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Lamellar Tearing

Arrachement lamellaire

Lamellares Aufreissen

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SUMMARY

This survey, founded on a large literature study [19], gives some examples of practical welded joints in which lamellar cracks were found, describes the mechanism of the lamellar cracking development and deduces the necessary conditions for its appearance. Afterwards, it gives the preventive measures generally used to avoid the phenomenon, describes the destructive and non destructive techniques used to assess lamellar tearing suceptibility and gives, finally, a description of the usual repairing methods. Some necking measurements, carried out on short transverse tensile tests, enable to deduce the minimal values of necking necessary to avoid the lamellar cracking phenomenon.

RÉSUMÉ

Cette revue, basée sur une importante étude bibliographique [19], donne quelques exemples de joints soudés où des fissures par arrachement lamellaire furent découvertes, et décrit le mécanisme de développement de la fissure d'arrachement lamellaire et en déduit les conditions nécessaires à son apparition. Elle énumère les mesures préventives généralement mises en œuvre pour éviter l'apparition du phénomène, décrit les méthodes destructives et non destructives utilisées dans le but d'évaluer la susceptibilité à l'arrachement lamellaire et donne, enfin, la description des méthodes habituelles de réparation. Quelques valeurs de striction mesurées sur des éprouvettes de traction prélevées en travers, permettent d'estimer les valeurs minimales de cette striction, nécessaires pour éviter le phénomène de fissuration par arrachement lamellaire.

ZUSAMMENFASSUNG

Im vorliegenden Bericht, der sich auf eine umfangreiche Literaturstudie [19] stützt, stellen die Autoren einige Beispiele geschweisster Verbindungen vor, bei denen Lamellenrisse beobachtet worden sind. Sie beschreiben anschliessend den Mechanismus der Entwicklung solcher Terrassenbrüche und folgern daraus die für deren Eintreten nötigen Bedingungen. Man erörtert die vorbeugenden Massnahmen und beschreibt die zur Bestimmung der Neigung zum lamellaren Aufreissen verwendeten Prüfverfahren (zerstörungsfreie und andere) sowie die üblichen Reparaturmassnahmen. Festgestellte Werte der Brucheinschnürung in Dickenrichtung erlauben eine Schätzung der entsprechenden Minimalwerte, bei denen Terrassenbrüche nicht mehr auftreten.

0. INTRODUCTION

"Lamellar tearing is a cracking phenomenon occuring in rolled products stressed normally to the plane of rolling. Though welding is not a necessary condition for its occurence in practice it is found almost exclusively in welded constructions where the welding is heavy, requiring a number of runs for its placement, where the plates are thick and there is considerable restraint within the joint giving rise to high stress and localized strains across the weld. It is this high stress and localized strains which causes the parent plate material to tear. The type of cracking which can be found in several welded constructions usually, but not exclusively, just beneath the heat affected zone within the parent material is shown is Fig. 1. Clearly to avoid this phenomenon it is necessary to keep shrinkage stresses within the weld to a minimum and the use of a filler material for the electrode which results in a lower yield high ductile deposit is beneficial, especially if the yield point of the deposit is below that of the transverse ultimate strength of the parent material. It is for this reason that in very special circumstances austenitic electrodes may have to be used.

Having become aware of the problem every effort should be made in the detail design of structures to avoid the use of such details for primary load-paths wherever possible".

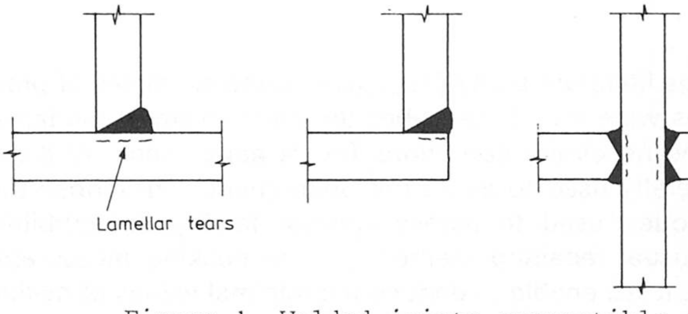
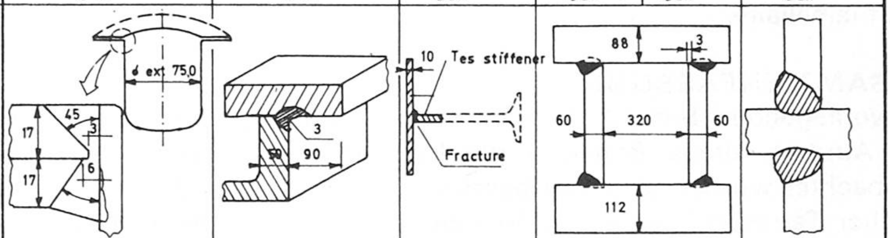


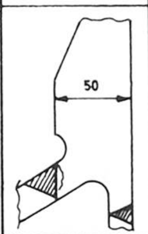
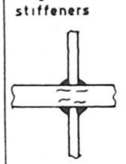
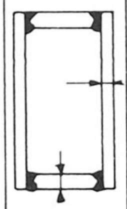
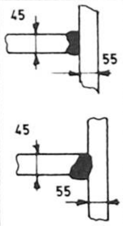
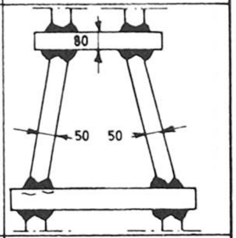
Figure 1. Welded joints susceptible to lamellar tearing.

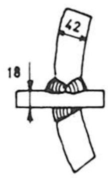
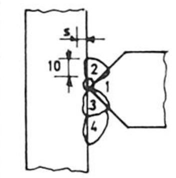
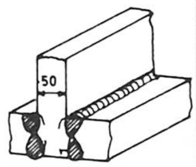
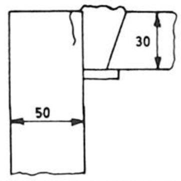
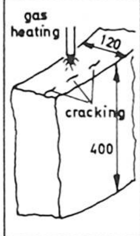
Figure 2 gives some examples of practical welded joints where lamellar cracking was found |9|.

