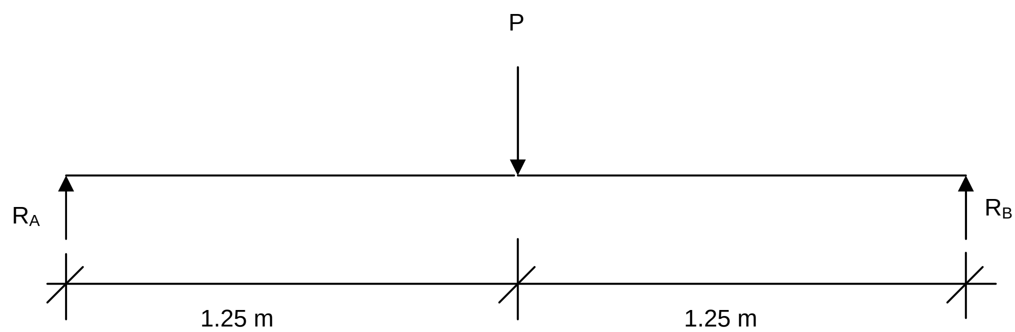
Steel Grade	Cyclic Load 1	Cyclic Load 2
300W	0.50P = 122 KN	0.75P = 184 KN
350W	0.50P = 122 KN	0.75P = 184 KN
460W	0.50P = 122 KN	0.75P = 184 KN

4.1.1 Grade 300W @ 0.50P

Specimen 1 of Grade 300W was loaded with 122 KN at the midspan until failure.

Moment determination:

P = 122 KN



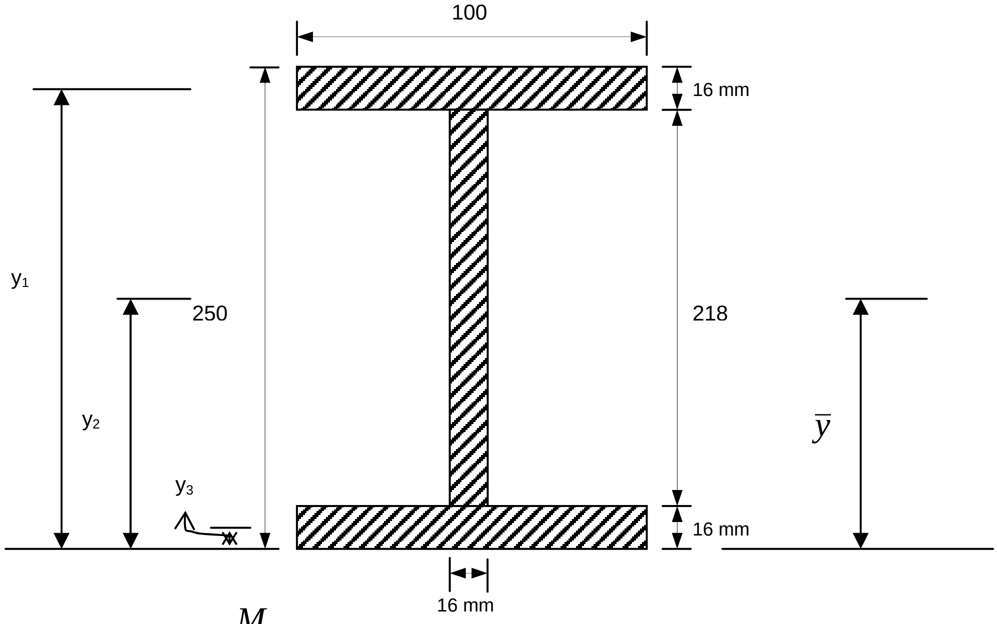
$$R_A = \frac{P}{2} = \frac{122KN}{2} = 61KN$$

Maximum moment (moment @ midpoint), M_{300} =

$$61KNx1.25m = 76.25KNm$$

Stress determination:

Considering the section at midspan directly under the point of loading where maximum stresses will be induced, as shown below.



$$\sigma_{midspan} = \frac{M_{midspan}}{I} c$$

Where:

$\sigma_{midspan}$ = maximum stress at midspan

$M_{midspan}$ = Applied bending moment at midspan

C = Distance from neutral axis to surface of the specimen

I = Cross-sectional moment of inertia

$$\bar{y} = \frac{\sum Ay}{\sum A}$$

$$A_1 = 100x16 = 1600mm^2$$

$$A_2 = 16x218 = 3488mm^2$$

$$A_3 = 100x16 = 1600mm^2$$

$$\sum A = A_1 + A_2 + A_3 = 6688mm^2$$

$$y_1 = 250 - 8 = 242mm$$

$$y_2 = \frac{218}{2} + 16 = 125mm$$

$$y_3 = \frac{16}{2} = 8mm$$

$$A_1 y_1 = 1600mm^2 x242mm = 387200mm^3$$

$$A\ y_2 = 3488mm^2 x125mm = 436000mm^3$$

$$A_3 y_3 = 1600mm^2 x8mm = 12800mm^3$$

$$\sum Ay = A_1 y_1 + A\ y_2 + A_3 y_3 = 836000mm^3$$

$$\therefore \bar{y} = \frac{\sum Ay}{\sum A} = \frac{836000mm^3}{6688mm^2} = 125mm$$

$$I_1 = \frac{b_1 d_1^3}{12} + A_1(y_1 - \bar{y})^2$$

$$= \frac{100mmx16^3 mm^3}{12} + 1600mm^2(242mm - 125mm)^2$$

$$I_1 = 21936533.33mm^4$$

$$I_2 = \frac{b_2 d_2^3}{12} + A_2(y_2 - \bar{y})^2$$

$$= \frac{16mmx218^3 mm^3}{12} + 1600mm^2(125mm - 125mm)^2$$

$$I_2 = 13813642.62mm^4$$

$$I_3 = \frac{b_3 d_3^3}{12} + A_3(\bar{y} - y_3)^2$$

$$= \frac{100mmx16^3 mm^3}{12} + 1600mm^2(125mm - 8mm)^2$$

$$I_3 = 21936533.33mm^4$$

$$\therefore I = I_1 + I_2 + I_3 = 57686709.33mm^4$$

$$M_{midspan} = 76.25x10^6 Nmm$$

$$c = 125mm$$

$$\therefore \sigma_{midspan} = \sigma_{\max} = \frac{76.25x10^6 Nmmx125mm}{57.69x10^6 mm^4} = 165N/mm^2$$

For minimum stress applied at midspan with P = 10 KN:

Minimum moment @ midspan, M_{min} = $5KNx1.25m = 6.25KNm$

$$\sigma_{\min} = \frac{6.25x10^6 Nmmx125mm}{57.69x10^6 mm^4} = 13.5N/mm^2$$

$\therefore$

$$\sigma_{\max} = 165N/mm^2$$

$$\sigma_{\min} = 13.5N/mm^2$$

$$Stress\,Range,\ \Delta\sigma = \sigma_{\max} - \sigma_{\min} = 151.5N/mm^2$$

$$Mean\,Stress, \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{178.5}{2} = 89.25N/mm^2$$

$$Stress\ Amplitude,\ \sigma_a = \frac{\Delta\sigma}{2} = 75.75N/mm^2$$

Strain gauge results

The strain values obtained during the experiment is shown below. The strain values were measured after every 100,000 cycles at a frequency of 1 Hz. 1 strain gauge was affixed at the top flange towards the support of the specimen while three strain gauges namely B, C and D were placed on the web within the zone of loading.

Table 4.2 – Strain gauge results

Cycles to failure	Top Flange (microstrain)	Web - B (microstrain)	Web - C (microstrain)	Web -D (microstrain)	Stress MPa
0	17380	14705	16400	18105	165
100000	16865	14830	16620	18365	165
200000	16980	14800	16660	18390	165
300000	16875	14780	16660	18370	165
400000	16855	14840	16630	18390	165
500000	16860	14840	16670	18395	165
600000	16860	14810	16665	18380	165
700000	16840	14850	16660	18410	165
800000	16865	14840	16645	18410	165
900000	16870	14835	16650	18390	165
1000000	16850	14830	16670	18395	165
1100000	16860	14850	16675	18395	165
At failure - 1200000	16750	14930	16720	18500	165

Since there were no changes in stresses, i.e. a constant stress was applied to the structure throughout the testing until failure; the stress-strain curve yielded a straight line as shown below:

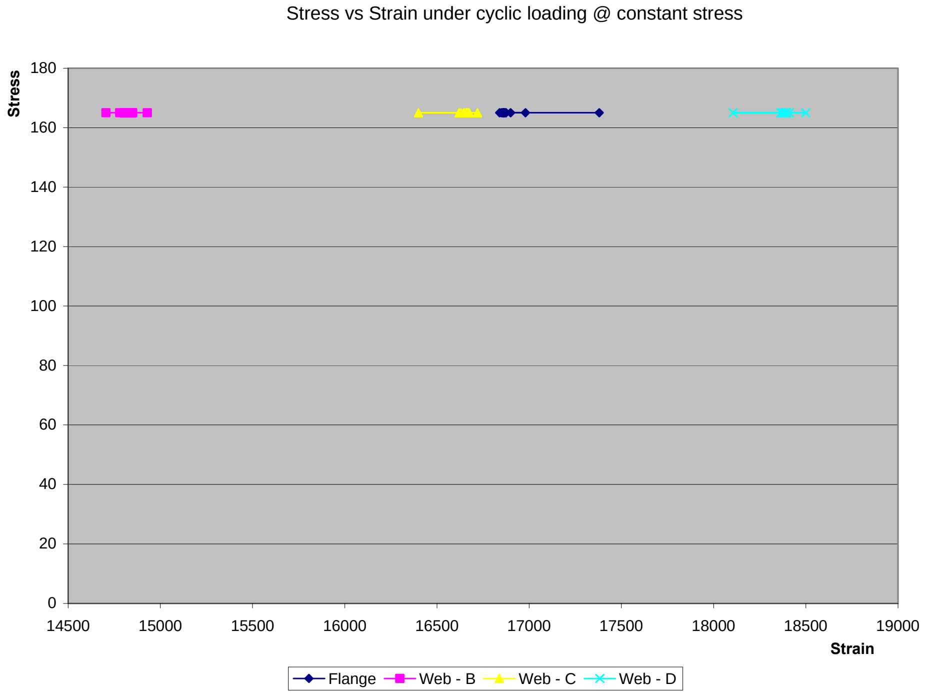


Figure 4.1 – Stress-strain curve

<u>Relationship between Strain and cycles to failure</u>

The changes in strain were monitored periodically using the strain gauges during the experiment. Microstrains were read off at every 100,000 cycles of loading.

Top flange

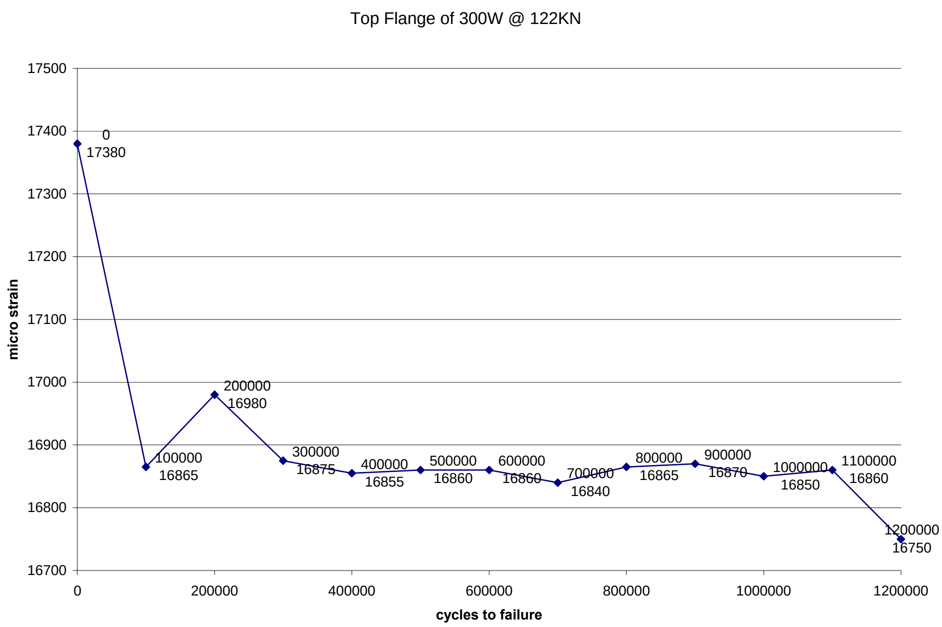


Figure 4.2 – Top flange

As can be seen from the figure above, there was a sharp contraction after the first 100,000 cycles and afterwards stabilization. This shows that the top flange was under compression.

