

FATIGUE PROPERTIES OF STAINLESS STEEL STRIP

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EFFECT OF STRENGTH

The fatigue strength, defined by the fatigue limit S_o (stress amplitude) in Wöhler curves at the life of $10^6 - 10^7$ load cycles can be related to the tensile strength (R_m) as shown in Table I and Figure 1 & 2.

Table I. Fatigue properties of stainless steel.

Steel type	S_o/R_m		Uncertainty	Limitations
Stress ratio	$R = -1$	$R = 0$		
Austenitic 1.4301, 1.4310, (304, 301)	0.45	0.35	0.04	$<R_{p0.2}$
Duplex 1.4362, 1.4462 (2304, 2205)	0.60	0.35	0.04	$<R_{p0.2}$

The fatigue limit, S_o has also been related to the yield strength (R_p), in Fig. 1 and 2. The fatigue ratio S_o/R_p exhibits a substantial variation with strength but the S_o/R_m -ratio is almost independent of strength within each steel type. The lower values of fatigue ratio for the austenitic steels compared to the duplex is a consequence of the low yield to tensile strength ratio for the austenitics. The effect of stress ratio, $R = S_{min}/S_{max}$, is as expected, reflecting only that the fatigue limit decreases with increasing mean load.

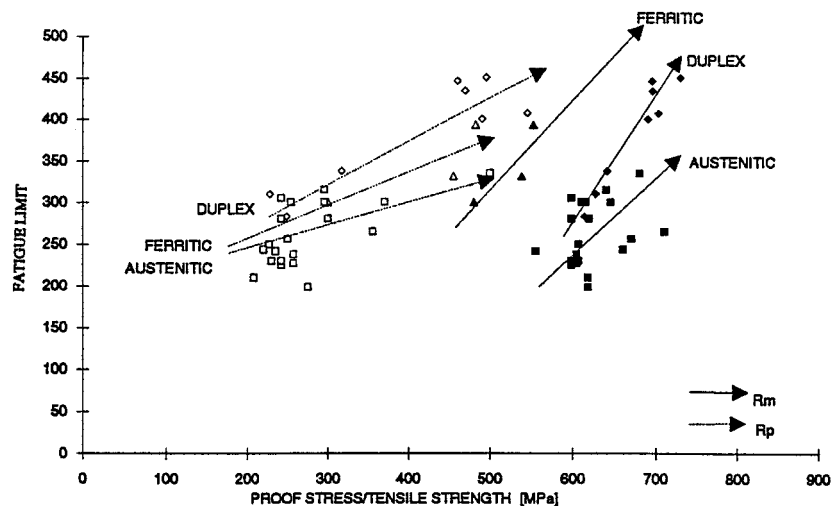


Fig. 1. The fatigue limit related to yield and tensile strength.

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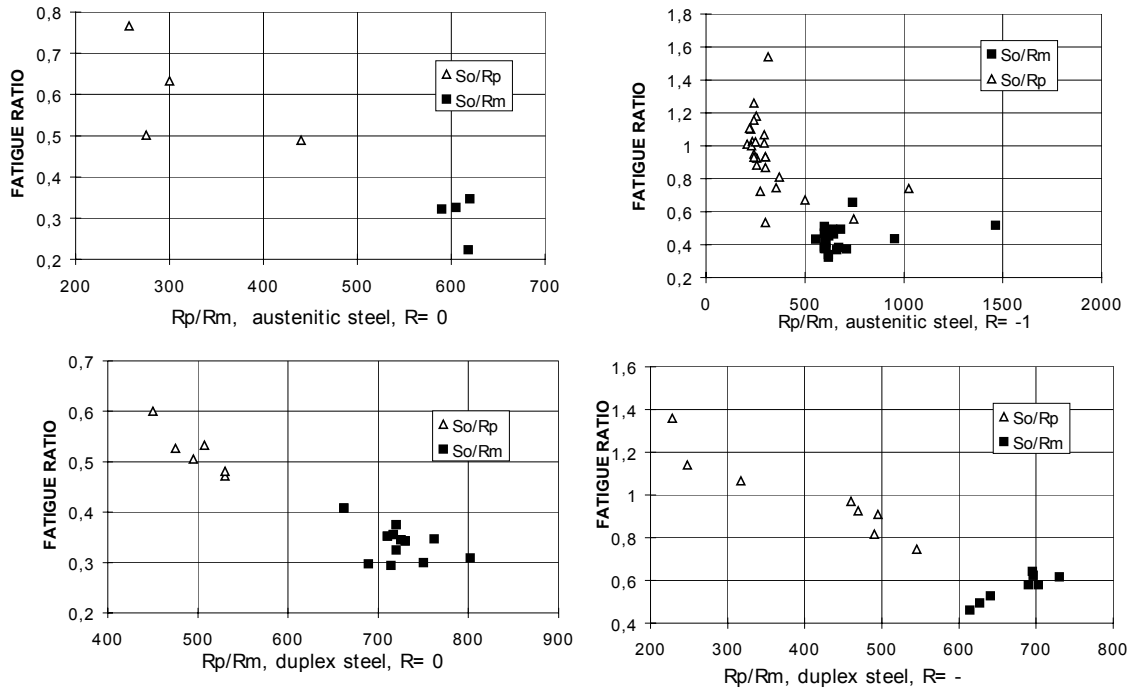