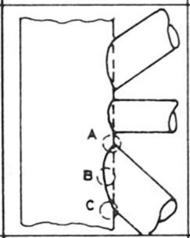
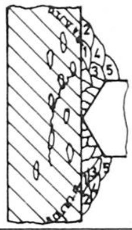
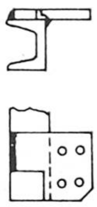
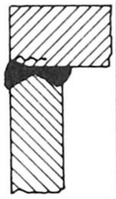
Case	1	2a	2b	3	4a	4b	5
through thickness	teared	teared	not teared	teared	teared	not teared	teared
réduction in area	1 1 2.3 5	5.3 9.9 14.4	17 22 27	0	15,8 17,4	15,8 17,4	0,2 2,3 5
tensile strenght ratio $\frac{Rm\ th}{Rm}$	0,33	0,70 0,90	0,93 0,97	0,67	0,86 0,89	0,86 0,89	
thickness	8mm	50mm		10mm	88 112	88 112	20mm
tension	σ sh	σ sh		σ sh	σ sh	σ sh	σ sh



	1	2a	2b	3	4a	4b	5
steel type	A 42	A 52 BS 4360 grade 50 b			A 283 C A42C2	A283C A42C2	W St E 47 Normal
steel strength	Re = 280 310 Rm = 420 430	Re=352 377 Rm=521 532			Re= 210 Rm=385 455		
analysis	not told	not told			not told		C Si Mn P S 0.14 .39 1.21 .12 .25 Cr Ni V Cu Nb .21 .69 .06 .51 .016
consumables		E 344B39 6-7pas...preh 80°C			CO_2 welding	MMA	
discovery	in service on repairing	on fabrication			on fabrication		during fabrication
restraint	normal						

Case	6	7	8	9	10	11
through thickness	teared	teared	teared	teared	teared	teared
reduction in area	23 23 17 26 23 10	0 (specimens)				
tensile strenght ratio $\frac{Rm\ th}{Rm}$	92	48 71				
thickness	50mm	11,5 – 32,5	36mm	70 or 65 or 50	55mm	80mm
tension	σ sh	σ sh	σ sh			
		Longitudinal stiffeners 				
steel type	SIS 142106 Normaliz.	DnV grade spécial	D 36 Normalized	MR St 37 2N	A St 41	A 37 S C
steel strength	Re = 380 Rm = 530	Re=390 Rm 490 590	Re = 390 Rm = 520			
analysis	C Si Mn P S .16 .47 1.33 .30 .013 Nb N .026 .005	C Si Mn .17 .22 .24 .43 1,2 1,7 P.026 S 045	C Si Mn P .15 .25 1.26 .020 S Nb .026 .045			C S P .11 .028 .025
consumables		O K 48 00		MMA basic electrodes	MMA	CO_2 in root run others MMA
discovery	on fabrication	on fabrication	on fabrication			in fabrication rut
restraint	very high restraint					

Case	12	13	14	15	16
short transverse	teared	teared	teared	teared	teared
réduction in area					17
tensile strenght ratio $\frac{Rm\ th}{Rm}$	18mm				
thickness	18mm	40mm	50mm	50mm	120mm
tension	σsh				
					
steel type	HT 50 normalized	HT 50	MS as rolled	HT 50 as rolled	HT 50normalized
steel strength		Re = 420 Rm = 550N/mm^2			Re = 360 Rm = 530
analysis		C Si Mn P S Nb .17 .39 1.36 .021 .020 .030			C Si Mn P S .17 .46 1.41 .021 .012 V: .07
consumables	MMA interpass 110°C	1.MMA 2.3.CO_2 4 SAW	MMA interpass 100 C E7016	MMA 100 C ASTM 7016 dried	
discovery	eye on fabrication	naked eye on fabrication	naked eye on fabrication	naked eye on fabrication	eye during gas heating
restraint				25000 kg/mm^2 mm	

Case	17	18	19	20	21	22
short transverse réduction in area	not teared ≥ 20	teared	teared	teared 0 0	teared 16	teared 25 15 25 20 11 15
tensile strenght $\frac{Rm\ th}{Rm}$ ratio				89	83	56 81 74
thickness	32mm	30 mm	25mm	14mm	70mm	20mm 30mm
tension	σ sh	σ sh	σ sh	σ sh + M_b dynamic	σ sh	
						
steel type steel strength analysis consumables discovery restraint	HT 50 normalized S .006 Ew 44 interpass temp. 150 MMA E 7016	AE 36D au Nb interp. basic dried eye after strees relief strees relief crack?	AE 36 D au Nb prehest 150 basic elect. on fabrication by ult	R St 37 2 DIN 17100 Re = 260 Rm = 420 C Si Mn P S N .12 .31 .39 .018 .31 .007	Re = 270 Rm 440	Re = 330 400 Rm = 513 515 C P .11 .14 .025 .029 S .019 .021

The mechanism of the lamellar cracking phenomenom is described on figure 3 in the general case of initiation and propagation in the parent metal [1].