Web - B

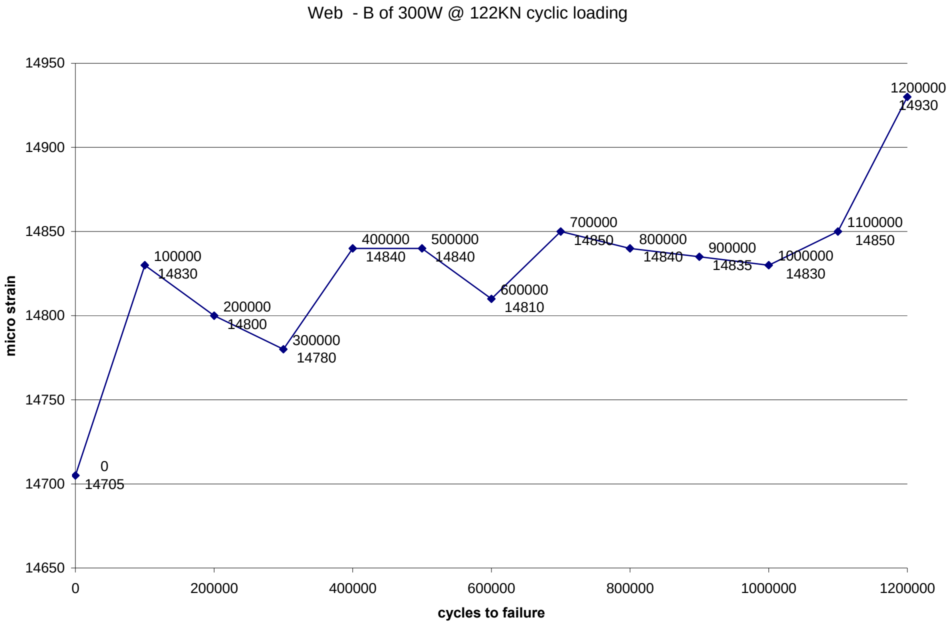


Figure 4.3 – Web B

Also, there was a sharp increment of the specimen at the web as measured using the strain gauges. This shows that the web was under tension. Two other strain gauges were placed on the web and these yielded similar result as shown in figures 4.4 and 4.5 below.

Web - C

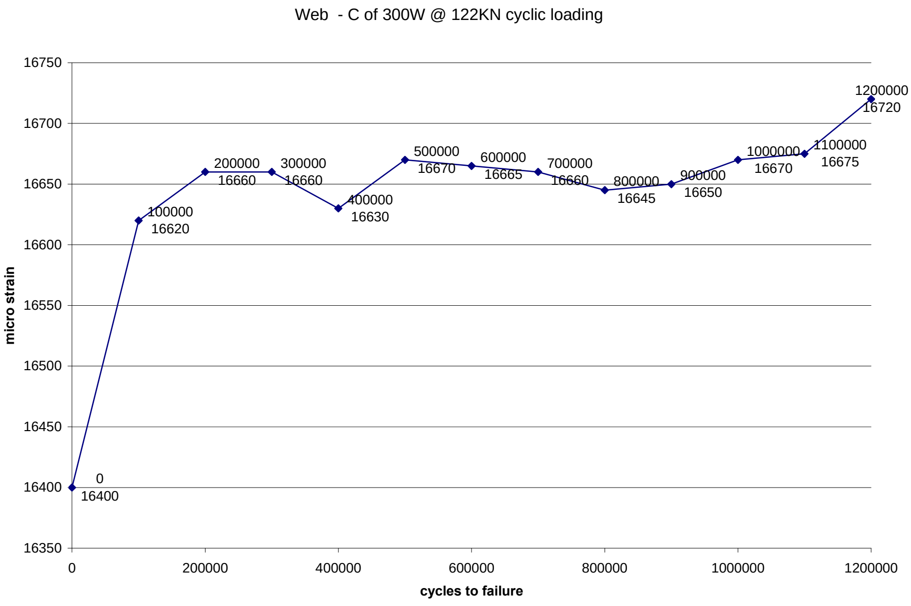


Figure 4.4 – Web C

Web - D

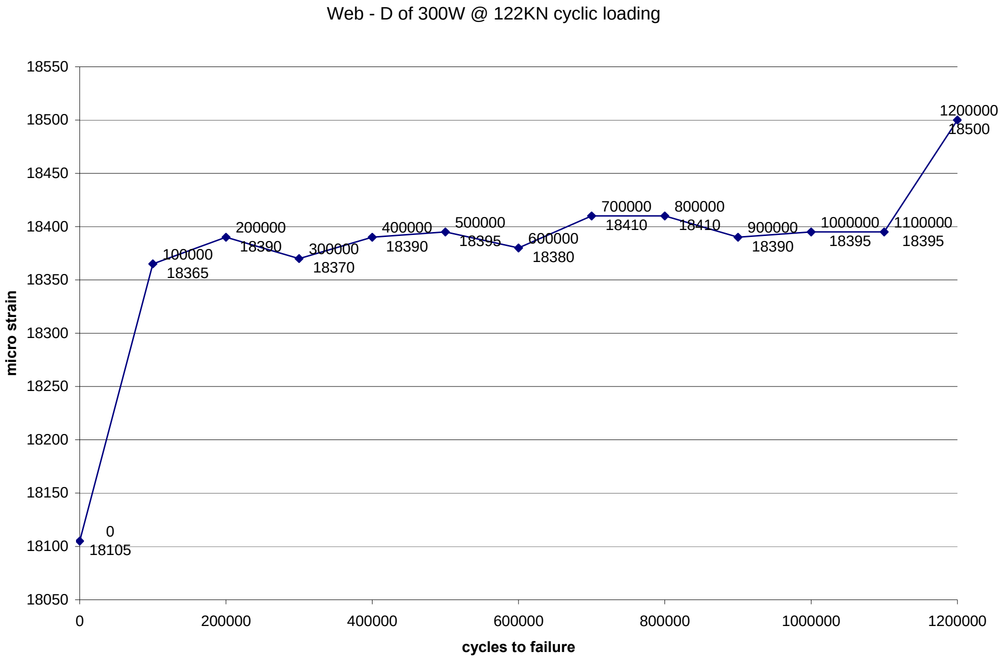


Figure 4.5 – Web D

<u>Failure Cycle, time and shape</u>:

The beam failed by out-of-plane global buckling (figure 4.6a) at 1,200,000 cycles, which was approximately 333 hours of testing. The beam also showed a sign of in-plane local buckling at both the supports (figure 4.6b) and the point of loading (figure 4.6c).

Figure 4.6a – Specimen at failure (out-of-plane global buckling)

Figure 4.6b – In-plane Local buckling at the support

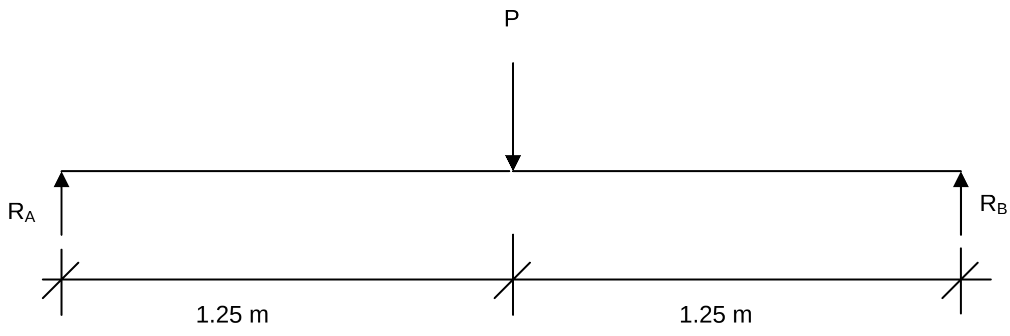
Figure 4.6c – In-plane Local buckling at the point of loading

4.1.2 <u>Grade 350W @ 0.50P</u>

Specimen 2 of Grade 350W was loaded with 122 KN at the midspan until failure.

Moment determination:

P = 122 KN

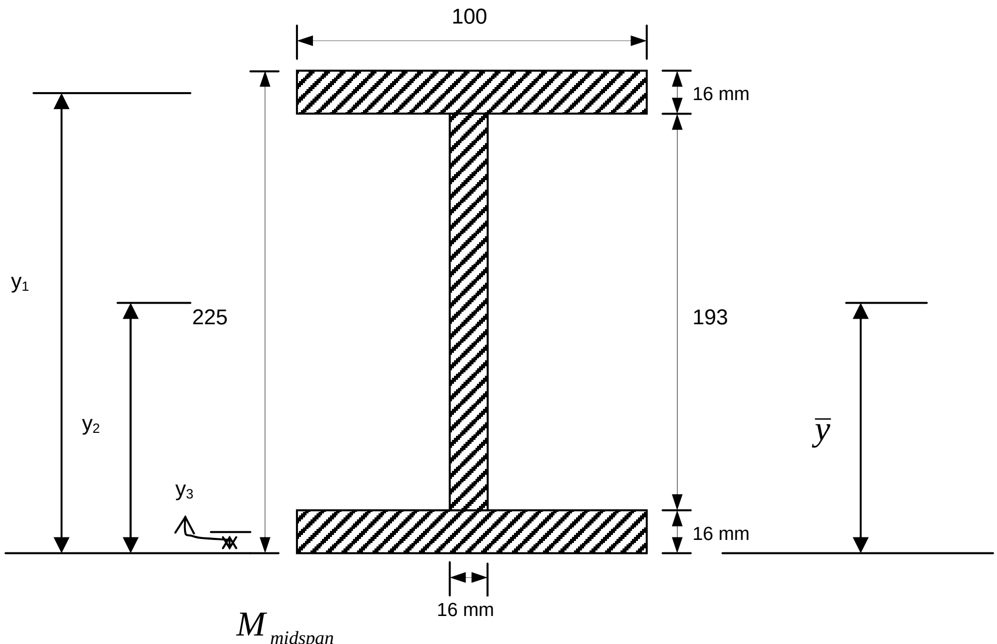


$$R_A = \frac{P}{2} = \frac{122KN}{2} = 61KN$$

Maximum moment (moment @ midpoint), M_{350} = $61KNx1.25m = 76.25KNm$

Stress determination:

Considering the section at midspan directly under the point of loading where maximum stresses will be induced, as shown below.



$$\sigma_{midspan} = \frac{M_{midspan}}{I} c$$

Where:

$\sigma_{midspan}$ = maximum stress at midspan

$M_{midspan}$ = Applied bending moment at midspan

C = Distance from neutral axis to surface of the specimen

I = Cross-sectional moment of inertia

$$\bar{y} = \frac{\sum Ay}{\sum A}$$

$$A_1 = 100x16 = 1600mm^2$$

$$A_2 = 16x193 = 3088mm^2$$

$$A_3 = 100x16 = 1600mm^2$$

$$\sum A = A_1 + A_2 + A_3 = 6288mm^2$$

$$y_1 = 225 - 8 = 217mm$$

$$y_2 = \frac{193}{2} + 16 = 112.5mm$$

$$y_3 = \frac{16}{2} = 8mm$$

$$A_1 y_1 = 1600mm^2 x217mm = 347200mm^3$$

$$A\ y_2 = 3088mm^2 x112.5mm = 347400mm^3$$

$$A_3 y_3 = 1600mm^2 x8mm = 12800mm^3$$

$$\sum Ay = A_1 y_1 + A\ y_2 + A_3 y_3 = 707400mm^3$$

$$\therefore \bar{y} = \frac{\sum Ay}{\sum A} = \frac{707400mm^3}{6288mm^2} = 112.5mm$$

$$I_1 = \frac{b_1 d_1^3}{12} + A_1 (y_1 - \bar{y})^2$$

$$= \frac{100mmx16^3 mm^3}{12} + 1600mm^2 (217mm - 112.5mm)^2$$

$$I_1 = 17506533.33mm^4$$

$$I_2 = \frac{b_2 d_2^3}{12} + A_2 (y_2 - \bar{y})^2$$

$$= \frac{16mmx193^3 mm^3}{12} + 1600mm^2 (112.5mm - 112.5mm)^2$$

$$I_2 = 9585409.33mm^4$$

$$I_3 = \frac{b_3 d_3^3}{12} + A_3 (\bar{y} - y_3)^2$$

$$= \frac{100mmx16^3 mm^3}{12} + 1600mm^2 (112.5mm - 8mm)^2$$

$$I_3 = 17506533.33mm^4$$

$$\therefore I = I_1 + I_2 + I_3 = 44598475.99mm^4$$

$$M_{midspan} = 76.25x10^{6}\,Nmm$$

$$c = 112.5mm$$

$$\therefore \sigma_{midspan} = \frac{76.25x10^{6}\,Nmmx112.5mm}{44.60x10^{6}\,mm^{4}} = 192.3N/mm^{2}$$

