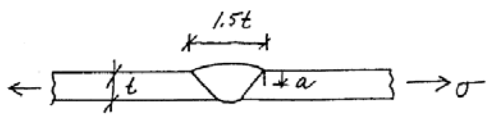
FATIGUE DESIGN (MMA115) 2009/10

Additional exercises

Example 1

A vertical crack with length a = 1.0 mm has been found at a butt weld as shown in the Figure. The crack is situated in a steel panel with thickness t = 8 mm. The panel is loaded by a membrane stress varying between σ = -20 MPa and σ = +60 MPa.



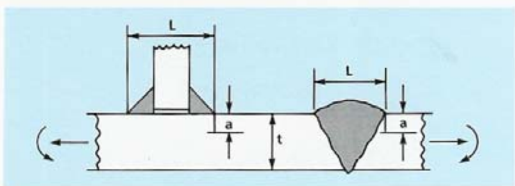
a) Using linear elastic fracture mechanics and Paris law for crack growth, estimate the number of cycles for the crack to grow to a depth equal to half the plate thickness. Use the following values for the material parameters: $C = 3.9 \cdot 10^{-12}$ and $n = 3$ (units $[\Delta K_I] = \text{MNm}^{-3/2}$ and $[a]$ = m]). The attached extract from the textbook: Dowling, N. E. Mechanical Behaviour of Materials, Second Edition may be used. (2p)

b) Estimate, using fracture mechanics, a value for the fatigue limit for the plate in a) assuming an initial crack with the length a = 1.0 mm, that is: how large stress range can be allowed if there should be no crack propagation. The material in the plate has the yield stress σ_Y = 250 MPa. The threshold stress intensity factor range ΔK_{Th} can be taken as

$$\Delta K_{Th} = 7.6 - 5.5\,R\ ,$$

where $R = \sigma_{min} / \sigma_{max}$, σ_{min} is the minimum and σ_{max} is the maximum stress in the weld during one load cycle including the welding residual stress, see also the Sheet Steel Handbook, p 4:86-87 (units as in a)). You may assume that the welding residual stress at the location of the crack is tensile with a magnitude ≈ the yield stress. (4p)

Figur 4.7.8 M_k *för stum- och kälsvets (ref 4:29).*
Observera att när a/t är förhållandevis stort, säg a/t > 0,2, gäller inte approximationen f=1,12 M_k



a/t	M_k vid ren dragning								
0,500	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,200	1,000	1,000	1,000	1,019	1,057	1,111	1,157	1,146	1,146
0,100	1,000	1,013	1,067	1,113	1,173	1,259	1,335	1,316	1,316
0,050	1,029	1,075	1,151	1,216	1,301	1,441	1,557	1,557	1,557
0,020	1,111	1,240	1,423	1,558	1,715	1,914	2,068	2,069	2,069
0,010	1,377	1,537	1,764	1,931	2,127	2,373	2,564	2,564	2,564
0,005	1,707	1,905	2,186	2,394	2,636	2,941	3,179	3,179	3,179
0,002	2,268	2,530	2,904	3,181	3,502	3,907	4,223	4,223	4,223
0,001	2,811	3,137	3,600	3,943	4,341	4,844	5,235	5,235	5,235
L/t	0,2	0,3	0,5	0,7	1,0	1,5	2,0	3,0	5,0

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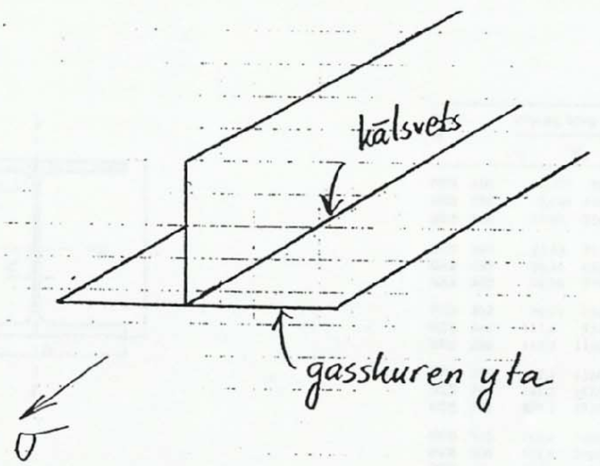
Example 2

The Figure below shows a beam where a horisontal flange has been fillet welded manually fillet welded (double sided with the Weld Class WB) to a vertical web. The ends of the beam have been gas cut (Cutting Class Sk 2). The beam is subject to a normal stress with a time variation that can be described with a load collective with stress ranges as shown below. The normal stress has $R = -1$.

n_i (cycles)	$4.0*10^2$	$1.6*10^3$	$1.0*10^5$	$1.0*10^6$	$1.0*10^7$
σ_r (MPa)	250	160	100	60	30