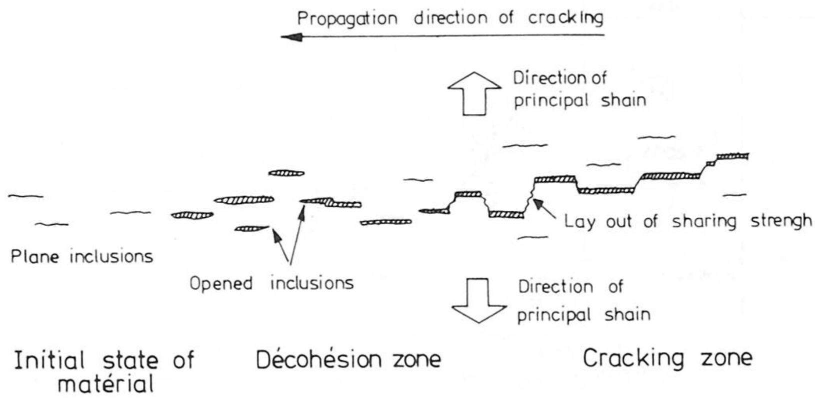
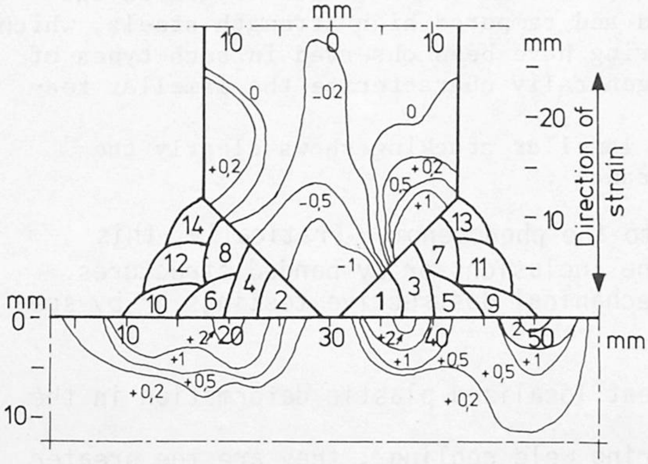


Figure 3. Mechanism of initiation and propagation of lamellar cracking.

The base metal, susceptible to the phenomenom, contains generally plane inclusions whose main plane is parallel to the rolling plane. In highly restrained welded joints, the strinkage during cooling involved not only high residual stresses but also very important localized strains as shown on figure 4. This figure, taken from |2|, shows the strain repartition under a K butt joint symmetrically welded. In spite of the precautions used to limit the value of the strains, these reach a measured maximum of 2 % very near to the weld, considerable strains, up to 0,5 %, from 7 to 10 mm. deep where also found in the plate susceptible to lamellar tearing. The effect of this strain accumulation is to open the plane inclusions and, if the parent metal does not posses a sufficiently good short tranverse ductility to permit strain concentrations at the end notches of the opened inclusions a characteristic strairs line crack propagation occurs. Typically lamellar cracks are given in the nexts photos |3, 4|.



Strain distribution in a T-butt weld measured by a Moiré fringe technique. Strains in (%)

Figure 4

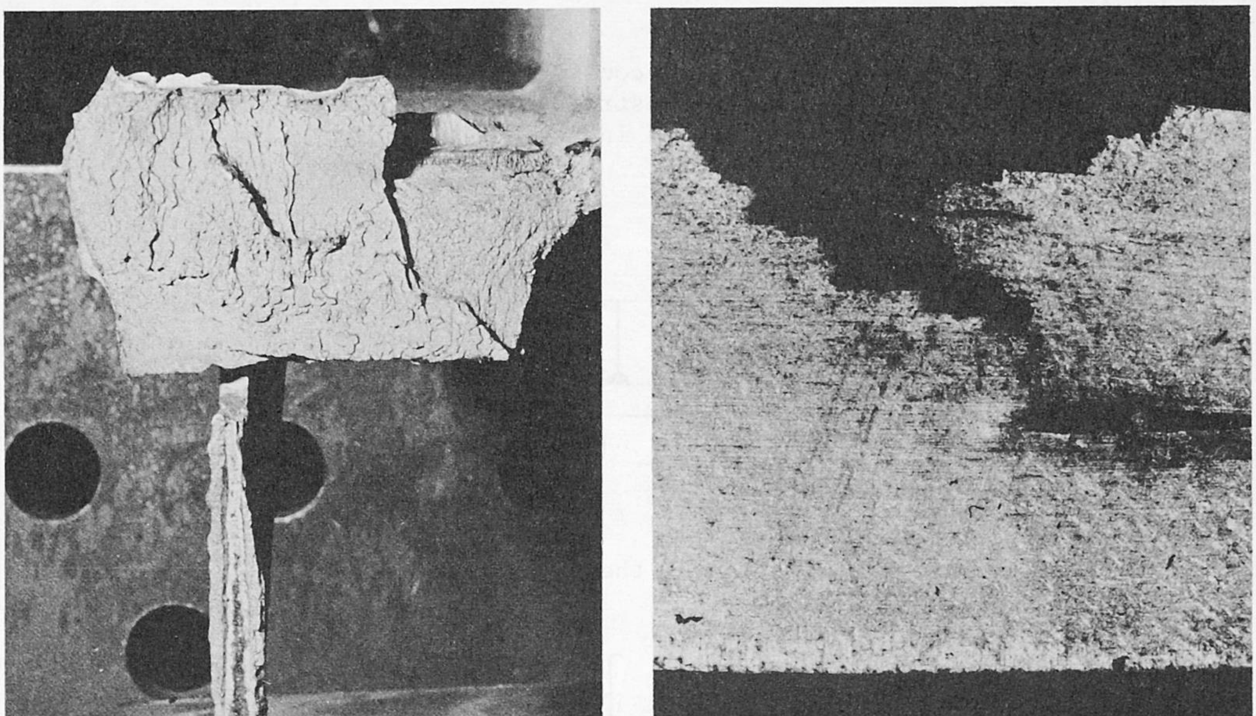


Figure 5. Examples of typical lamellar cracks and ruptures.

In exeptional cases, cracking by lamellar tearing can also initiated in the heat affected zone by a preliminary cold crack ; it can also have its origin in the banded structures of low alloyed quenched and tempered high strength steels, which explains that some cases of lamellar tearing have been observed in such types of plates having no plane inclusions which generally characterize the lamellar tearing susceptibility |5|.
The described mechanism of initiation of lamellar cracking shows clearly the three necessary conditions for its appearance :

1. The parent metal must be susceptible to the phenomenon. Pratically, this susceptibility is revealed either by plane inclusions or by banded structures. This susceptibility can be detected by mechanical destructive testings or by special ultrasonic scanning techniques.