For minimum stress applied at midspan with P = 10 KN:

Minimum moment @ midspan, M_{min} = $5KNx1.25m = 6.25KNm$

$$\sigma_{\min} = \frac{6.25x10^{6}\,Nmmx125mm}{44.60x10^{6}\,mm^{4}} = 17.5N/mm^{2}$$

$\therefore$

$$\sigma_{\max} = 192.3N/mm^{2}$$

$$\sigma_{\min} = 15.5N/mm^{2}$$

$$Stress\,Range,\ \Delta\sigma = \sigma_{\max} - \sigma_{\min} = 176.8N/mm^{2}$$

$$Mean\,Stress, \sigma_{m} = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{207.8}{2} = 103.9N/mm^{2}$$

$$Stress\ Amplitude,\ \sigma_{a} = \frac{\Delta\sigma}{2} = 88.4N/mm^{2}$$

<u>Strain gauge results</u>

The strain values obtained during the experiment is shown below. The strain values were measured after every 100,000 cycles at a frequency of 1 Hz. 1 strain gauge was affixed at the top flange while another one was placed on the web within the zone of loading.

Table 4.2 – Strain gauge results

Cycles to failure	**Web**	**Flange**	**Stress**
0	17295	17050	192.3
100000	18450	16910	192.3
200000	18485	16900	192.3
300000	18490	16870	192.3
400000	18490	16885	192.3
500000	18480	16870	192.3
600000	18530	16900	192.3
700000	18010	17000	192.3
At failure 786000	17880	17400	192.3

Since there were no changes in stresses, i.e. a constant stress was applied to the structure throughout the testing until failure; the stress-strain curve yielded a straight line as shown below:

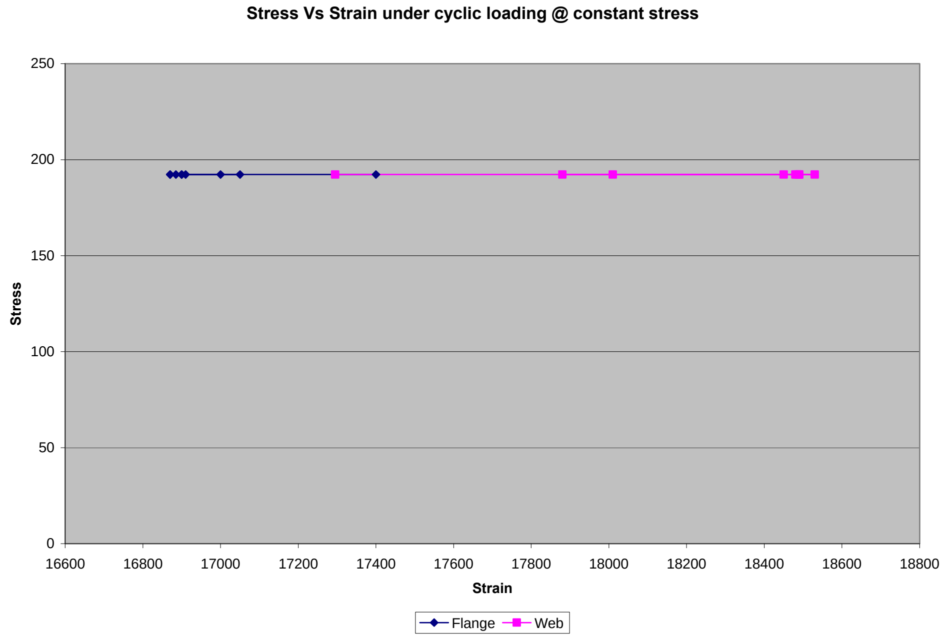


Figure 4.7 – Stress-strain curve

<u>Relationship between Strain and cycles to failure</u>

The changes in strain were monitored periodically using the strain gauges during the experiment. Microstrains were read off at every 100,000 cycles of loading.

Top flange

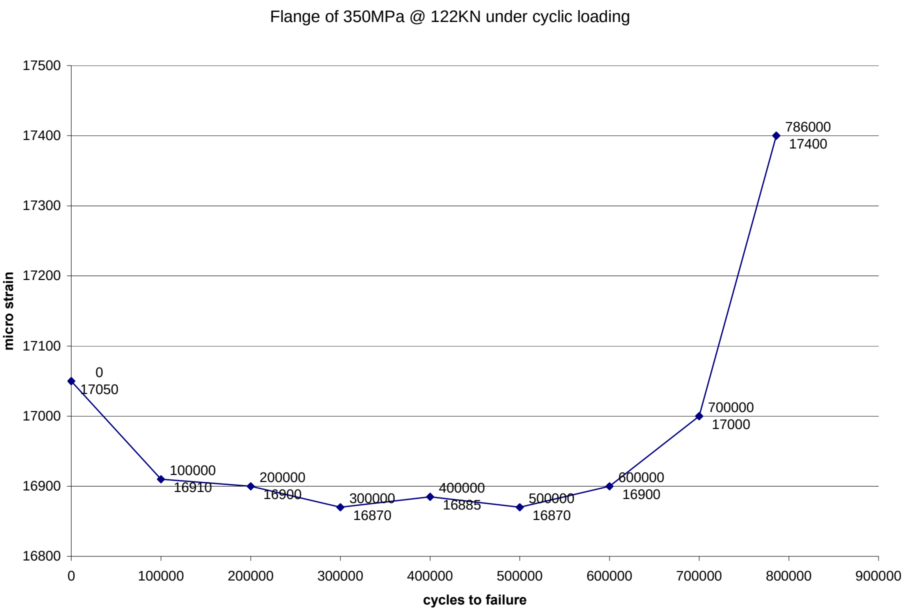


Figure 4.8 – Top flange

As can be seen from the figure above, there was a sharp contraction after the first 100,000 cycles and afterwards stabilization. This shows that the top flange was under compression.

Web

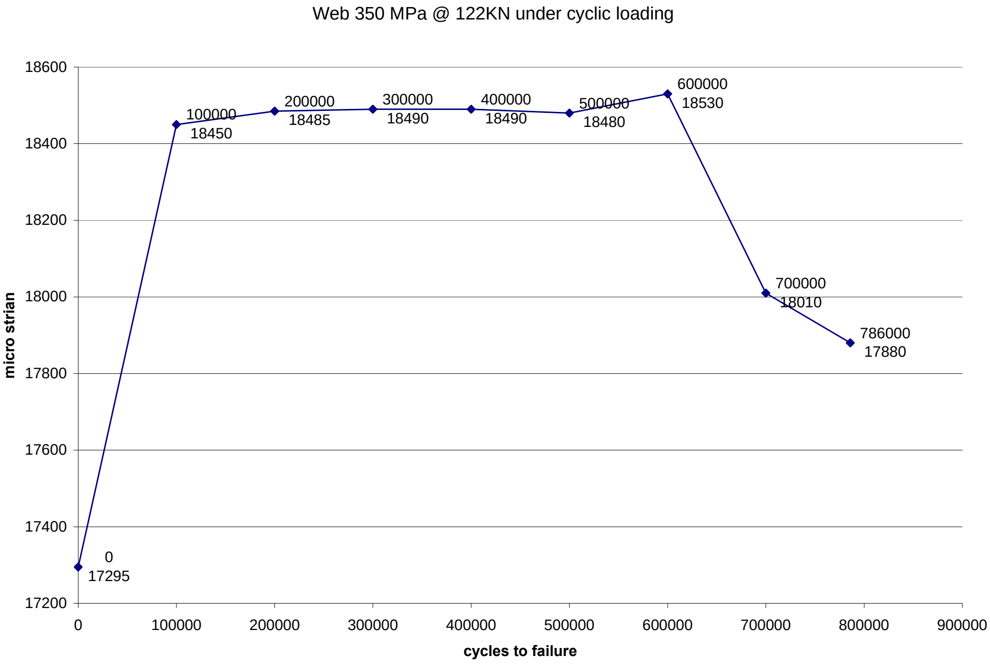


Figure 4.9 – Web B

Also, there was a sharp increment of the specimen at the web as measured using the strain gauges. This shows that the web was under tension. See figure 4.8 above.

<u>Failure Cycle</u>:

The beam failed by fracture at 786,000 cycles, which was approximately 218 hours of testing. The fracture occurred a small distance away from the point of loading. But since there was a carton packing of 120 mm long at the point of loading to help distribute the load, it can be said that failure occurred within the zone of loading.

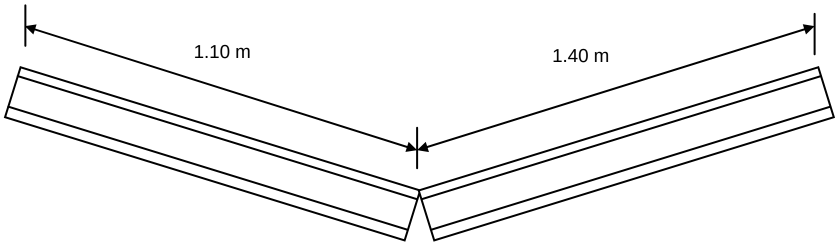


Figure 4.10a

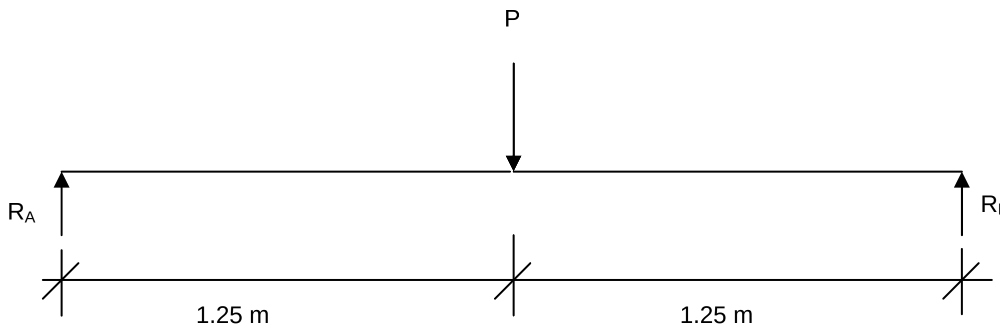
Figure 4.10b – Specimen at failure

4.1.3 <u>Grade 460W @ 0.50P</u>

Specimen 3 of Grade 460W was loaded with 122 KN at the midspan until failure.

