International Institute of Welding Doc. XVI - -73-E

Creep rupture strength and long term weld strength factors for welded high density polyethylene and polypropylene pipes and sheets*

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In an earlier publication [1, 2] the methods normally employed in welding high density polyethylene (hot gas welding with filler rod, heated wedge welding, extrusion welding and heated tool butt welding) were described (see fig. 1). In order to determine the weld strength factors attainable by these methods, sample lengths of pipe and of sheet up to 30 mm in thickness were welded, and from these test welds tensile test pieces were prepared for creep strength determination. In order to shorten the period of test, the creep strength determinations were carried out in water at 80° C, as is customary in the testing of high density polyethylene pipes. The long term weld strength factor was then calculated as the quotient of the two stress values at which equal service life for the welded joint and the parent material was obtained. Conclusions leading to improvement in welding conditions were drawn from the characteristic types of rupture in the creep test on joints made by the different welding methods.

The present publication includes further results on polyethylene samples, and describes analogous investigations on welded sheets and pipes made form polypropylene.

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* Condensed version of a paper to be published in Kunststoffe, 63 (1973), September number

Butt welded pipes under internal pressure stress*

Results obtained on 32 - 800 mm diameter butt welded high density polyethylene pipes in creep strength tests under internal pressure have shown that the service life of welded pipes made in this way exceeds the minimum period prescribed for pipes without welded joints, provided that the pipe specimens are of satisfactory quality and the welding conditions specified have been followed.

Cracking occurred, not in the weld but in the parent material in most of the specimens tested. The tests also confirmed that the creep rupture strength/temperature correlation is the same for butt welded pipes as for pipes without welds.

Experiments with heated tool butt welded polypropylene pipes gave identical results.

Tensile test pieces from butt welded pipes

The stress resulting from internal pressure and acting vertically to the seam of a welded pipe joint ist only half as great as the hoop stress. It is thus not possible to gain any advance indication of the weld strength factor from tests on creep strength under internal pressure stress. We have therefore carried out creep tests on tensile test bars prepared from butt welded polyethylene pipes. These specimens were tested in water at 80 °, 50 ° and 20 °C. The results show that for both welded and non-welded specimens, failure occurs within the same region. The temperature correlation is thus also valid for butt welded tensile specimens. Well-made butt welded joints attain a long term weld strength factor of 1 [1, 2]. Creep strength tests on tensile test specimens from welded polypropylene pipe produced the same results.

* The term butt welding is used throughout this paper as an abbreviation for heated tool butt welding.

Hot gas welding, heated wedge welding, extrusion welding and butt welding

Determination of long term weld strength factor

In order to determine the long term weld strength factors of welded tensile test bars, the position of the range variation for welded and non-welded test pieces in the lower steep portion of the creep strength curve - i.e. the range concerned in practical application - must be ascertained at different temperatures. The testing periods are shortened by carrying out the tests at raised temperatures (PE at 80 °C in water, PP at 120 °C in air). The long term weld strength factor is then the quotient of the two stress values at which equal service life is obtained for the welded seam and for the parent material.

Preparation of the test specimens

Samples of welded sheets and pipe segments were submitted for the experimental determinations. Normal commercial grade extruded or compression moulded sheets of 15 to 30 mm thickness were employed, and the pipes used had the dimensions 630 x 20 mm. The creep test specimens were taken from the welded sheets and pipes as shown in fig. 2. In addition to the creep test determinations, tensile tests and flexural tests were also carried out in the course of this experimental programme. Details of the shape and dimensions of the test specimens are given in [1, 2].

High density polyethylene

In the case of high density polyethylene pipes and sheets, several experimental series were investigated for each method of welding. Each experimental series included 6 to 12 sheet specimens or pipe segments, and from each sample of sheet, 1 creep test specimen, 2 to 3 tensile test bars and 2 to 4 flexural test specimens were tested.

In fig. 3, the diagram shows the experimental series with the best results in each case from the various methods of welding which are arranged in the order of increasing service life. The bending angles also show a tendency to increase, but do not however always proceed in conformity with the service life periods. The mean tensile strength values show relatively small variation.