2. A highly restrained joint leads to great localized plastic deformation in the parent metal, close to welded joint.
The strains result from the shrinkage during weld cooling ; they are the greater the restraint and weld metal volume are higher.

3. The susceptibility to lamellar cracking increase when the shape of the groove permit the devellopping of the shrinkage strains normally to the rolling plane.

A shrinkage normal to the rolling plane is also normal to the main plane of the inclusions, this makes easier the inclusion opening and, in the same way, lamellar cracking initiation. Preventive measures used to limit the risk of lamellar tearing concern on the one hand the design and execution of the welded joints and, on the other hand, the use of no susceptible materials in the cases of T, L and cruciform joints.

1. PREVENTIVE MEASURES.

1.1. Joints design.

Joints design to limit lamellar cracks consists in the limitation of plastic strain which occurs near the highly restrained weld and in avoiding a weld shrinkage normally to the main plane of inclusions.

1.1.1. Strain limitation

a) by reduction of the weld metal.

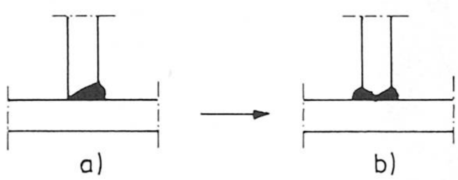


Figure 6

b) by reduction of the localization of the plastic strains.

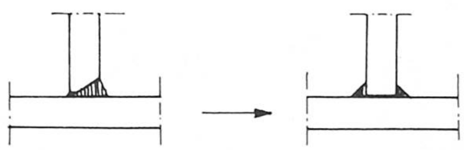


Figure 7

The use of fillet weld in place of V groove weld assume, of course, that the volume of the weld metal is not greater in figure 7 b than in figure 7 a.

c) by the use of a shaped groove which limits the component of weld shrinkage normal to the rolling plane.

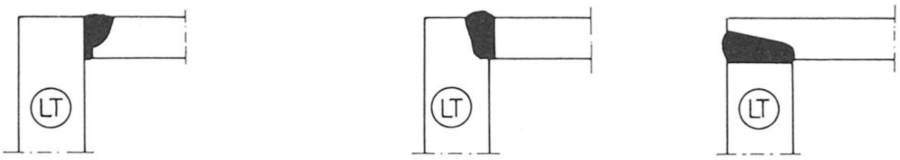


Figure 8

(LT) plate susceptible to lamellar tearing.

1.1.2. Local use of non susceptible material.

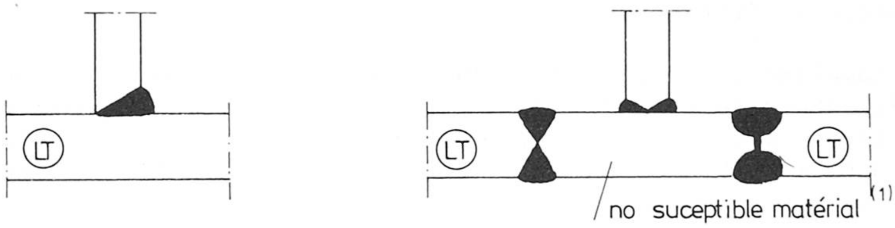
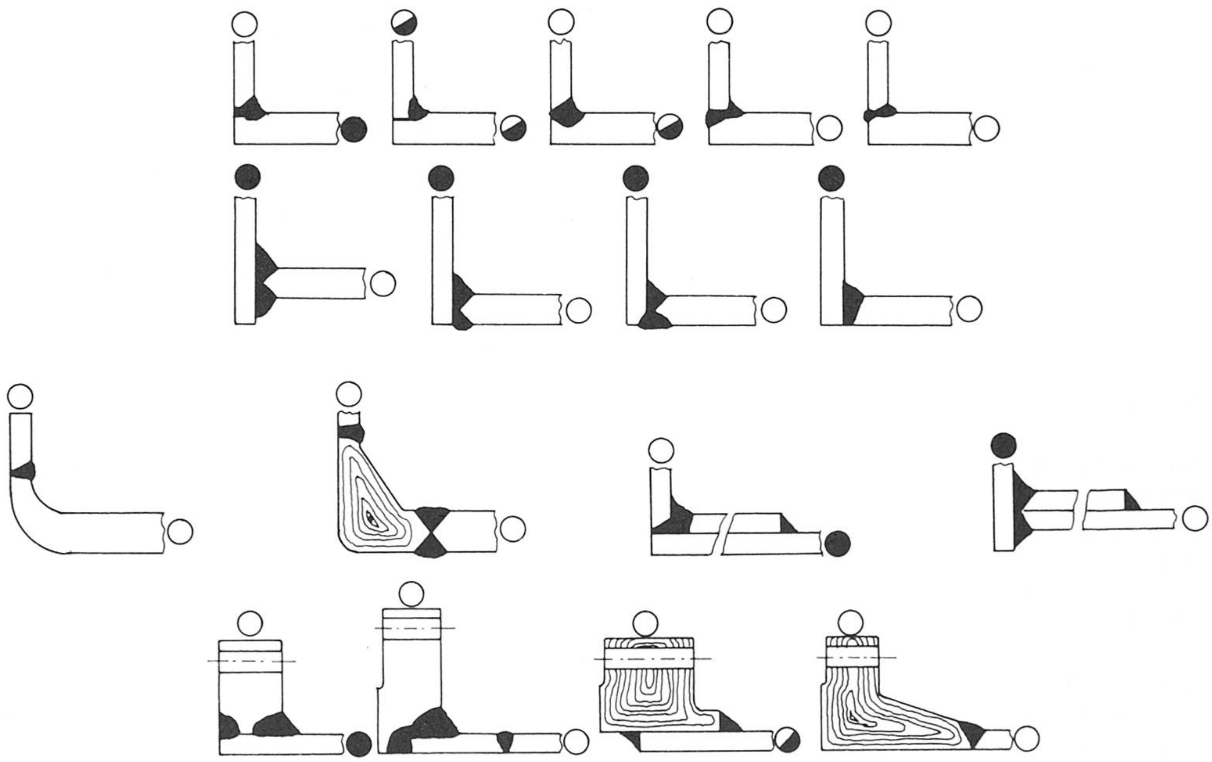


Figure 9

(1) Well known non susceptible steels are Z steels and forged steels.