<u>Moment determination</u>:

P = 122 KN



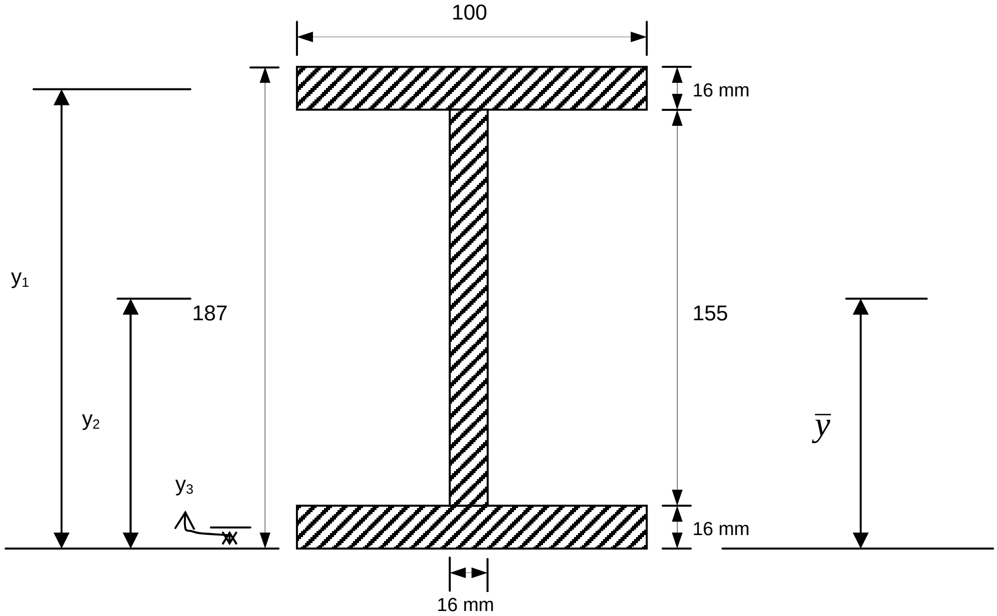
$$R_A = \frac{P}{2} = \frac{122KN}{2} = 61KN$$

Maximum moment (moment @ midpoint), M_{460} =

$$61KNx1.25m = 76.25KNm$$

Stress determination:

Considering the section at midspan directly under the point of loading where maximum stresses will be induced, as shown below.



$$\sigma_{midspan} = \frac{M_{midspan}}{I} c$$

Where:

$\sigma_{midspan}$ = maximum stress at midspan

$M_{midspan}$ = Applied bending moment at midspan

C = Distance from neutral axis to surface of the specimen

I = Cross-sectional moment of inertia

$$\bar{y} = \frac{\sum Ay}{\sum A}$$

$$A_1 = 100x16 = 1600mm^2$$

$$A_2 = 16x155 = 2480mm^2$$

$$A_3 = 100x16 = 1600mm^2$$

$$\sum A = A_1 + A_2 + A_3 = 5680mm^2$$

$$y_1 = 187 - 8 = 179mm$$

$$y_2 = \frac{155}{2} + 16 = 93.5mm$$

$$y_3 = \frac{16}{2} = 8mm$$

$$A_1 y_1 = 1600mm^2 x179mm = 286400mm^3$$

$$A\ y_2 = 2480mm^2 x93.5mm = 231880mm^3$$

$$A_3 y_3 = 1600mm^2 x8mm = 12800mm^3$$

$$\sum Ay = A_1 y_1 + A\ y_2 + A_3 y_3 = 531080mm^3$$

$$\therefore \bar{y} = \frac{\sum Ay}{\sum A} = \frac{531080mm^3}{5680mm^2} = 93.5mm$$

$$I_1 = \frac{b_1 d_1^3}{12} + A_1\left(y_1 - \bar{y}\right)^2$$

$$= \frac{100mmx16^3 mm^3}{12} + 1600mm^2\left(179mm - 93.5mm\right)^2$$

$$I_1 = 11730533.33mm^4$$

$$I_2 = \frac{b_2 d_2^3}{12} + A_2\left(y_2 - \bar{y}\right)^2$$

$$= \frac{16mmx155^3 mm^3}{12} + 1600mm^2\left(93.5mm - 93.5mm\right)^2$$

$$I_2 = 4965166.67mm^4$$

$$I_3 = \frac{b_3 d_3^3}{12} + A_3\left(\bar{y} - y_3\right)^2$$

$$= \frac{100mmx16^3 mm^3}{12} + 1600mm^2\left(93.5mm - 8mm\right)^2$$

$$I_3 = 11730533.33mm^4$$

$$\therefore I = I_1 + I_2 + I_3 = 28426233.33mm^4$$

$$M_{midspan} = 76.25x10^6\ Nmm$$

$$c = 93.5mm$$

$$\therefore \sigma_{midspan} = \frac{76.25x10^6\ Nmmx93.5mm}{28.43x10^6\ mm^4} = 251N/mm^2$$

For minimum stress applied at midspan with P = 10 KN:

Minimum moment @ midspan, M_{min} = $5KNx1.25m = 6.25KNm$

$$\sigma_{\min} = \frac{6.25x10^6\ Nmmx125mm}{28.43x10^6\ mm^4} = 27.5N/mm^2$$

$\therefore$

$\sigma_{\max} = 251 N/mm^2$

$\sigma_{\min} = 27.5 N/mm^2$

$$Stress\,Range,\ \Delta\sigma = \sigma_{\max} - \sigma_{\min} = 223.5 N/mm^2$$

$$Mean\,Stress, \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{278.5}{2} = 139.25 N/mm^2$$

$$Stress\ Amplitude,\ \sigma_a = \frac{\Delta\sigma}{2} = 111.75 N/mm^2$$

Strain gauge results

The strain values obtained during the experiment is shown below. The strain values were measured after every 100,000 cycles at a frequency of 1 Hz. 1 strain gauge was affixed at the top flange while another one was placed on the web within the zone of loading.

Table 4.3 – Strain gauge results

Cycles to failure	**Web**	**Flange**	**Stress**
0	17400	23975	251
50000	18100	21855	251
100000	18060	22035	251
150000	18000	22610	251
At Failure 182400	19300	18290	251

Since there were no changes in stresses, i.e. a constant stress was applied to the structure throughout the testing until failure; the stress-strain curve yielded a straight line as shown below:

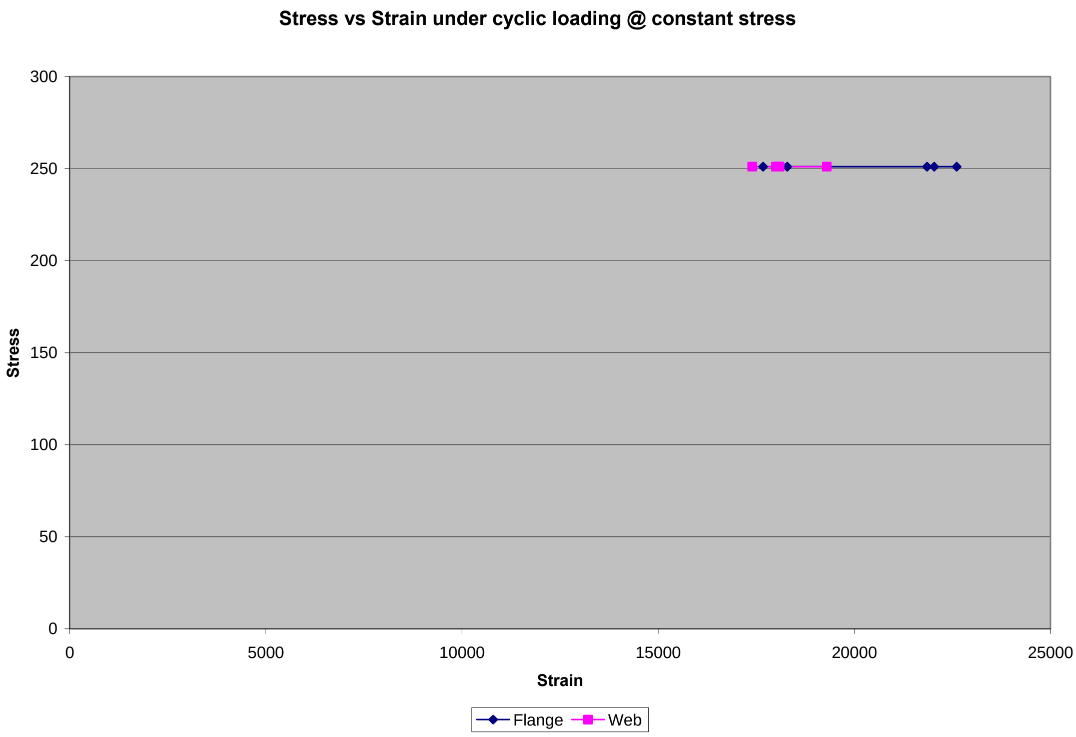


Figure 4.11 – Stress-strain curve

<u>Relationship between Strain and cycles to failure</u>

The changes in strain were monitored periodically using the strain gauges during the experiment. Microstrains were read off at every 50,000 cycles of loading.

Top flange

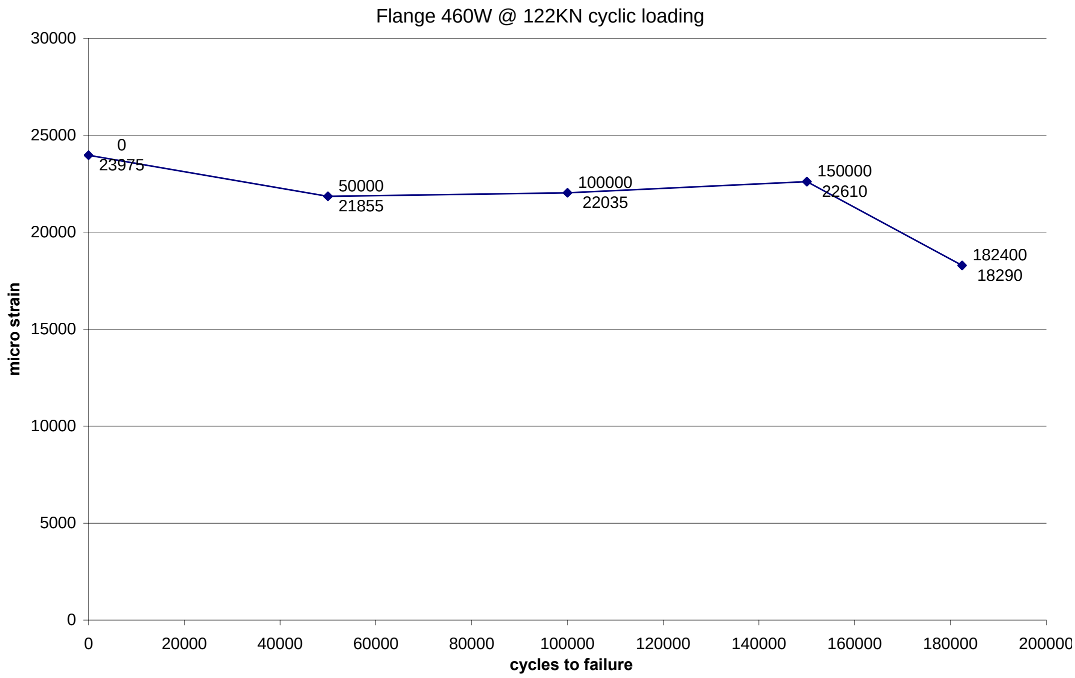


Figure 4.12 – Top flange

As can be seen from the figure above, there was a sharp contraction after the first 50,000 cycles and afterwards stabilization. This shows that the top flange was under compression.

Web

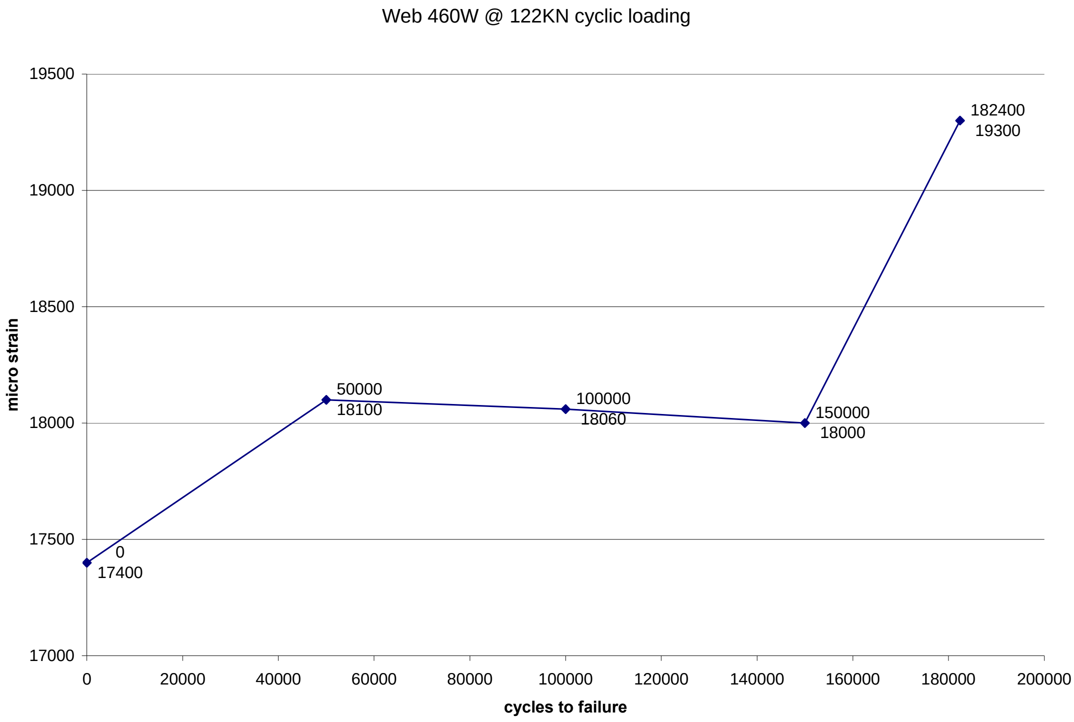


Figure 4.13 – Web B

Also, there was a sharp increment of the specimen at the web as measured using the strain gauges. This shows that the web was under tension. See figure 4.11 above.