In compiling the table of optimum welding results, the service life periods were measured under stress loadings of 40 and 20 kgf/cm^2, and thereafter the long term strength factors were determined, and are shown in fig. 4. The slope of the creep strength curves is less pronounced with decrease in the quality of the welds. If extrapolated in a straight line downwards they intersect the curve for the parent material in the region of 2 to 5 kgf/cm^2. Assuming that this straight line extrapolation is correct, the service life periods of welded joints would at these low stress levels be equal to that of the parent material.

Supplementary experiments with hot gas welded specimens have confirmed the linear continuation of the curve a downwards to 5 kgf/cm^2.

Corresponding to the different slopes of the creep strength curves for welded seams, and parent material, at the stress level $\sigma = 20$ kgf/cm^2 higher weld strength factors are shown than at $\sigma = 40$ kgf/cm^2. These are entered in fig. 4 at the appropriate points. The less steep slope of the creep strength curves for welded seams thus indicates a favourable weld strength factor. In practice, high density polyethylene is mainly used at about 20 ^oC. The permissible dimensioning stress level of 50 kgf/cm^2 at 20 ^oC corresponds at 80 ^oC to a stress level of 20 kgf/cm^2. We therefore consider it justified to employ at 20 ^oC the weld strength factor determined at 80 ^oC and $\sigma = 20$ kgf/cm^2 [1, 2].

Polypropylene

The creep strength experiments with the polypropylene welded specimens were carried out at 120 ^oC and $\sigma = 23$ and 15 kgf/cm^2

In fig. 5 the measured service life periods at 23 kgf/cm^2 and the tensile strength values and bending angles at 20 ^oC are listed. The tensile strength values are in fairly good conformity with the service life periods. The bending angles are substantially lower than in the case of the PE specimens except in the case of parent material. The creep strength curves determined at 23 and 15 kgf/cm^2 and the long term weld strength factors calculated at 20 kgf/cm^2 for the polypropylene test specimens are shown in fig. 6. The reference stress of 20 kgf/cm^2 at 120 ^oC was chosen since it produces the same deformation (~2 %) as the permissible stress of 50 kgf/cm^2 at 20 ^oC.

Summary of results

The long term weld strength factors for high density polyethylene and polypropylene are compiled in table 1. The weld strength factors listed were achieved under careful observance of the most favourable welding conditions and also as far as possible with notch - free transition and root areas. V- notches in root and transition areas reduce the service life period to a few hours, and thus the weld strength factor to 0.3 and even less. Ideal configuration and construction of the weld seam without notches have at least as great an influence on the weld quality as optimum welding conditions (temperature, pressure, time). Rounding of the root and transition areas by machining is advantageous in extrusion and hot wedge welding - in contrast to hot gas welding (figs 3 and 5) - and has produced long term weld strength factors in excess of 0.8. The fracture characteristics have been described in the earlier publication [1, 2] and the welding conditions are discussed in the original paper.

Table 1

Long term weld strength factors for HD polyethylene and polypropylene

Welded joints seam not machined	Weld strength factors for HD polyethylene (80°C, 20 kgf/cm^2)	Weld strength factors for polypropylene (120°C, 20 kgf/cm^2)
Heated tool butt welding	0.9 - 1	0.9 - 1
Extrusion welding single V-joint	0.6 (0,75 bearbeitet?)	0.55
Extrusion welding double V-joint	0.5 (0,45)	
Heated wedge welding double V-joint	0.55	
Heated wedge welding single V-joint	0.45	0.6
Hot gas welding single V-joint 20 mm	0.35	0.35
Hot gas welding single V-joint 4 and 10 mm	up to 0.6	up to 0,65

bearbeitung? ja

Special types of welded joints

Longitudinally seamed pipes

HD polyethylene pipe samples 63 x 5.7 mm longitudinally seamed were submitted to creep strength tests under internal pressure to provide a comparison with the creep strength tests carried out on tensile test bars. From the mean value curves prepared, the following long term weld strength factors (σ = 20 kgf/cm^2) were obtained:

Extrusion welding,	single V-joint, not machined	0.65
	single V-joint, machined	0.78
Hot gas welding,	single V-joint, not machined	0.43

These values agree fairly well with those measured in the creep strength test on tensile test pieces.