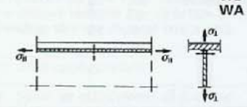
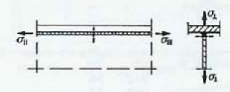
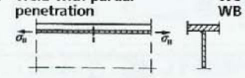
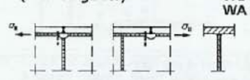
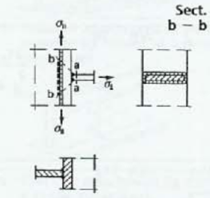
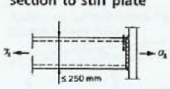
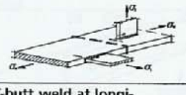
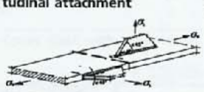
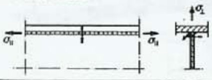
Can the welded joint be approved if it is designed according to the Palmgren-Miner linear damage accumulation rule? The consequence of a failure is serious. The design shall be based on the Steel Sheet Handbook. You may assume that the weld does not have a fatigue limit. You may put $\gamma_f = 1.0$ and $\varphi_t = 1.0$.

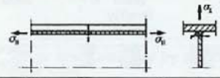
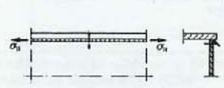
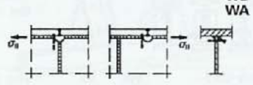
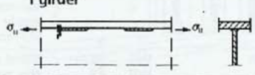
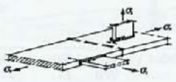
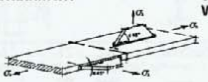
Fatigue tests with variable amplitude loads on welded joints show that peaks in the welding residual stress distribution will be relaxed after a short time period. Investigate if the fatigue life prediction is altered if you may assume that the welding residual stress σ_{ws} = 80 MPa.

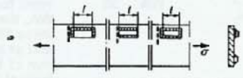
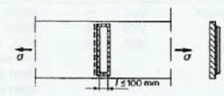
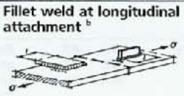


Kälsvets = fillet weld
Gasskuren yta = Gas cut surface (Thermally cut surface)
Use Joint classes from Sheet Steel Handbook handout and appended page

Fig. 4.6.27 a) (cont)

No	Joint configuration	Weld quality level	$C_{\parallel}$	$C_{\perp}$	Remarks
22	**Double V T-butt weld** 	**WC** **WB** **WA**	**80** **100** **112**	**56** **71** **90**	
23	**Single V T-butt weld** 	**WC** **WB** **WA**	**71** **90** **100**	**50** **63** **80**	**Root with sealing run. Symmetrical cross section, I or box section**
24	**Weld with partial penetration** 	**WC** **WB**	**63** **71**	**–** **–**	**Penetration shall be equal to at least half the sheet thickness (bottom sheet in figure)**
25	**T-butt weld at girder splice (welded girder)** 	**WC** **WB** **WA**	**63** **71** **80**	**–** **–** **–**	**Drilled or ground hole. Values of C apply for the ends of the T-weld**
26	**T-butt weld, e.g. at beam-column joint** 	**Sect. a – a** **WC** **WB** **WA** **Sect. b – b** **WC** **WB** **WA**	**–** **–** **–** **80** **100** **112**	**56** **71** **90** **56** **71** **90**	**The force at Section b – b may be assumed dispersed over 45° as in the figure (applies also to rolled column of I section, in which case the values of $C_{\perp}$ for Section b – b may be put equal to 90)**
27	**Continuous single V butt weld at attachment of circular or rectangular hollow section to stiff plate** 	**WC** **WB**	**–** **–**	**45** **50**	
28	**T-butt weld at longitudinal attachment** 	**WC** **WB** **WA**	**–** **45** **50**	**–** **45** **50**	
29	**T-butt weld at longitudinal attachment** 	**WC** **WB** **WA**	**50** **56** **71**	**45** **50** **56**	
30	**Fillet weld** 	**WC** **WB** **WA**	**71** **80** **100**	**50** **56** **63**	**[a] Manual welding**

No	Joint configuration	Weld quality level	$C_{\parallel}$	$C_{\perp}$	Remarks
31	**Fillet weld** 	**WC** **WB** **WA**	**80** **90** **100**	**50** **56** **63**	**Mechanized welding**
32	**Fillet weld on one side only** 	**WC** **WB** **WA**	**63** **71** **80**	**–** **–** **–**	
33	**Fillet weld at girder splice** 	**WC** **WB** **WA**	**56** **63** **80**	**–** **–** **–**	**Drilled or ground hole. Values of C apply for the ends of the fillet weld. Other sections must also be checked, see e.g. No 12**
34	**Intermittent fillet weld between flange and web of I girder** 	**WC** **WB**	**50** **56**	**–** **–**	
35	**Fillet weld at longitudinal attachment** 	**WC** **WB** **WA**	**–** **45** **50**	**–** **45** **50**	**Values of C given also apply to sections through the weld metal**
36	**Fillet weld at longitudinal attachment** 	**WC** **WB** **WA**	**50** **56** **71**	**45** **50** **56**	**Values of C given also apply to sections through the weld metal**