<u>Failure Cycle</u>:

The beam failed by fracture at 182,400 cycles, which was approximately 51 hours of testing. Fracture at a distance slightly away from the centre of the beam but still within the zone of loading as shown below.

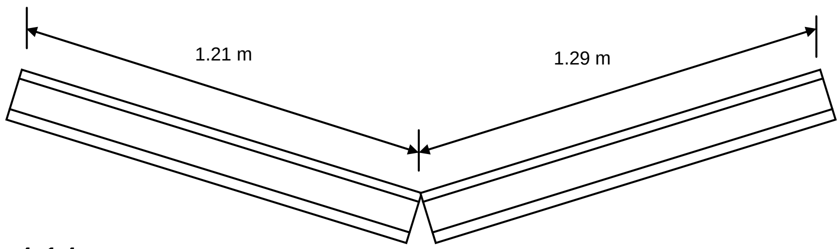


Figure 4.14a

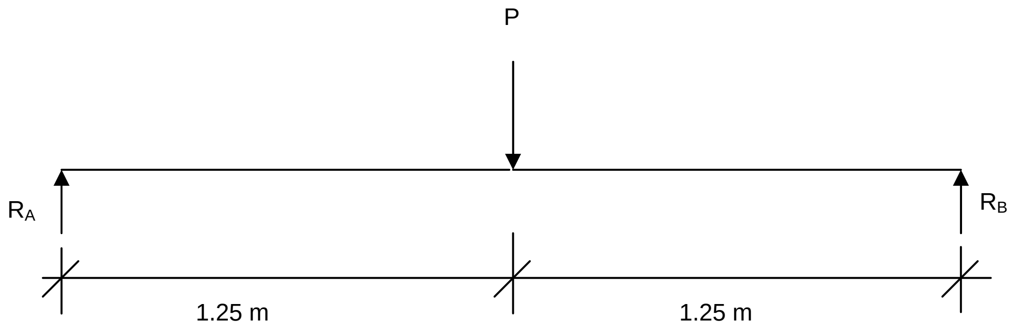
Figure 4.14b – Specimen at failure

4.1.4 Grade 300W @ 0.75P

Specimen 4 of Grade 300W was loaded with 184 KN at the midspan until failure.

Moment determination:

P = 184 KN

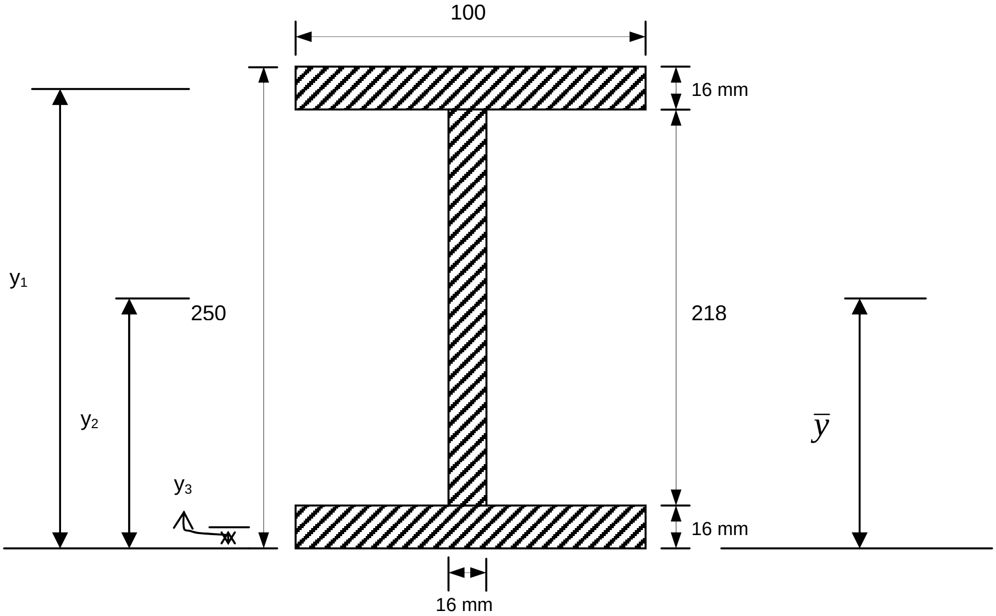


$$R_A = \frac{P}{2} = \frac{184KN}{2} = 92KN$$

Maximum moment (moment @ midpoint), M_{300} = $92KNx1.25m = 115KNm$

Stress determination:

Considering the section at midspan directly under the point of loading where maximum stresses were induced, as shown below.



$$\sigma_{midspan} = \frac{M_{midspan}}{I} c$$

Where:

$\sigma_{midspan}$ = maximum stress at midspan

$M_{midspan}$ = Applied bending moment at midspan

C = Distance from neutral axis to surface of the specimen

I = Cross-sectional moment of inertia

As previously determined,

$$\therefore I = 57686709.33mm^4$$

$$M_{midspan} = 76.25x10^6 Nmm$$

$$c = 125mm$$

$$\therefore \sigma_{midspan} = \frac{115x10^6 Nmmx125mm}{57.69x10^6 mm^4} = 249N/mm^2$$

For minimum stress applied at midspan with P = 10 KN:

Minimum moment @ midspan, M_{min} = $5KNx1.25m = 6.25KNm$

$$\sigma_{min} = 13.5N/mm^2$$

$\therefore$

$$\sigma_{\max} = 249 N/mm^2$$

$$\sigma_{\min} = 13.5 N/mm^2$$

$$Stress\ Range,\ \Delta\sigma = \sigma_{\max} - \sigma_{\min} = 235.5 N/mm^2$$

$$Mean\ Stress, \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{262.5}{2} = 131.25 N/mm^2$$

$$Stress\ Amplitude,\ \sigma_a = \frac{\Delta\sigma}{2} = 117.75 N/mm^2$$

Strain gauge results

The strain values obtained during the experiment is shown below. The strain values were measured after every 100,000 cycles at a frequency of 1 Hz. 1 strain gauge was affixed at the top flange while another one was placed on the web within the zone of loading.

Table 4.4 – Strain gauge results

Cycles to failure	**Web**	**Flange**	**Stress**
0	16455	18330	249
100000	16600	16600	249
200000	16630	16640	249
300000	16610	16590	249
At failure 322023	16590		249

Since there were no changes in stresses, i.e. a constant stress was applied to the structure throughout the testing until failure; the stress-strain curve yielded a straight line as shown below:

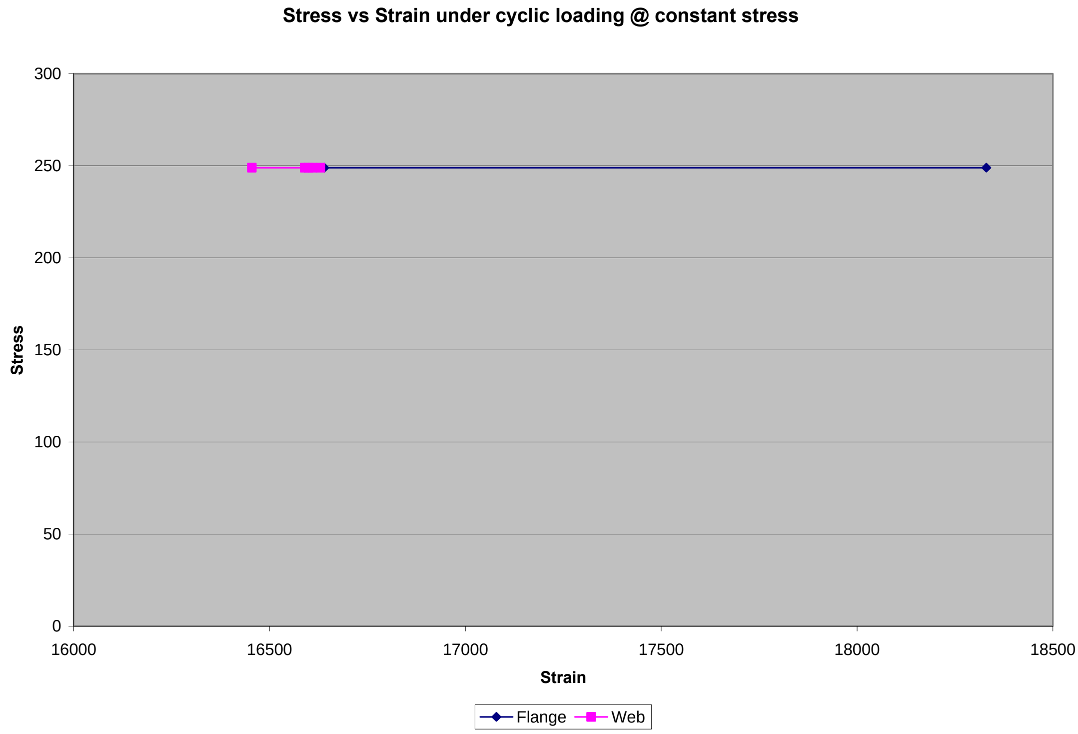


Figure 4.15 – Stress-strain curve

<u>Relationship between Strain and cycles to failure</u>

The changes in strain were monitored periodically using the strain gauges during the experiment. Microstrains were read off at every 100,000 cycles of loading.

Top flange

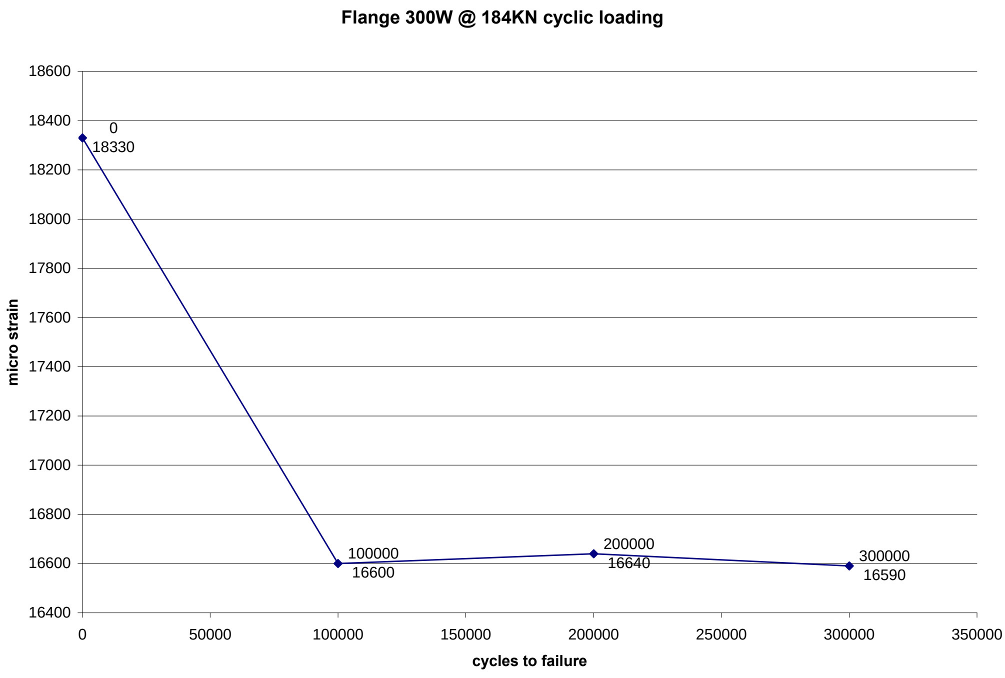


Figure 4.16 – Top flange

As can be seen from the figure above, there was a sharp contraction after the first 100,000 cycles and afterwards stabilization. This shows that the top flange was under compression.