Fig. 2 Fatigue ratio, S_o/R_m alt. S_o/R_p , related to yield and tensile strength.

Comparing austenitic and duplex steel show that the duplex grade have higher fatigue limit at the same static strength. The fatigue limit increases with static strength for both steel types, fig.1.

Of particular interest is how the fatigue properties respond to cold work (cold rolling or stretching). In fig.3 the fatigue limit is related to the static strength for temper rolled strips of 1.4310 (AISI 301) in the 800 to 1700 MPa strength range. The fatigue limit increases up to a tensile strength of 1500 MPa and the levels off. These data also indicate that the fatigue ratio, S_o/R_m , being approximately 0.35 at $R \approx 0$ and typical for austenitics is unchanged up to $R_m \sim 1500$ MPa.

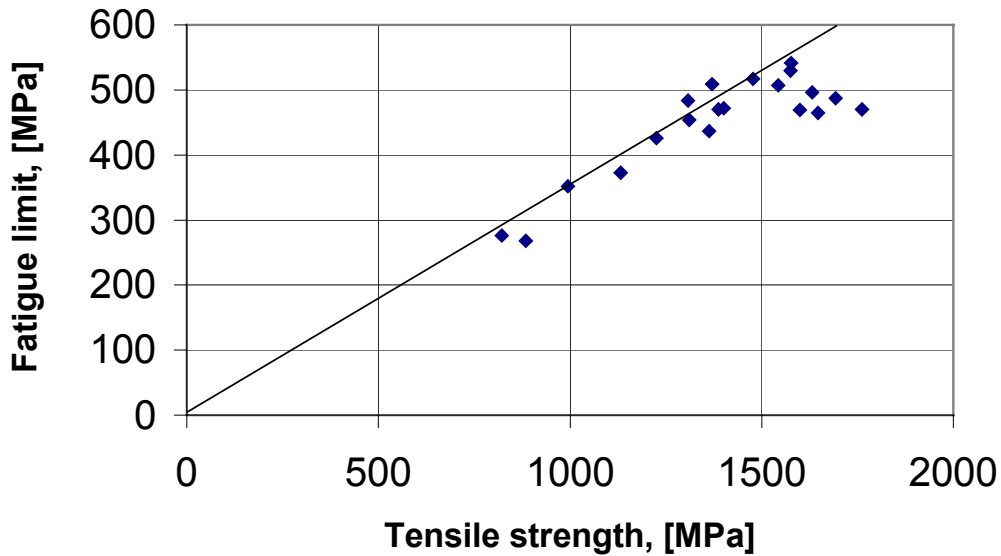


Fig. 3. Fatigue limit for the austenitic stainless steel 1, 1.4310 (301), cold worked to different strength levels.
 $R = 0,1$. Thickness 0,15 – 0,8 mm. The 0.35 slope is indicated.

Similar data for plane bending fatigue, $R = -1$, is shown in Fig. 4. As for alternating tensile loading the fatigue ratio, S_o/R_m , ca. 0.45 at $R \approx -1$, and typical for austenitics, seem to be unchanged up to very high strength levels.