As shown on figure 10, welded tube joints can also reveal lamellar cracks. The I.I.W. proposes in Doc. IIW XI-286-73 some examples of welded tube joints to avoid lamellar cracking. This figure represent a longitudinal section of the tube |6|. The symbol ● concerns the tubes for which lamellar cracks influences the joint behaviour, the symbol ○ represents the opposite behaviour.



1.2. Procedure and Practical welding conditions.

The influence of the procedure and of the practical welding conditions on cracking by lamellar tearing is mentionned in almost all studies concerning this phenomenon |7|, although it seems that no systematic investigation has already been made to date.

1.2.1. Influence of the welding process.

The influence of the welding process on the risk of lamellar tearing has not been proved ; at the very most, it is reported in the specialized literature that the use of low hydrogen electródes and fluxes can help to diminish the risk of lamellar cracking whithout elimination it completely |7|. This can be explained on the one hand by the influence of hydrogen on the cold crack appearance which can initiate lamellar tearing and, on the other hand, by the diminution of the notch toughness in presence of hydrogen |8|.

1.2.2. Influence of filler metal.

The risk of lamellar tearing can be limited by the use a low yield and ductile filler metal. The effect of the use of such a filler metal permits to localize the strains in the weld metal and to avoid strains in the parent metal. The use of nickel and nickel alloys as filler metal is generally recommended for critical joint welding.

1.2.3. Influence of welding technology.

a) Surfaces "buttering".

The so called "buttering" technique consist to lay, before effective welding, a 5 to 10 mm. low yield and high ductile filler metal on the surface of the piece susceptible to lamellar cracking.

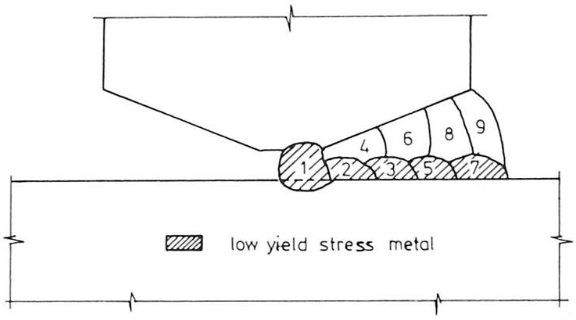


Figure 11 "Buttering" technique

b) Symmetrical welding.

In fact, this technique permits a certain uniformisation of the restraining strains under the welded joint. This limits the value of localized strains. Nevertheless, figure 4 shows that, in all cases the restraining strains remain very high.

c) Other methods.

Other methods like preheating, hammering or intermediate relaxing can be used to limit the risk of lamellar tearing but they do not permit its complete elemination |7|.

2. ASSESSING THE LAMELLAR TEARING SUSCEPTIBILITY.

2.1. Non destructive methods |9|.

Ultrasonic testing of plates is widely used to reveal and localize lamination and large inclusions. The extension of destructive techniques to assess the risk of lamellar tearing has been done. The best results have been obtained by special techniques using high frequency probes : measurements of the fading out or attenuation of the signal at multiple backwall echos and defect area integrating test with water immersion seems to be given the best results |9|. Extensive conventionnal ultrasonic testing is not useless in this respect, the experience is that tearing incidents have been reduced by about 40 % applying such expensive techniques |17-10|. From a safety joint of view such extensive conventionnal ultrasonic scanning is not sufficient.

If high frequency improves the testing sensibility for attenuation measurements, the determination of acceptation levels, in relation to the risk of lamellar tearing seems somewhat difficult because the metallurgical grain dimensions becomes a signifiant parameter of this attenuation |11|. The ultrasonic testing with attenuation measurements can detect local variations of inclusion distribution and thus determine the most susceptible part of the plate where destructive testing can be made to assess safety the risk of lamellar tearing of the tested plate.

2.2. Destructive methods.

Generally the proposed destructive testing to characterize the risk of lamellar tearing measure the through thickness properties of the material, it seems that the deformation measures are the most adequate in this respect. Two types of tests can be distinguished : test with and without welding. Among the test without welding, which permits a classification of parent metals regarding the risk of lamellar cracking, the I.I.W. test |12|, the slice bend test |13|, the Brodeau test |14| and the bend test on notched test pieces |15| can be mentionned. Among the tests with welding, the most usual are the I.I.W. test on modified test piece, the CRANFIELD or NICHOLS-ELLIOT test |15|, the FARRAR test |14| and the LEHIGH test |18|.

2.3. Description of the destructive tests.

2.3.1. Tests without welding.

Among the tests without welding, a special attention must be given to the I.I.W. test because it has obtained the agreement from international specialists.

The I.I.W. proposes two types of test according to the plate thickness : a test without welding and a test which use welding. Test pieces of the first type are recommended for plates having a thickness over 25 mm. This is a cylindrical tensile test piece machined in a thoughthickness direction in the tested plate : figure 12 gives its geometry.

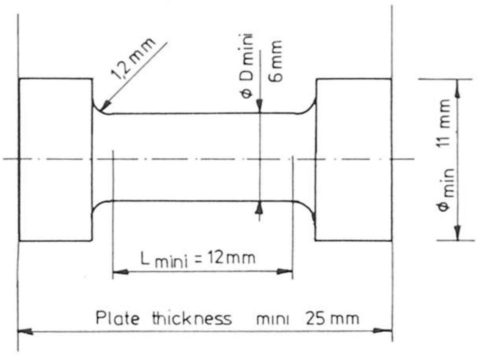


figure 12

The values represented on this figure are minimum values ; the condition L > 2 D must always observed. In the case of the tested plate have a thickness up to 25 mm. the testpiece is machined out of the plate to which extensions have been welded by stud or friction welding (figure 13) or out of a cruciform-welded test (figure 14).