Web - B

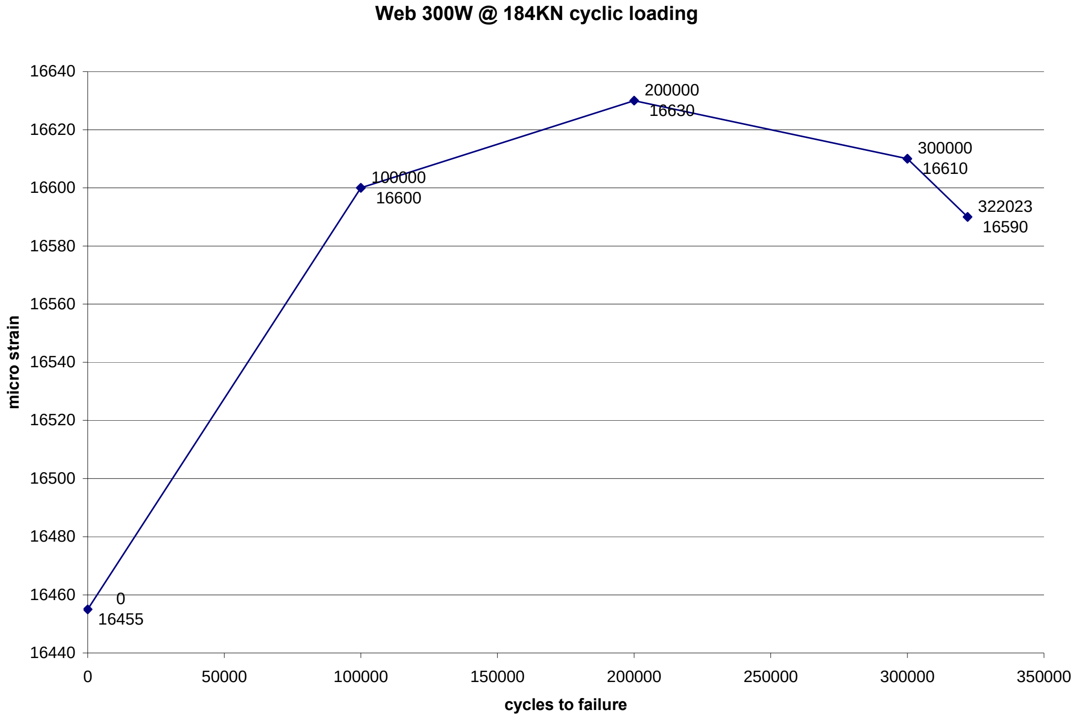


Figure 4.17 – Web B

Also, there was a sharp increment of the specimen at the web as measured using the strain gauges. This shows that the web was under tension.

<u>Failure Cycle</u>:

The beam failed by fracture at 322,023 cycles, which was approximately 89 hours of testing. Fracture occurred approximately at the middle of the beam within the zone of loading.

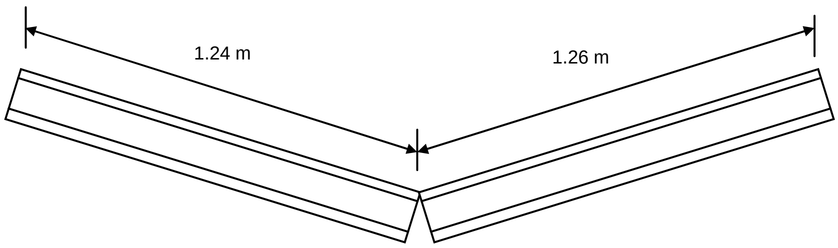


Figure 4.18a

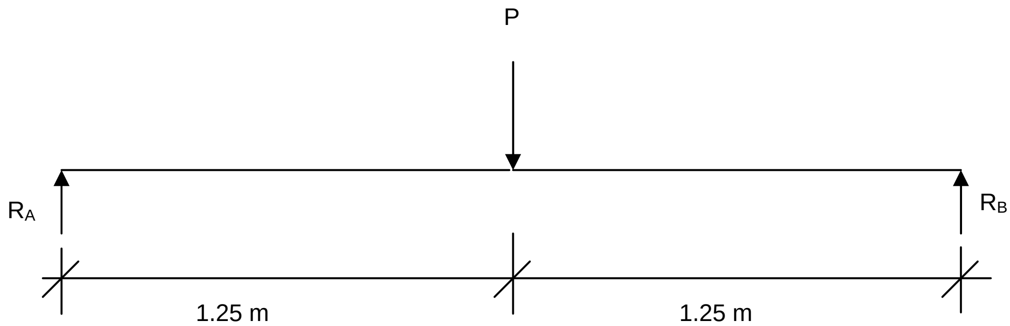
Figure 4.18b – Specimen at failure

4.1.5 <u>Grade 350W @ 0.75P</u>

Specimen 5 of Grade 350W was loaded with 184 KN at the midspan until failure.

<u>Moment determination</u>:

P = 184 KN



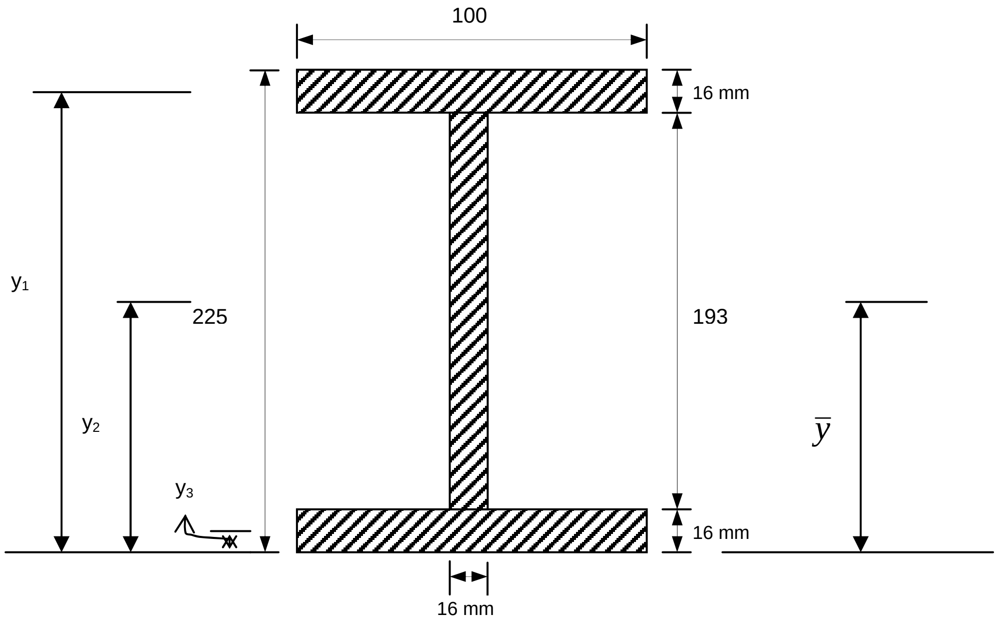
$$R_A = \frac{P}{2} = \frac{184KN}{2} = 92KN$$

Maximum moment (moment @ midpoint), M_{350} =

$92KNx1.25m = 115KNm$

<u>Stress determination</u>:

Considering the section at midspan directly under the point of loading where maximum stresses will be induced, as shown below.



$$\sigma_{midspan} = \frac{M_{midspan}}{I}c$$

Where:

$\sigma_{midspan}$ = maximum stress at midspan

$M_{midspan}$ = Applied bending moment at midspan

C = Distance from neutral axis to surface of the specimen

I = Cross-sectional moment of inertia

As already determined earlier,

$$\therefore I = 44598475.99mm^4$$

$$M_{midspan} = 115x10^6 Nmm$$

$$c = 112.5mm$$

$$\therefore \sigma_{midspan} = \frac{115x10^6 Nmmx112.5mm}{44.60x10^6 mm^4} = 290N/mm^2$$

For minimum stress applied at midspan with P = 10 KN:

Minimum moment @ midspan, M_{min} = $5KNx1.25m = 6.25KNm$

$$\sigma_{min} = 17.5N/mm^2$$

$\therefore$

$$\sigma_{\max} = 290 N/mm^2$$

$$\sigma_{\min} = 17.5 N/mm^2$$

$$Stress\ Range,\ \Delta\sigma = \sigma_{\max} - \sigma_{\min} = 272.5 N/mm^2$$

$$Mean\ Stress, \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{307.5}{2} = 153.25 N/mm^2$$

$$Stress\ Amplitude,\ \sigma_a = \frac{\Delta\sigma}{2} = 136.25 N/mm^2$$

Strain gauge results

The strain values obtained during the experiment is shown below. The strain values were measured after 60 cycles at a frequency of 1 Hz when the structure deformed in its global axis. 1 strain gauge was affixed at the top flange while another one was placed on the web within the zone of loading.

Table 4.4 – Strain gauge results

Cycles to failure	Flange	Web	Stress
0	17610	17050	290
At failure 60	17185	19370	290

Since there were no changes in stresses, i.e. a constant stress was applied to the structure throughout the testing until deformation occurred; the stress-strain curve yielded a straight line as shown below:

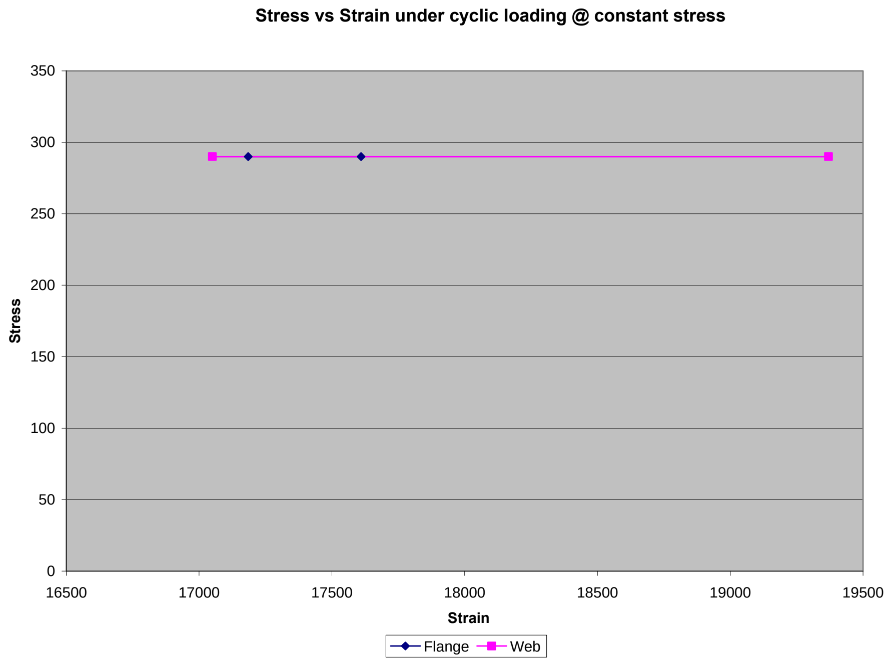


Figure 4.19 – Stress-strain curve

Relationship between Strain and cycles to failure

The changes in strain were monitored periodically using the strain gauges during the experiment. Microstrains were read off at the end of the 60 cycle deformation.

Top flange

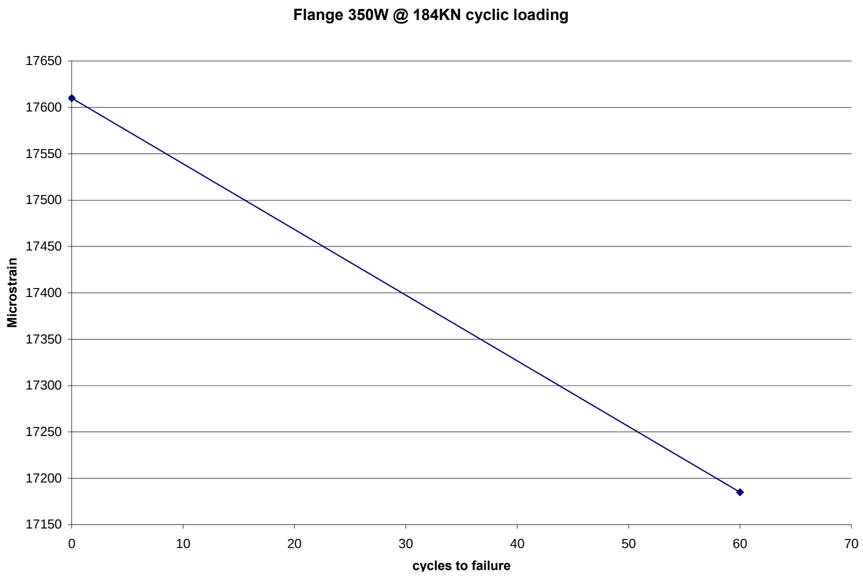


Figure 4.20 – Top flange

As can be seen from the figure above, there was a sharp reduction after the 60 cycles of loading. This shows that the top flange was under compression.