Fillet welds on sheets

The creep strength curves and the long term weld strength factors at 20 kgf/cm^2 were determined on extrusion welded specimens from 20 mm thick HD polyethylene sheets exhibiting various types of fillet welds (fig. 7). The stress applied was calculated on the minimum weld seam cross section. Test pieces with fillet welds as shown in fig. 7a gave the relatively high long term weld strength factor of approximately 0.55; with fillet welds as shown in fig. 7b the long term weld strength is much lower (approx. 0.2). Values of 0.1 to 0.2 were obtained on 50 mm thick samples. Experimental work with a view to attaining higher values is in progress.

Fillet welds on pipes

High density polyethylene pipe samples 90 x 8.2 mm, were inserted into the larger size 110 x 10 mm and the pipes were joined together by fillet welds (sleeve welding) as shown in fig. 8a. The creep strength curve was ascertained at 80 ^{o}C, and the long term weld factors determined for a stress level of 20 kgf/cm^2, the stress level being based on the weld seam thickness. Long term weld strength factors of 0.31 for hot gas welding and 0.43 for extrusion welding are obtained.

Fillet welds in hot gas welded joints as in fig. 8b were investigated in the same way. The long term weld strength factor obtained amounts to 0.25 for test samples with fillet welds on the outside face and 0.35 for test samples with fillet welds on both outside and inside faces. These particular tests were carried out in order to elucidate the long term weld strength factor for welded-on connections.

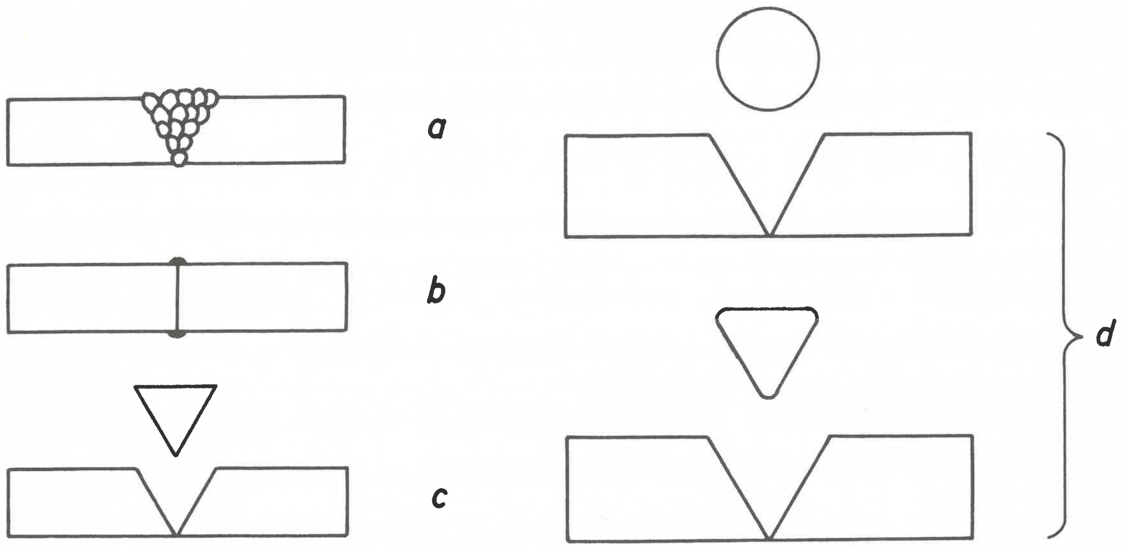
Comprehensive experimental work is in progress to determine the extent to which loss in strength is caused by fittings prepared by the various welding methods, and the results will be reported in due course.