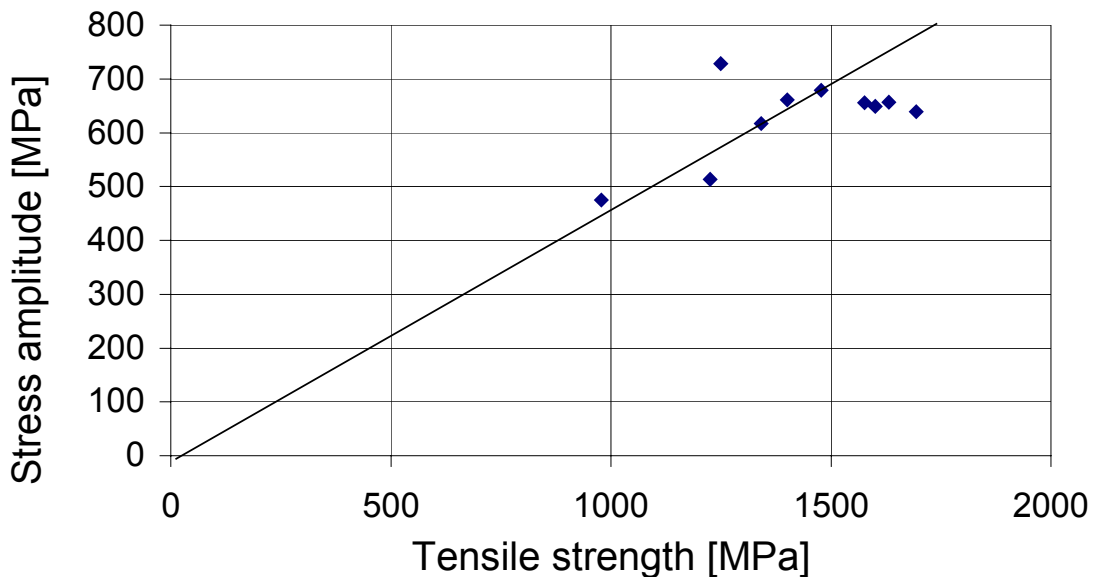


Figure 4 Fatigue properties at reversed plane bending
 1.4310-typ (304), Thickness 0,25 – 0,8 mm. The 0.45 slope is indicated.

The effect of static strength on fatigue properties of the austenitic steels 1.4301 (AISI 304) and 1.4310 (301) have also been studied for the case where the high strength have been achieved by cold stretching. The result are compared with the properties of the high strength

duplex stainless steels 1.4362 ("2304") and 1.4462 ("2205"). Tensile properties are given in Table II and the fatigue properties in Fig. 5

Table II. Tensile properties of materials studied in fatigue.
The pre-stretching in the testing direction is 10%..

Material	1.4310	1.4310 (10%)	1.4301	1.4301 (10%)	1.4462 (2205)	1.4362 (2304)
R _{p0.2} (L), MPa	255	439	278	495	618	567
R _{p1.0} (L), MPa	295	502	315	525	678	619
R _{pm} (L), MPa	849	933	640	704	823	750
A ₅ (L), %	54	45	61	50	39	40
R _{p0.2} (T), MPa	259		284		668	594
R _{p1.0} (T), MPa	296		318		727	642
R _{pm} (T) MPa	817		630		852	765
A ₅ (T), %	58		65		34	35