Web - B

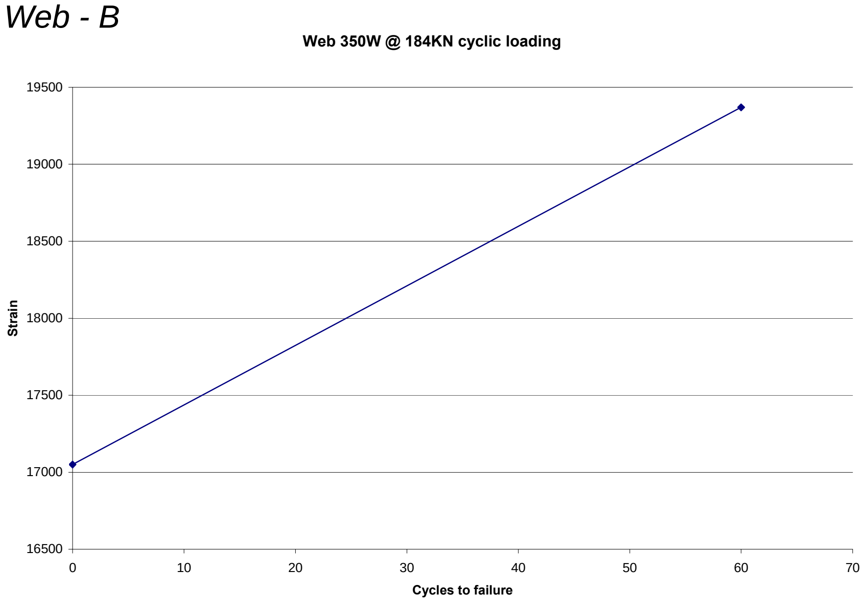


Figure 4.21 – Web B

Also, there was a sharp increment of the specimen at the web as measured using the strain gauges. This shows that the web was under tension.

Failure Cycle:

The beam failed by deformation at 60 cycles, which was approximately 1 minute of testing. Deformation of 30 mm maximum occurred at the centre of the beam.

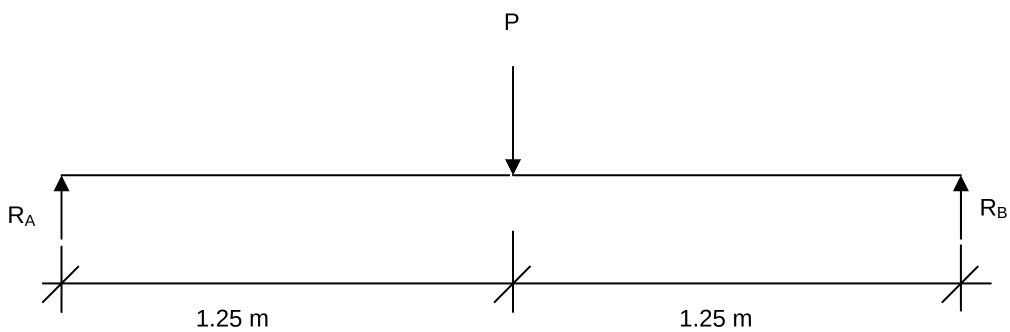
Figure 4.22 – Specimen at failure

4.1.6 Grade 460W @ 0.75P

Specimen 6 of Grade 350W was loaded with 184 KN at the midspan until failure.

Moment determination:

P = 184 KN

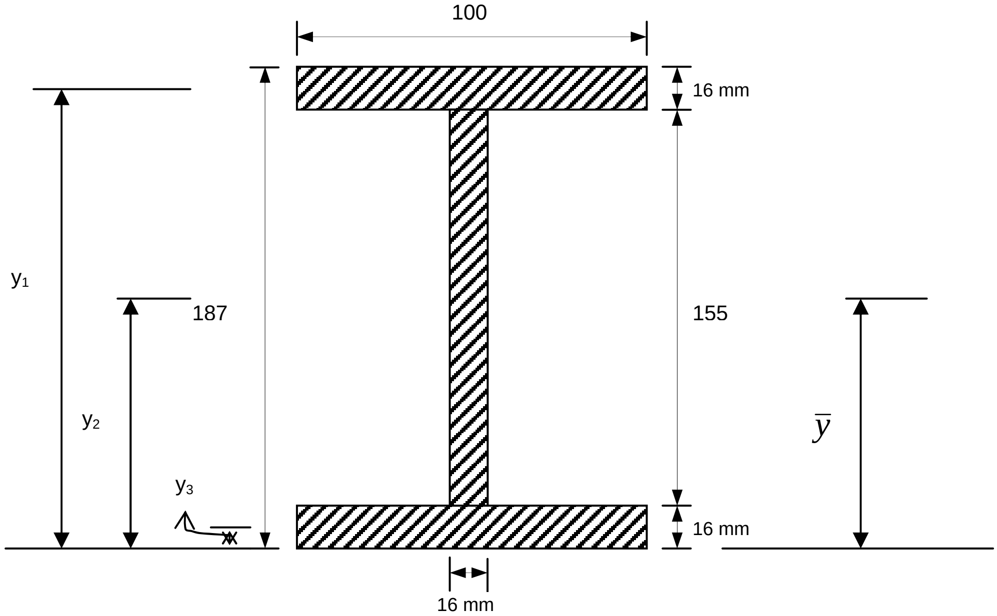


$$R_A = \frac{P}{2} = \frac{184KN}{2} = 92KN$$

Maximum moment (moment @ midpoint), M_{460} = $92KNx1.25m = 115KNm$

<u>Stress determination</u>:

Considering the section at midspan directly under the point of loading where maximum stresses will be induced, as shown below.



$$\sigma_{midspan} = \frac{M_{midspan}}{I} c$$

Where:

$\sigma_{midspan}$ = maximum stress at midspan

$M_{midspan}$ = Applied bending moment at midspan

C = Distance from neutral axis to surface of the specimen

I = Cross-sectional moment of inertia

As already determined earlier,

$$\therefore I = 28426233.33mm^4$$

$$M_{midspan} = 115x10^6 \ Nmm$$

$$c = 93.5mm$$

$$\therefore \sigma_{midspan} = \frac{115x10^6\,Nmmx93.5mm}{28.43x10^6\,mm^4} = 378N/mm^2$$

For minimum stress applied at midspan with P = 10 KN:

Minimum moment @ midspan, M_{min} = $5KNx1.25m = 6.25KNm$

$\sigma_{\min} = 27.5N/mm^2$

$\therefore$

$\sigma_{\max} = 378N/mm^2$

$\sigma_{\min} = 27.5N/mm^2$

$$Stress\,Range,\ \Delta\sigma = \sigma_{\max} - \sigma_{\min} = 350.5N/mm^2$$

$$Mean\,Stress, \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{405.5}{2} = 202.75N/mm^2$$

$$Stress\ Amplitude,\ \sigma_a = \frac{\Delta\sigma}{2} = 175.25N/mm^2$$

<u>Strain gauge results</u>

The strain values obtained during the experiment is shown below. The strain values were measured after 50 cycles at a frequency of 1 Hz when the structure deformed in its global axis. 1 strain gauge was affixed at the top flange while another one was placed on the web within the zone of loading.

Table 4.4 – Strain gauge results

Cycles to failure	**Flange**	**Web**	**Stress**
0	18310	17780	378
At failure 50	17420	19650	378

Since there were no changes in stresses, i.e. a constant stress was applied to the structure throughout the testing until deformation occurred; the stress-strain curve yielded a straight line as shown below:

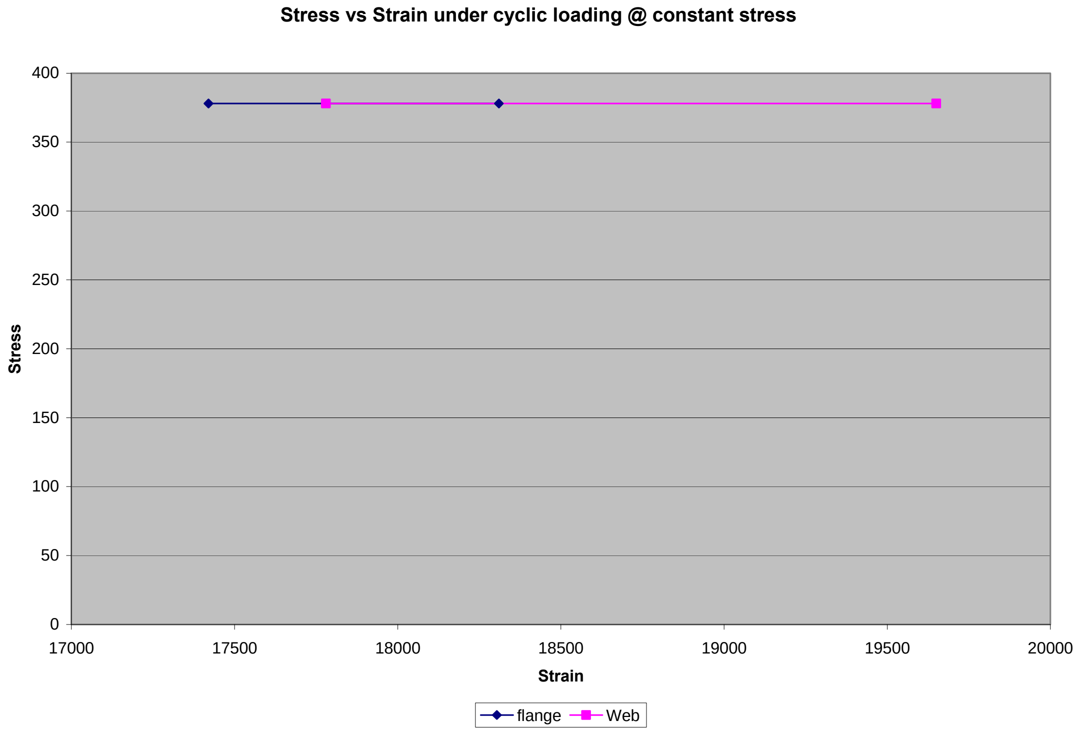


Figure 4.23 – Stress-strain curve

<u>Relationship between Strain and cycles to failure</u>

The changes in strain were monitored periodically using the strain gauges during the experiment. Microstrains were read off at the end of the 50 cycle deformation.

Top flange

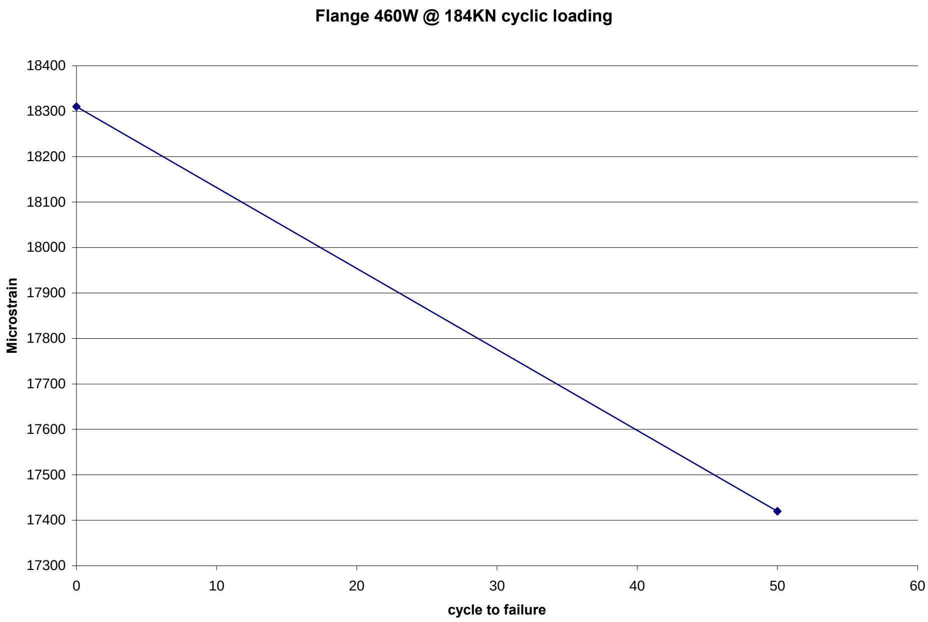


Figure 4.24 – Top flange

As can be seen from the figure above, there was a sharp reduction after the 60 cycles of loading. This shows that the top flange was under compression.