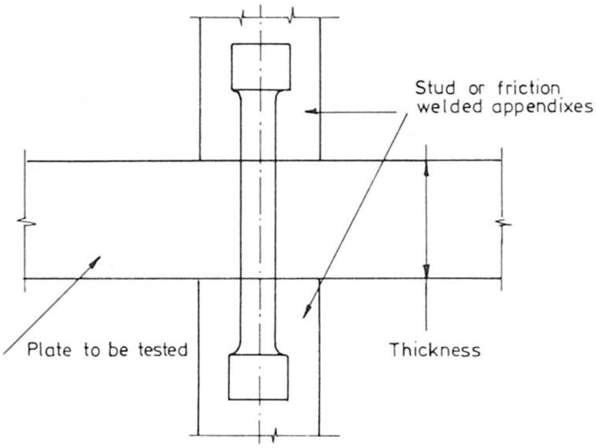


figure 13

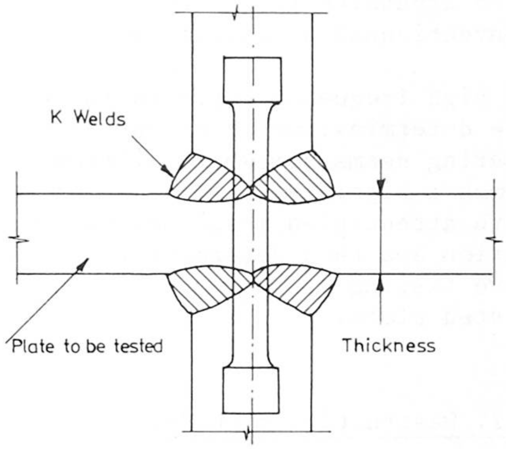


figure 14 a

Figure 14b represents the stages of machining when cruciform welded specimens are used. In this last case special precautions must be taken to avoid cold cracks. The technology of the I.I.W. test on welded joint try to minimize the effects of this welding on the lamellar cracking. The parameter measured to caracterize the risk of lamellar tearing is the pourcentage reduction of area Z. This is the ratio between the ultimate variation $S_o - S_u$ of a tranversal cross-sectional area S_o expressed as a percentage :

$$Z = 100 \frac{S_o - S_u}{S_o} \%$$

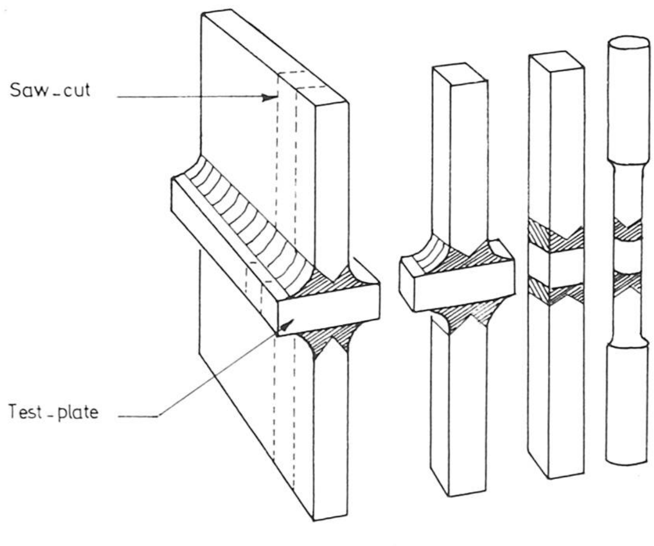


figure 14 b

2.3.2. Tests with welding.

The so called test with welding are tests which uses the restraining effect of welding to induces the stresses and strains in the plate susceptible to lamellar tearing. No one of these tests seems to have been generally accepted, anyway the most usual, in our opinion, are described afterwards.

1. Cranfield or NICHOLS-ELIOTT test |15|.

The test piece used is described on figure 15. The stress acting normally to rolling plane is essentially due to the weld strinkage effect.

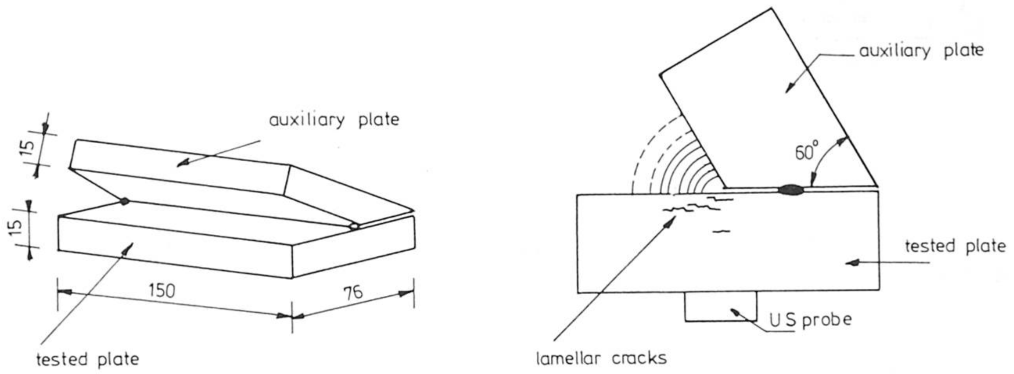


Figure 15

An auxiliary 60° beveled plate is used. The fillet weld is deposited horizontally with covered low hydrogen electrodes. The bevel angle chosen permits the initiation and propagation of lamellar tearing in the test plate. The electrode diameter and, of course, the welding current increase progressively when the welded joint is progressively filled. After any run, the complete cooling of the joint is necessary and a conventional ultrasonic scanning is performed to detect the lamellar cracks. If no cracks are discovered, a new run is welded, if cracks are found, the auxiliary plate is rocked to make the cracks visible.