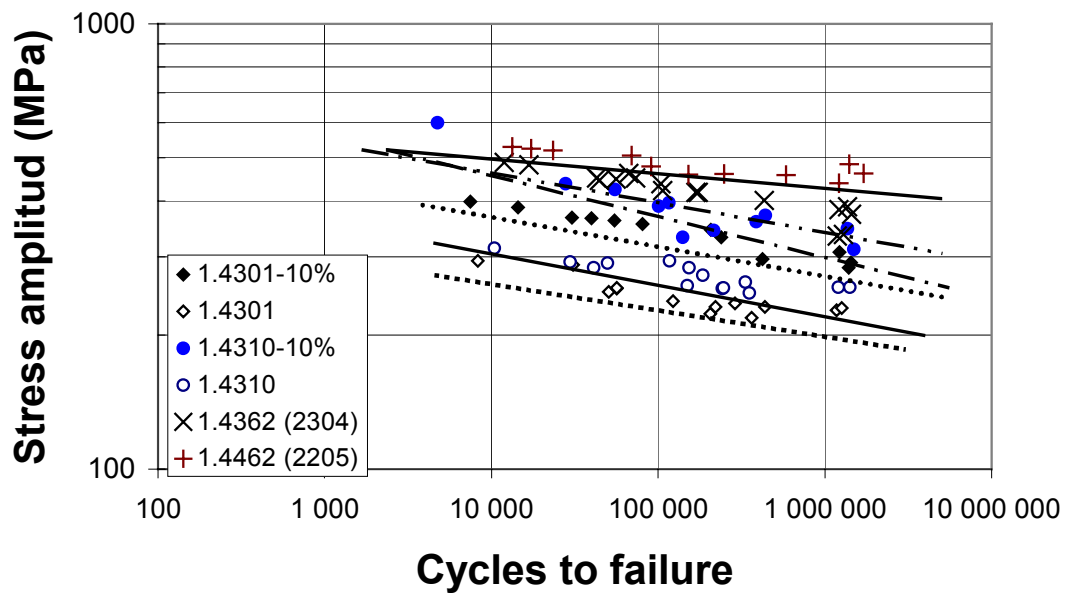


Figure 5 S-N-curves for 1,5 mm strip steel tested under tension-compression (R=-1).

FATIGUE NOTCH SENSITIVITY

Notches affect a materials fatigue properties in various ways. The degree of the notch effect is usually given as the fatigue notch factor:

$$K_f = \frac{S_o}{S_{notch}}$$

where S_o is the fatigue limit for unnotched and S_{notch} is the fatigue limit for notched specimens.

The fatigue notch sensitivity, q , is defined as:

$$q = \frac{K_f - 1}{K_t - 1}$$

where K_t is the stress concentration at the root of the notch assuming elastic behaviour. K_f is normally substantial lower than that expected from the stress concentration. $K_f = K_t$ and $q = 1$ at full notch sensitivity. The notch sensitivity factor varies from 0 for a totally notch insensitive material to 1 where the fatigue property reduction corresponds to the elastic stress concentration.

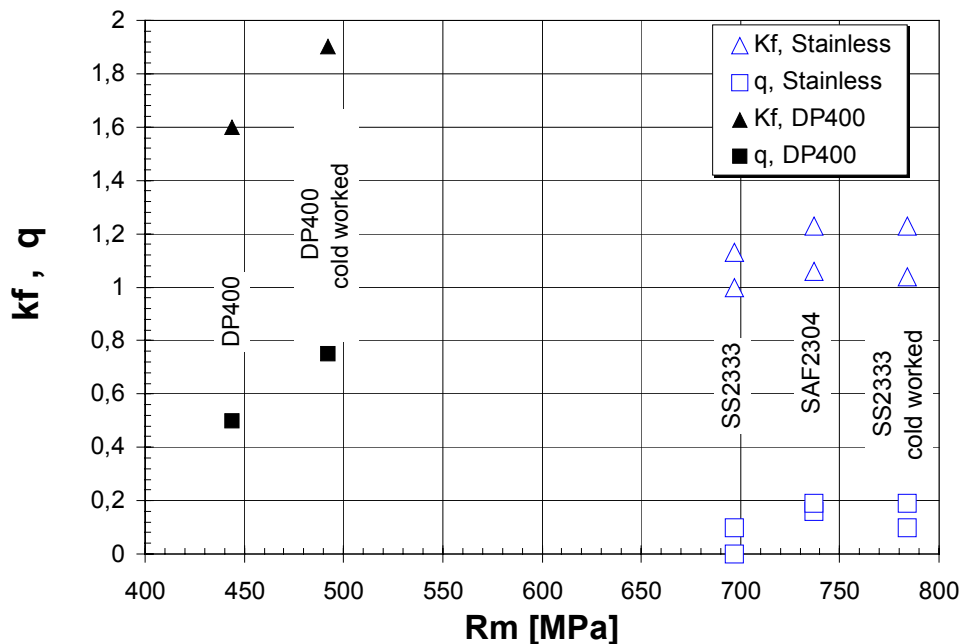


Fig. 6 The fatigue notch factor, K_f (S_o/S_{notch}), and fatigue notch sensitivity factor, q , for stainless steels and carbon steels at different strength levels.