Literature references

[1] IIW - Doc. XVI - 148 - 70 - E

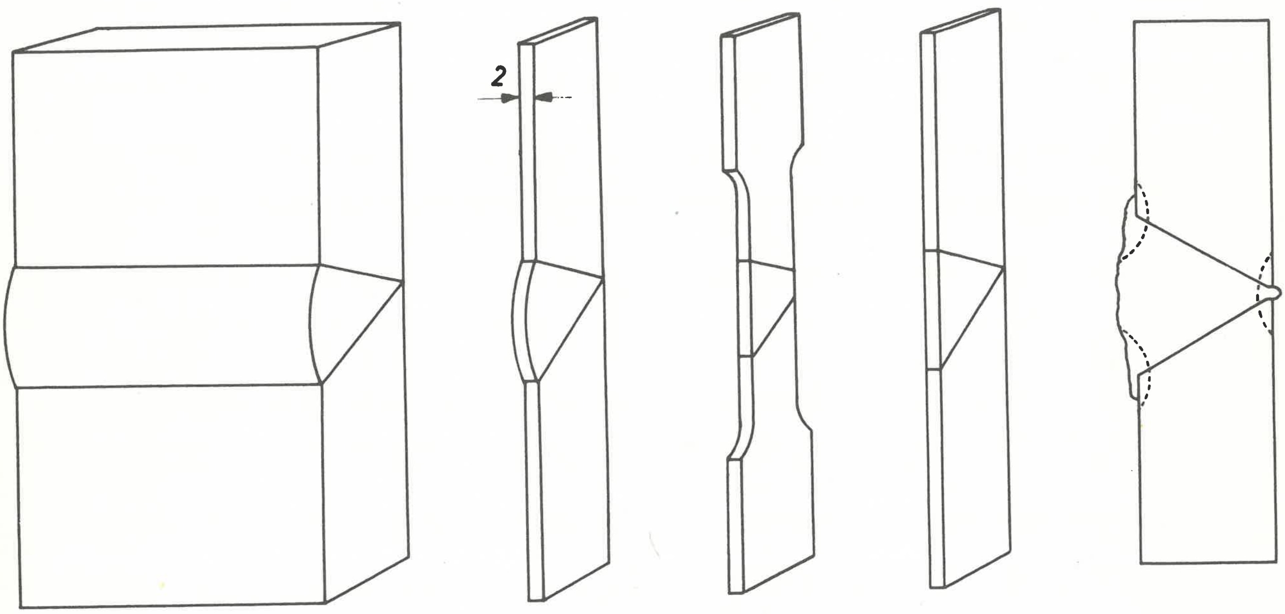
[2] G. Diedrich and E. Gaube, Kunststoffe Vol. 60 (1970) pp. 74 - 80 (further references are quoted in this paper)

Fig. 1 Methods of welding



a) hot gas welding
b) heated tool butt-welding
c) heated wedge welding
d) extrusion welding