2. Window test |16|

The test method used is briefly described on figure 16. A massive plate with a machined window is used, the test piece is put in this window and welded with massive plate to make a very highly restrained welded joint for which the shrinkage kage does normally to the rolling planes of the tested piece.

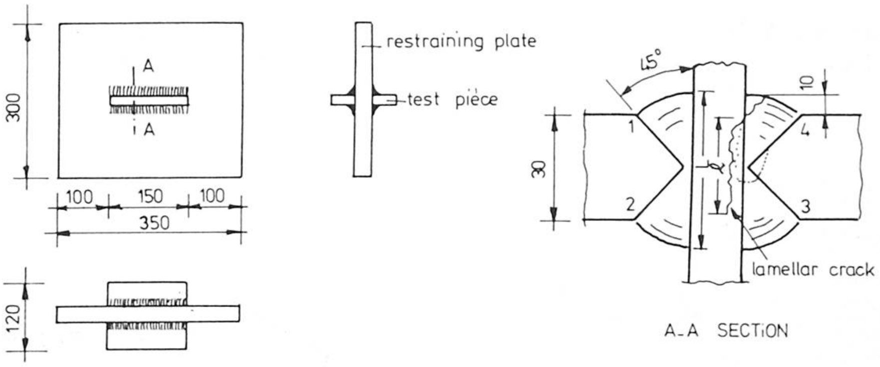


figure 16

The lamellar tearing susceptibility is characterized by $(\frac{\Sigma \ell}{\Sigma L})$ 100 %, where ℓ and L are definied on the figure.

3. FARRAR test |14|.

The test piece used in the FARRAR test is machined out a half V (45°) groove weld as shown on figure 17

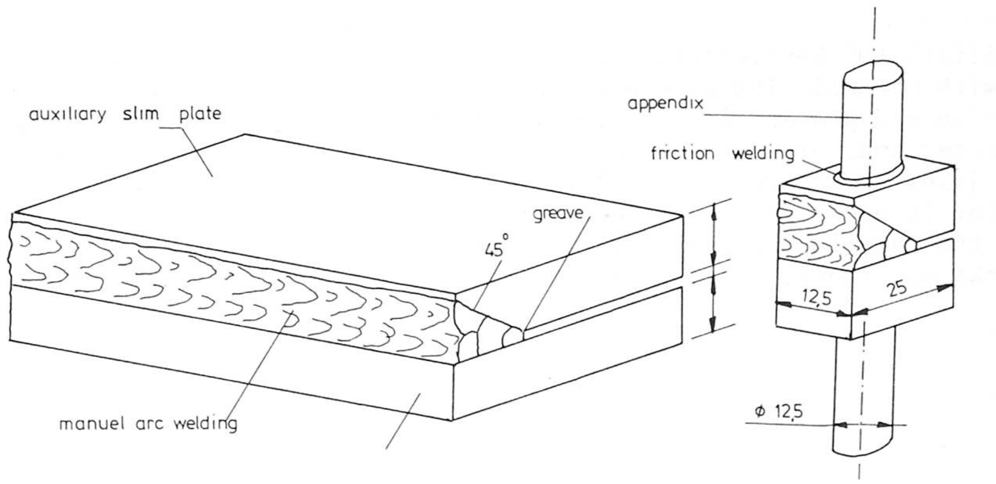


Figure 17

Tensile or bending test piece

This machined piece is finished by adding, generally by friction welding, a double appendix to complete the test piece for a tensile or bending test.

4. LEHIGH test.

The test method used in the LEHIGH test is described on figure 17.

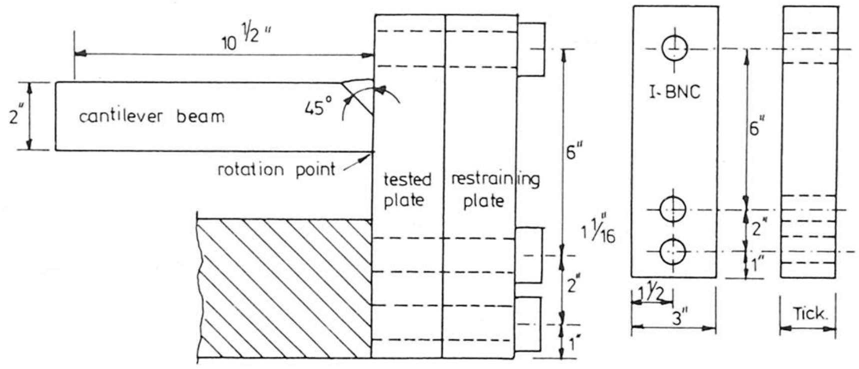


Figure 17

A cantilever beam is welded with a half Y (45°) groove weld on the test plate. A known external force is applied on the beam to initiate lamellar tearing. The lamellar cracks are detected by conventional ultrasonic scanning of the tested plate. The main advantage of this test is its very easy practical interpretation.

2.3.2. Conclusions.

The main disavantage of destructive testing is the obligation to measure the risk of lamellar tearing of a localized part of the piece that will not necessarily be used afterwards in the construction. From a safety point of view it is thus necessary to machine the test pieces in the most susceptible part of the structural element which can be localized by ultrasonic methods.

3. REPAIRING.

3.1. Detection of lamellar cracking.

The lamellar cracks propagate parallel to the rolling plane ; the most appropriate non destructive techniques for its detection is conventional ultrasonic scanning ; angle probes (45° ou 70°) must be generally used. In certain cases straight beam tranducers can also be used. Figures 18 a) an b) show the techniques in both cases. Only the straight beam tranducer permits a good localisation of the lamellar cracks by using 20 dB probes. In certain cases, it can be useful for small defects to make calibration against small flat bottomed holes |9|.