The effect of notches on the fatigue strength of the austenitic stainless steel 1.4301 (304) in annealed and cold worked condition and the duplex stainless steel 1.4362 (2304) are compared with the carbon steel DP400 in both annealed and cold worked condition, fig. 6. The notch sensitivity is much higher for the carbon steels despite their lower static strength. Furthermore, the effect of strength is more pronounced for the carbon steels and almost non-existent for the stainless steels.

Fatigue testing of thin strip are often done on specimen with grounded or polished edges and corners. Punched and laser cut specimens of carbon and stainless have been fatigue tested under pulsating loading., fig. 7 and 8. The results are compared in fig.9 and show that laser cut samples show better fatigue performance for the stainless steels. The difference is related to the difference in surface topography due to the manufacturing process.

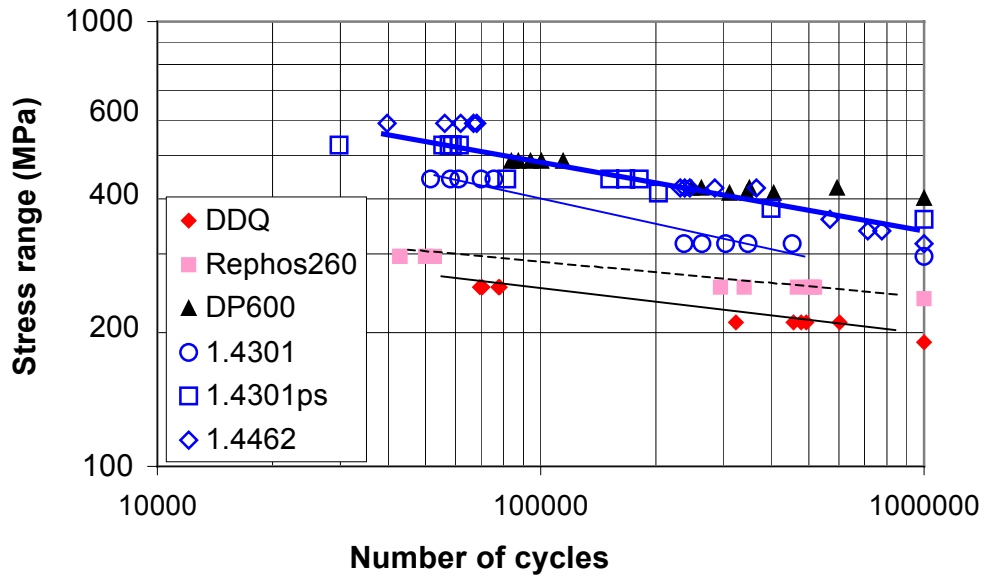


Figure 7 SN-curves for punched 1.5 mm thick fatigue specimens.