Fig. 2 Test specimens for creep tests



welded plate

a) weld not machined

b) sample machined flat on both sides

c) only the weld machined flat

d) transition zone and root rounded

Symbols used in the diagrams

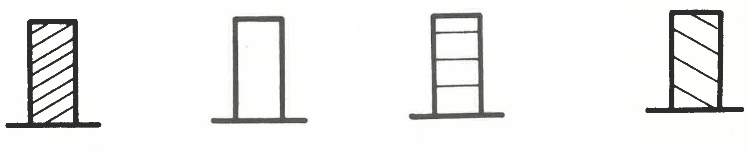


Fig. 3

Welded joints of polyethylene of optimum design

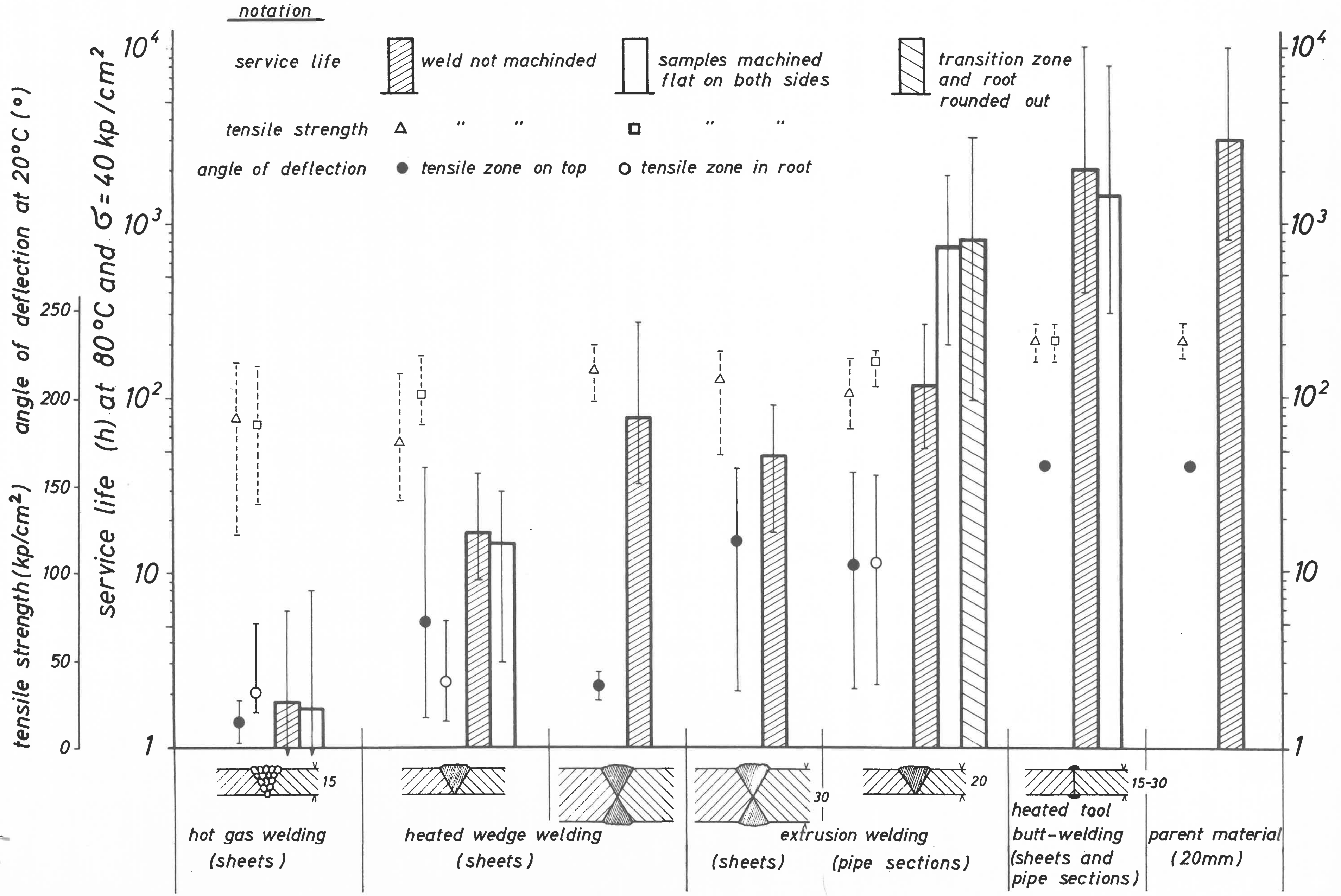


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Fig. 5

Welded joints of polypropylene of optimum design

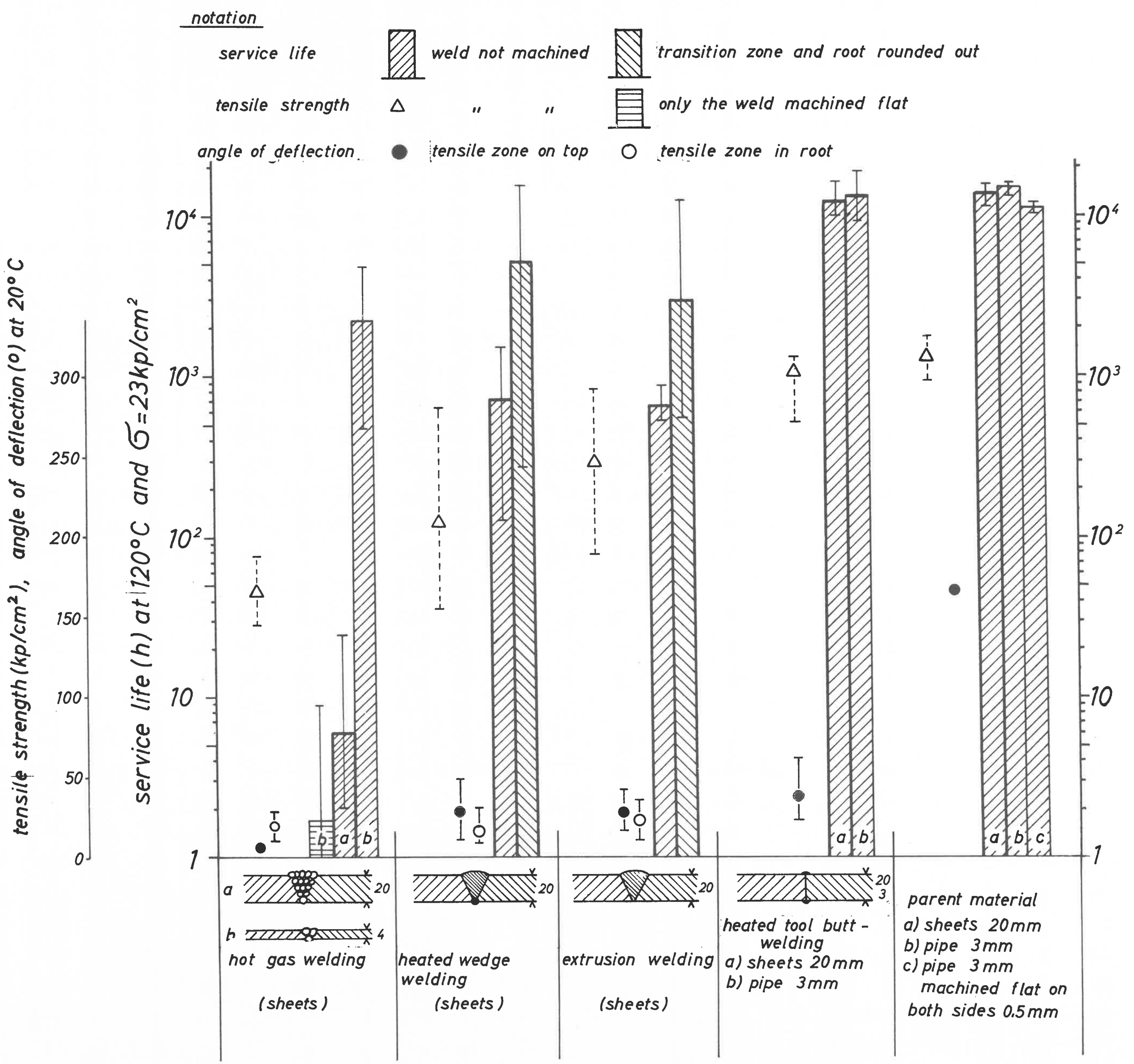

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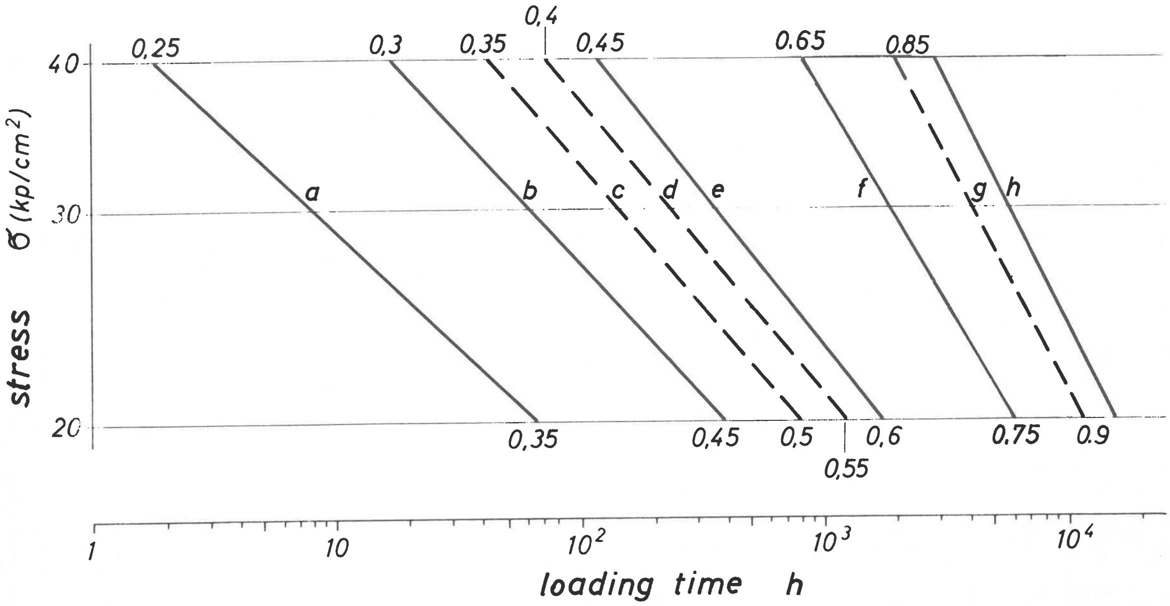
Fig. 4 Creep curves for welds of polyethylene (fig. 3), 80° C