Web - B

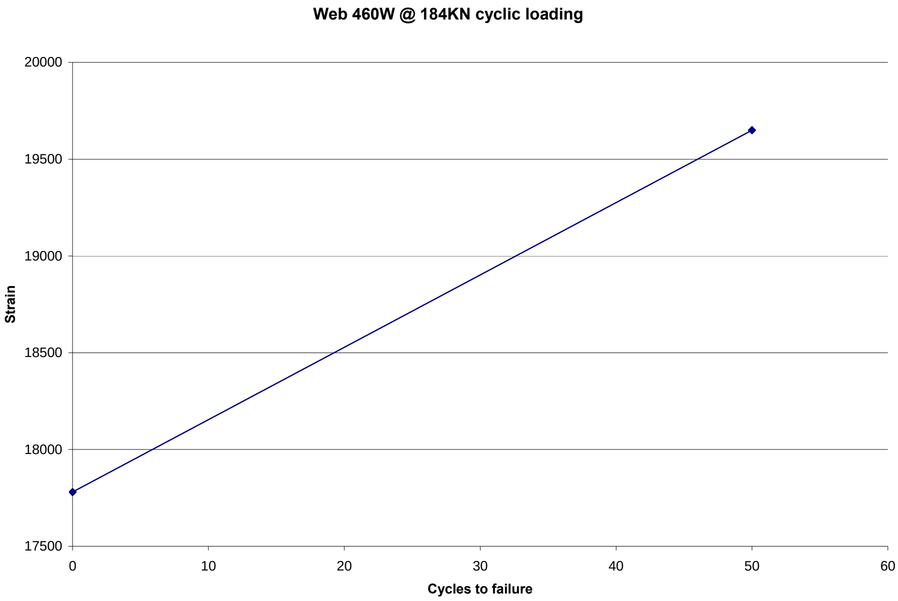


Figure 4.25 – Web B

Also, there was a sharp increment of the specimen at the web as measured using the strain gauges. This shows that the web was under tension.

<u>Failure Cycle</u>:

The beam failed by deformation at 50 cycles, which was approximately 1 minute of testing. Deformation of 70 mm maximum occurred at the centre of the beam.

Figure 4.26 – Specimen at failure

4.2 FURTHER DISCUSSIONS

4.2.1 Cycles to failure

It is observed that as the steel grades increase in yield stress with lower web depth, their cycle to failure reduces. As a summary, the tables below show the points and mode of failure for the various steel grades tested under the same load factor.

Under 0.5P = 122KN

Table 4.5

Steel Grades	Failure Cycle	Testing Time	Comment
300W	1,200,000	333 hours	Buckling
350W	786,000	218 hours	Fracture
460W	182,400	51 hours	Fracture

Under 0.75P = 184KN

Table 4.6

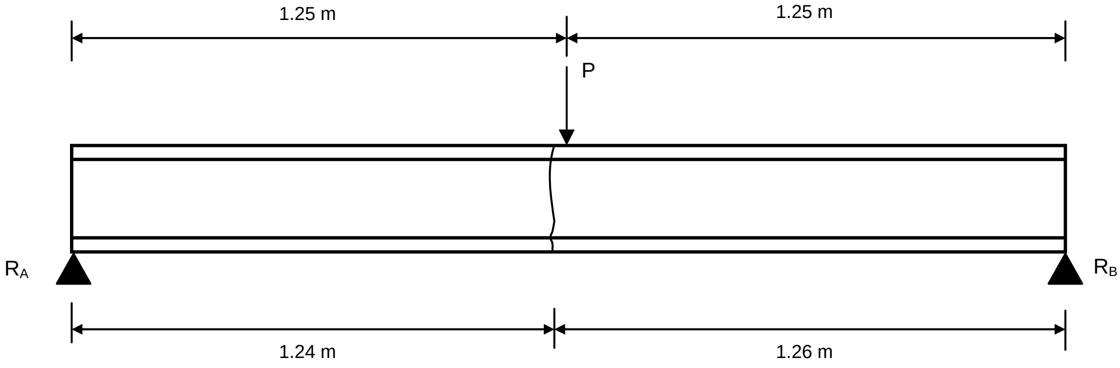
Steel Grades	Failure Cycle	Testing Time	Comment
300W	322,023	89 hours	Fracture
350W	60	1 minute	Buckling
460W	50	50 seconds	Buckling

As already been indicated, all the beams have the same moment capacity but varies in section dimension. The thickness and the flange dimension of all the specimen were kept constant, only the depth of flanges were changed in other to achieve equal capacity.

4.2.2 Determination of stresses at the point of failure

Stresses will be determined for 300W @ 184 KN, 350 @ 122 KN and 460W @ 122 KN which were the beams that failed by fracture.

300W @ 184 KN



$$P = 184KN$$

$$R_A = R_B = \frac{184KN}{2} = 92KN$$

$$M_{1.24} = 92KNx1.24m = 114.08KNm$$

$$\sigma_{1.24} = \frac{M_{1.24}}{I}c$$

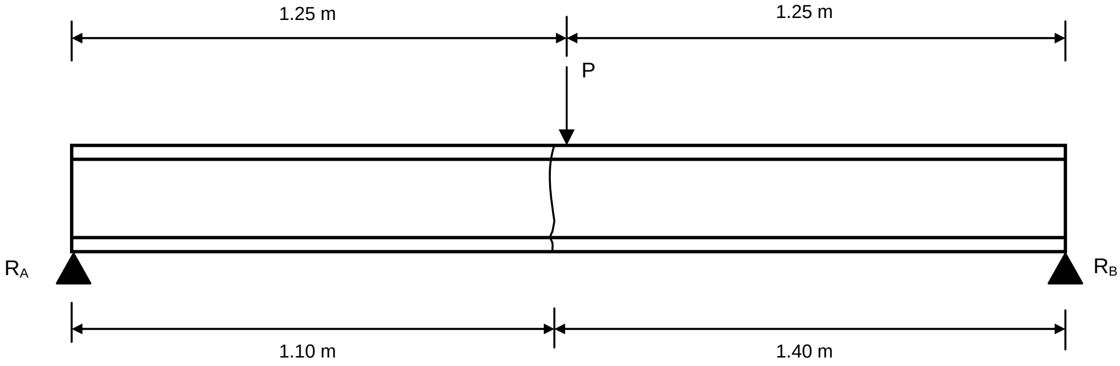
From previous calculations,

$$I = 57.69x10^6 mm^4$$

$$c = 125mm$$

$$\therefore \sigma_{1.24} = \frac{114.08x10^6 Nmm}{57.69x10^6 mm^4} x125mm = 247.2N/mm^2$$

350W @ 122 KN



$$P = 122KN$$

$$R_A = R_B = \frac{122KN}{2} = 61KN$$

$$M_{1.10} = 61KNx1.10m = 67.1KNm$$

$$\sigma_{1.10} = \frac{M_{1.10}}{I}c$$

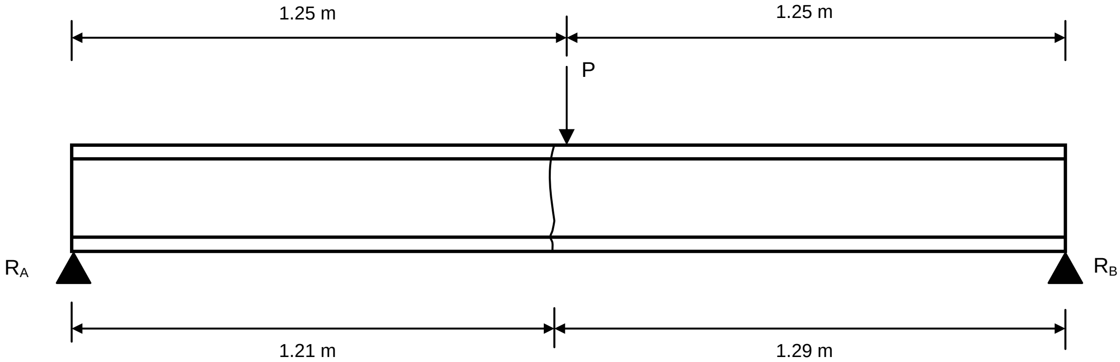
From previous calculations,

$$I = 44.6x10^6\,mm^4$$

$$c = 112.5mm$$

$$\therefore \sigma_{1.10} = \frac{67.1x10^6\,Nmm}{44.6x10^6\,mm^4}x112.5mm = 169.3N/mm^2$$

460W @ 122 KN



$$P = 122KN$$

$$R_A = R_B = \frac{122KN}{2} = 61KN$$

$$M_{1.21} = 61KNx1.21m = 73.81KNm$$

$$\sigma_{1.21} = \frac{M_{1.21}}{I}c$$

From previous calculations,

$$I = 28.43x10^6\,mm^4$$

$$c = 93.5mm$$

$$\therefore \sigma_{1.21} = \frac{73.81x10^6\,Nmm}{28.43x10^6\,mm^4}x93.5mm = 243N/mm^2$$

Summarily, the moment and stress at the point of fracture as compared to the maximum moment and stresses applied at midspan are represented in the table below:

Table 4.5

Specimen	Maximum Moment @ midspan	Moment at point of failure	Maximum Stress @ midspan	Stress at point of failure
300 @ 184 KN	115 KNm	114.08 KNm	249 N/mm^2	247.2 N/mm^2
350 @ 122 KN	76.25 KNm	67.1 KNm	192.3 N/mm^2	169.3 N/mm^2
460 @ 122 KN	76.25 KNm	73.81 KNm	251 N/mm^2	243 N/mm^2

Stress Table:

Table 4.6 – Stress Table

Specimen	Maximum Stress, σ_{max} (N/mm^2)	Minimum Stress, σ_{min} (N/mm^2)	Stress Range, $\Delta\sigma$ (N/mm^2)	Mean Stress, σ_m (N/mm^2)	Stress Amplitude, σ_m (N/mm^2)
300@122KN	165	13.5	151.5	89.25	75.75
350@122KN	192.3	15.5	176.8	103.9	88.4
460@122KN	251	27.5	223.5	139.25	111.75
300@184KN	249	13.5	235.5	131.25	117.75
350@184KN	290	17.5	272.5	153.25	136.25
460@184KN	378	27.5	350.5	202.75	175.25

4.2.3 Relationship of graph curves

As can be seen in the above graphs plotted, the behaviour of the strain gauge is similar to each other.

All the strain measurements were similar (see figures 4.2, 4.8, 4.12, 4.16, 4.20 and 4.24), i.e. there was a visible contraction in length after the first 100,000 cycles of testing, then stabilization. This notably shows that the flanges were subjected to initial compression. The stabilization was a fluctuation between contractions and expansions as the beam was been dynamically loaded. This shows that the beam was experiencing both strain hardening and softening as it was been loaded.

Also, all the strain gauges placed on the web, figures 4.3, 4.4, 4.5, 4.16, 4.9, 4.13, 4.17, 4.21 and 4.25 showed similar behaviour, i.e. there was a visible expansion in length after the first 100,000 cycles of testing, then stabilization. This notably shows that the webs were subjected to initial tension. The stabilization was a fluctuation between contractions and expansions as the beam was been dynamically loaded. In other words, the beam was experiencing both strain hardening and softening as it was been loaded.

The values of the strain gauges after failure seem outrageous and should be neglected in design analysis since they were obtained after failure. This was caused by a snap of the strain gauges since the failure instantaneously.

4.2.4 Relationship of the zone of failure

As can be seen from the failure modes, all the specimens failed, whether fracture or deformation, within the zone of loading. The stresses induced at the point of failure where close to the maximum stresses induced at the midspan of the specimens. Even the specimen 1 (300W @ 122 KN) which failed by global buckling, the maximum deformation occurred at the zone of loading.