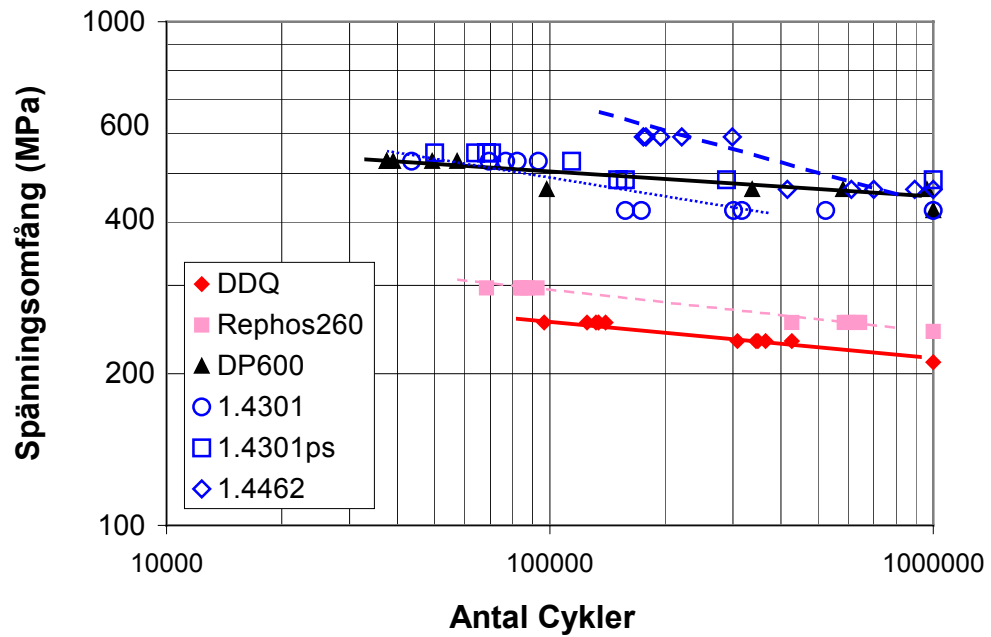


Figure 8 SN-curves for laser cut 1.5 mm thick fatigue specimens..

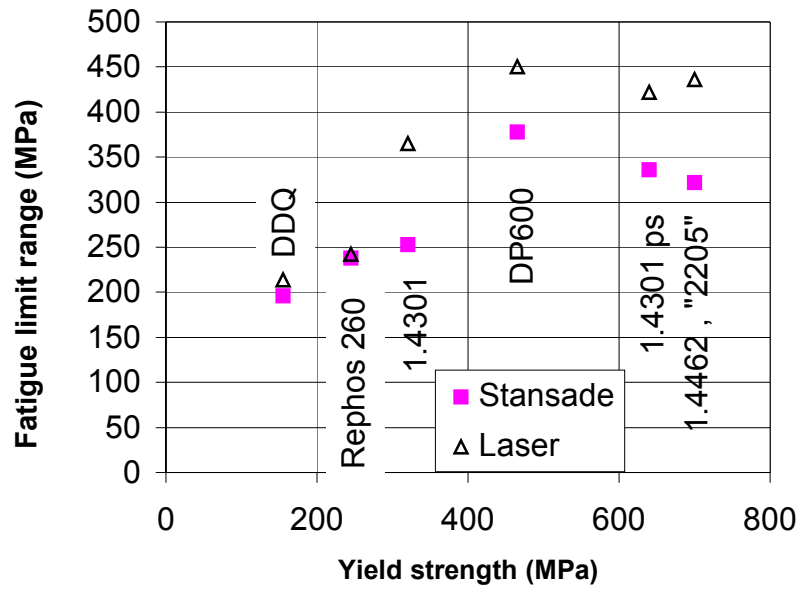


Figure 9 Fatigue limit ($N = 10^6$ cycles) for punched and laser cut specimen.

LOCAL DEFORMATION

The geometrical effect and the effect of cold deformation have been investigated for two types of stiffeners. The 2D and 3D geometry specimens are shown in fig.10. Tensile data for the investigated steel grades 1.4310 (301), 1.4301 (304), 1.4462 (2205) and 1.4362 (2304) are given in table III

Table III Tensile data for investigated steel grades. Transverse direction.

Material	Thickness mm	$R_{p0.2}$ MPa	$R_{p1.0}$ MPa	R_m MPa	A_5 %
1.4310	1.46	259	296	817	58
1.4301	1.45	300	332	672	65
1.4462	1.45	670	724	863	45
1.4362	1.54	566	622	763	39

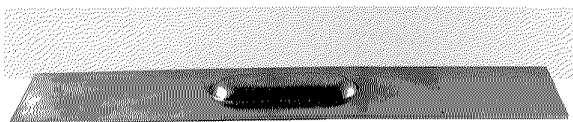
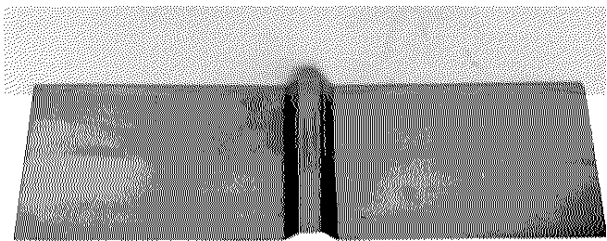


Figure 10a. 2D- specimen. -.

Figure 10b 3D-specimen.