a) hot-gas welding, V-weld
b) heated wedge welding, V-weld
c) extrusion welding, X-weld
d) heated wedge welding, X-weld
e) extrusion welding, V-weld
f) extrusion welding, V-weld, machined flat away x
g) heated tool butt-welded
h) base material

x) machined flaton both sides or transition zones and root rounded out

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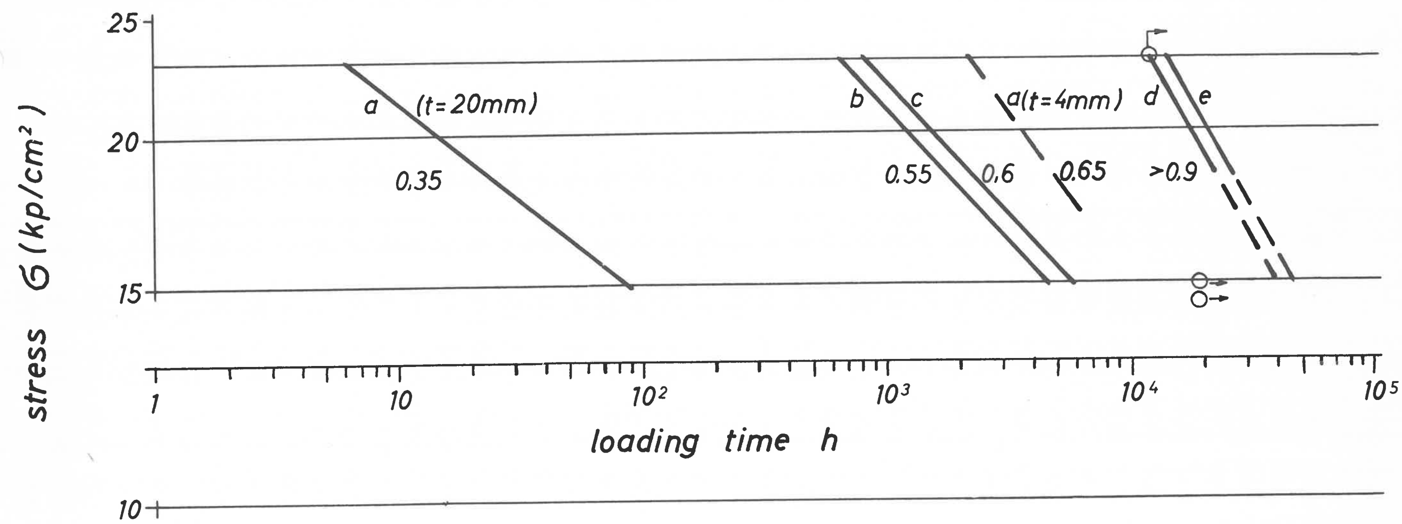
Fig. 6 Creep curves for welds of polypropylene (fig. 5), 120 °C



a) hot-gas welding, V-weld
b) extrusion welding, V-weld
c) heated wedge welding, V-weld
d) heated tool butt-welded
e) base material