No	Joint configuration	Weld ...	C	Remarks
37	**Fillet welded longitudinal cleat [b]** 	**WC** **WB** **WA**	**45** **50** **63**	**When L ⩽ 100 mm, the values of C may be increased by one step**
38	**Fillet welded transverse cleat [b]** 	**WC** **WB** **WA**	**45** **50** **63**	**If the width of the cleat is less than half the sheet width values of C may be increased by one step. If L ⩾ 100 mm, No 48 shall be applied**
39	**Fillet weld at transverse attachment [b]** 	**WC** **WB** **WA**	**45** **56** **80**	**Weld not returned at the ends. The values of C given may also be applied to T-butt welds**
40	**Fillet weld at transverse attachment [b]** 	**WC** **WB** **WA**	**45** **63** **90**	**Weld returned at the ends. The values of C given may also be applied to T-butt welds**
41	**Fillet weld at longitudinal attachment [b]** 	**WC** **WB** **WA**	**45** **50** **63**	**When L ⩽ 100 mm, values of C may be increased by one step. The weld is not designed for transmission of force**

2010-05-09

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Example 3

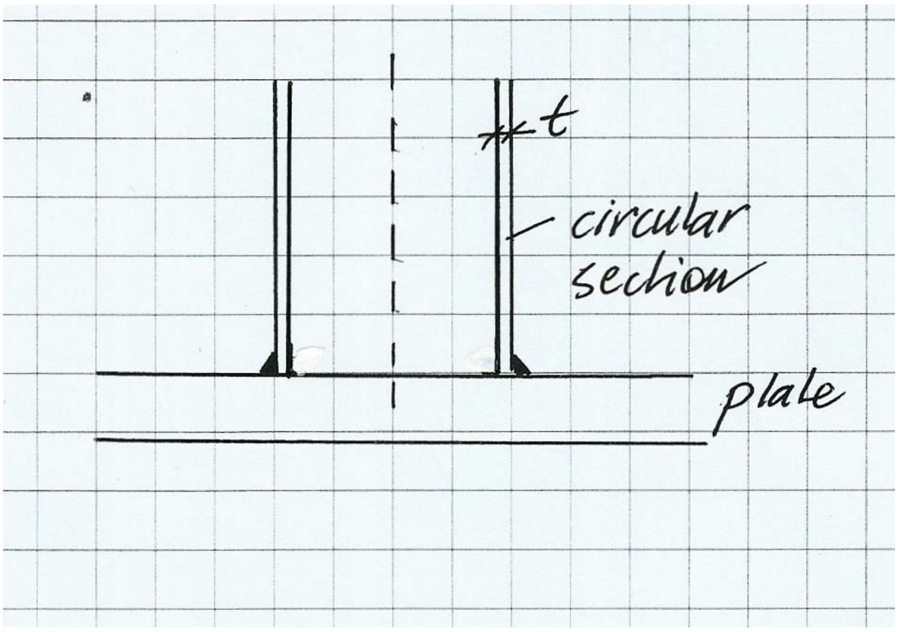
a) In a piping system there is a weld between a circular section and stiff supporting plate. The fillet weld is manually welded with weld quality WC. The circular section is subject to an axial stress with the stress ratio R = -1 and a load spectrum with the spectrum parameter κ = 1/3. Estimate the fatigue life if the dimensioning stress range σ_{rd} shall be 120 MPa. The circular cylinder has the wall thickness t = 10 mm. You may put γ_f = 1. The consequence of a failure is serious. (4 p)

b) To increase the fatigue life (for the same dimensioning stress range σ_{rd} =120 MPa) two alternatives are considered

1. to increase the weld quality to WB
2. to shot peen the weld toe region so that the residual stress at the surface is σ_{res} = - 70 MPa

Which alternative improvement would you propose? (4p)

c) Assume that weld above between circular section and the plate, with the weld quality WC, s subject to the load spectrum above for 10^5 cycles. What will the accumulated damage be, based on the Palmgren-Miner damage accumulation rule? If the weld also is subject to 10^3 overloads with σ_r = 250 MPa (at constant amplitude) what will those overloads give for accumulated damage? (4 p)



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Example 4

5. When the machine part shown in Figure a) is loaded by completely reversed forces for a number of amplitudes the following set of data is obtained:

P (kN)	N (cycles to fracture)
13,1	54 000
11,9	102 800
10,0	365 600
8,9	804 200
8,1	1 603 000

Find an approximate stress-life (*S-N*) curve for this case, and determine how many load sequences according to Figure b) that are likely to be sustained before fracture.

The ultimate tensile strength σ_u of the material is 600 MPa and the yield stress σ_o is 420 MPa. (12 p)