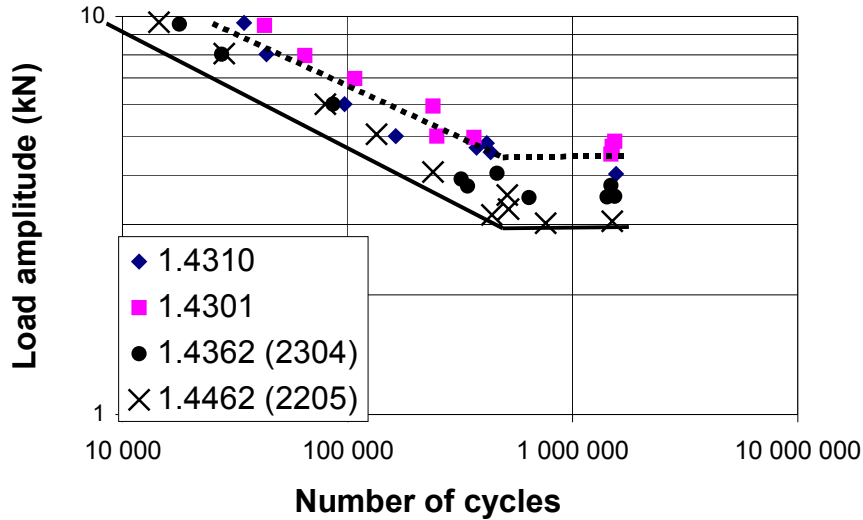


Figure 11 Fatigue results for 2D-specimen. R=0,05.

Specimen with 2D geometry were tested under pulsating axial load with results given in fig.11. The austenitic steels have better fatigue properties than the duplex. Specimen with 3D geometry were tested in a rig for 4-point bend testing. The results as given in fig.12 indicate that the duplex grades did resist a higher bending moment.

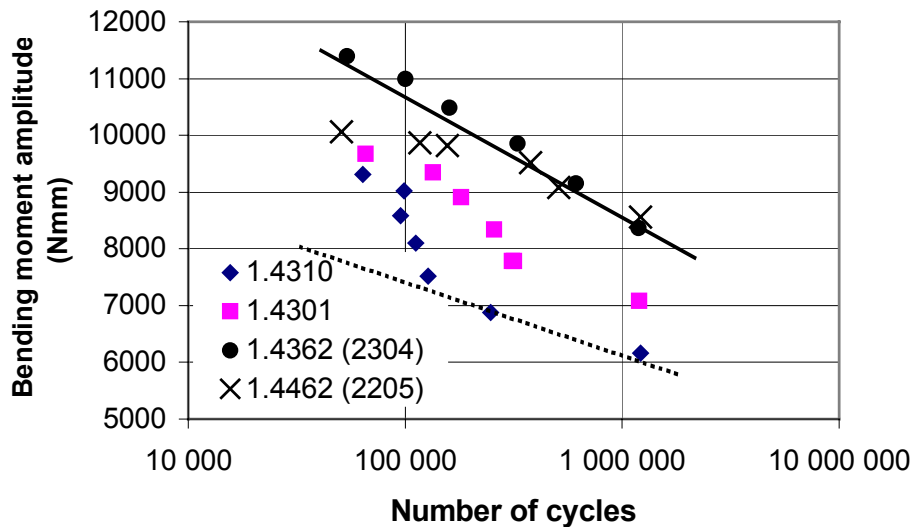


Figure 12 Bending moment amplitude versus fatigue life for 3D-specimens.

The property relations are different for specimens with 2D geometry, 3D geometry or strain controlled fatigue testing of flat specimens. The results are summarised in fig. 13. Tests on flat specimens give lower fatigue lives for 1.4301 (304) than for 1.4310 (301). Tests on cold deformed specimens changes this relation. 1.430 show better fatigue performance than 1.4310. The duplex grades are slightly different. Duplex 2D-specimen have lower fatigue lives than 1.4310. but duplex 3D-specimen are better than 1.4310. The results seems to indicate that strain controlled fatigue data correlate with 2D geometry and stress controlled fatigue data on flat specimen correlate with the results for 3D-geometry.