Fig. 7 Fillet welds on sheets

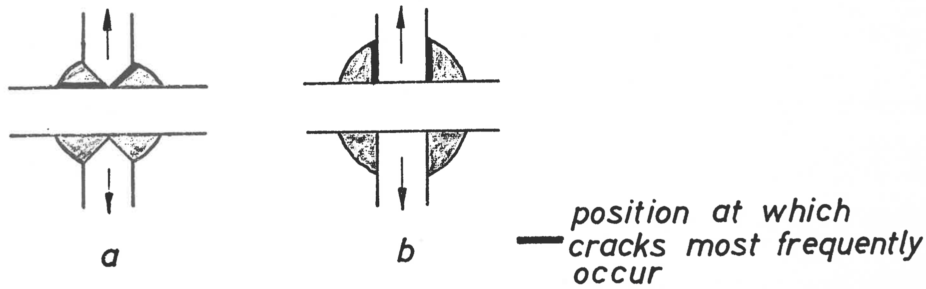
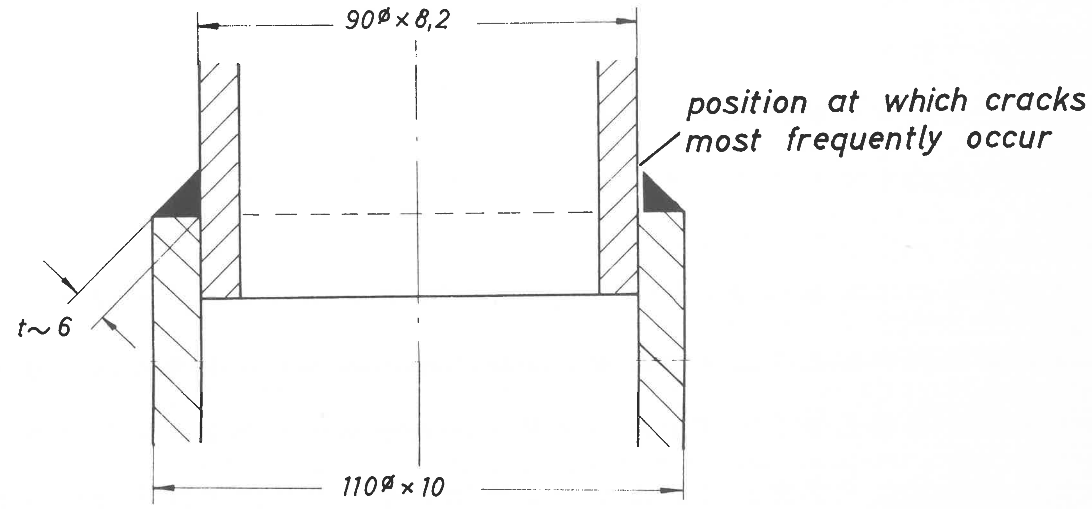


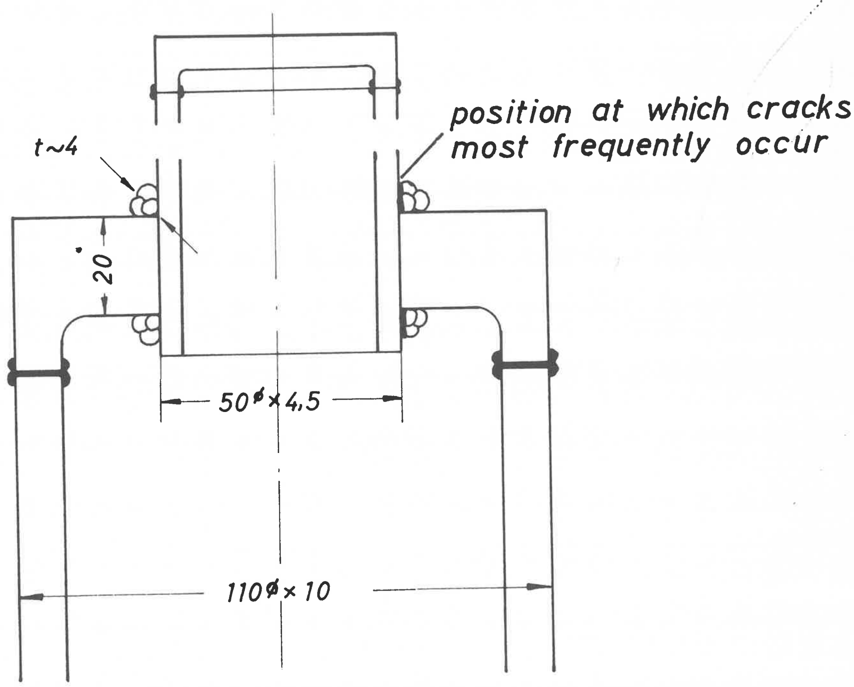
Fig. 8 Fillet welds on pipes

(a



$$\sigma_V = p \cdot \frac{d}{4t}$$

(b



$\sigma_V = p \frac{d}{8t}$ for 2 weld seams

$\sigma_V = p \frac{d}{4t}$ for 1 weld seam