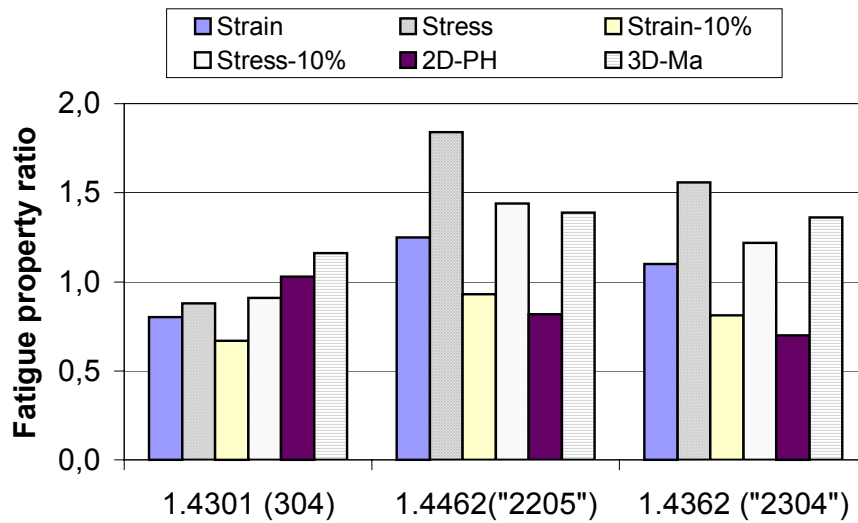


Figure 13 Relative fatigue properties after different testing methods. Properties are related to 1.4310 (AISI 301).

COMPARISON WITH CARBON STEELS

The fatigue strength of austenitic and duplex stainless steels are compared with those of high strength ferritic-martensitic carbon steels, DP steel, at the same yield strength levels.

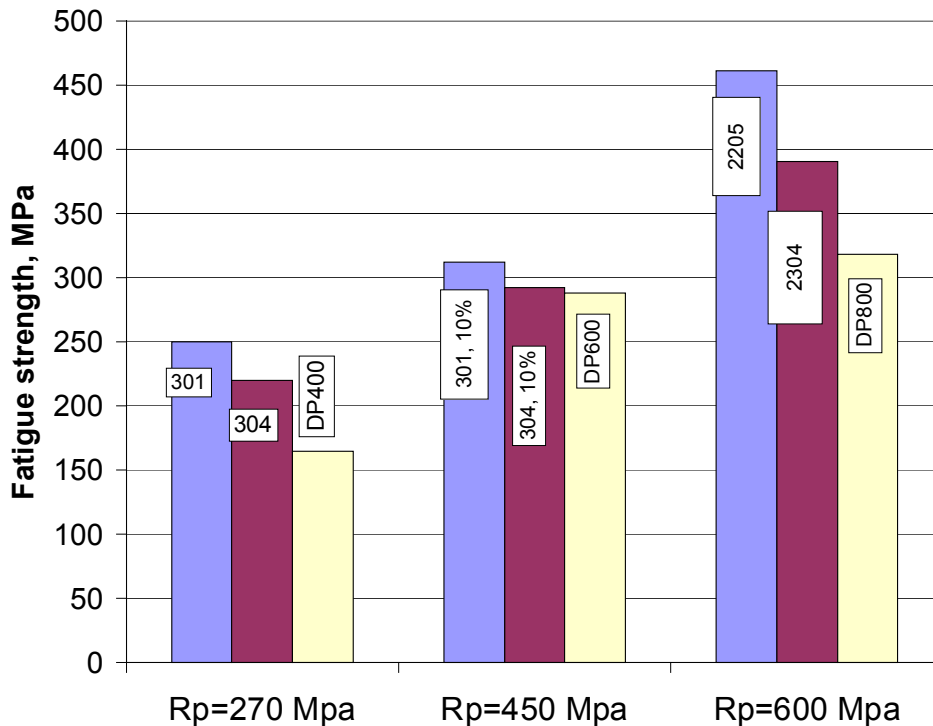


Figure. 14. Comparison of fatigue properties between stainless and carbon steels at different yield strength levels.

The result of this comparison is given in fig. 14. On all strength levels studied the stainless steel showed better, and often substantially better, fatigue properties than corresponding carbon steel.

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