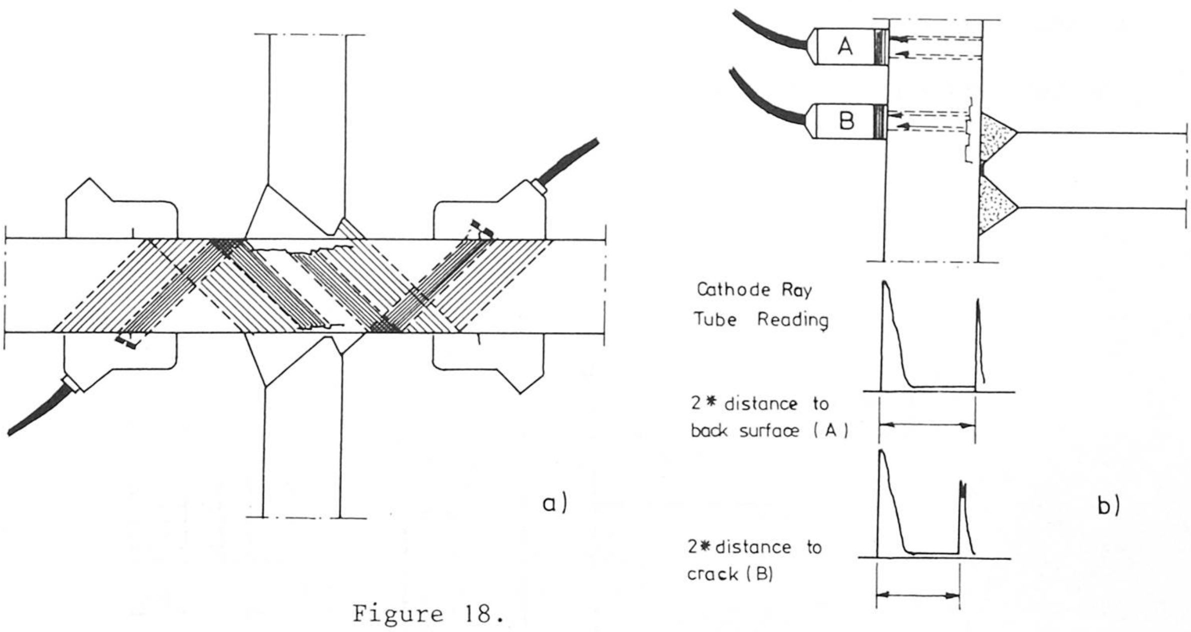


Figure 18.

Non destructive radiography or grammagraphy test do not permit a safe detection of such cracks because their orientation.

3.2. Reparing techniques.

The repairing techniques used begin, in all cases with the removal of the cracked zone of the lamellar teared piece. Afterwards, this removed part of the piece is filled with low yiels weld metal, what is called "buttering", or a new piece, which does not risk lamellar tears, is butt welded in place of the removed piece. This two techniques are respectively represented on figure 19.

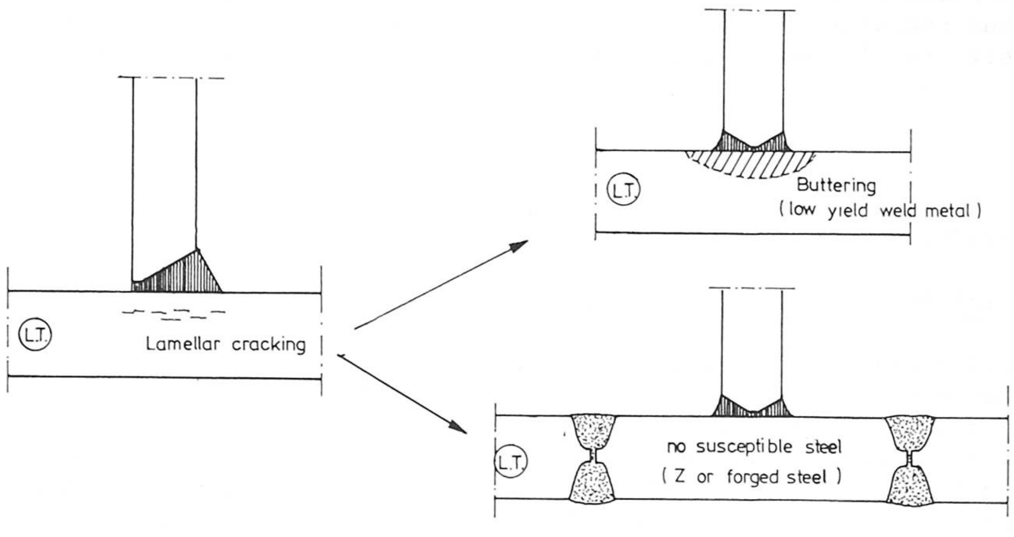


Figure 19

The high residual stresses that appear with the use of this methods require the relaxation of the repaired joint or, in case of buttering, intermediate relaxations during repairing.

4. CONCLUSIONS.

The risk of cracking by lamellar tearing must always be considered by the designer of a welded structures, especially when this structures contains welded T, L or cruciform joints of elements whose thickness exceeds 25 mm. In general, for thickness up to 25 mm., the risk of lamellar tearing is very small, but special attention is necessar when quenched and tempered high strength steel is used. The banded structures, which are frequent in these type of steel, can initiate this cracking phenomenom.

The prevention of this risk must be done :

1. At the level of the general design, which must be such as to reduce to a minimum the stressing of the rolled products normally to the rolling plane. The external stresses are not at the origin of the phenomenom but they can help to propagate the cracking, especially in the case of fatigue.

2. At the level of the joint design, by adhering to the rules given in section 1.1., which concern mainly the strain limitation in the parent metal and the local use of no susceptible materials. In certain specific cases of tube joints the I.I.W. recommendation can be adopted |6|.

3. At the level of joint welding, by choosing a welding procedure minimizing the strains caused by the restraining effects, by using systematically symmetrical welding, by depositing the minimum weld metal and by using filler metal whose mechanical characteristics although being ductile arc, nervertheless, compatille with the service conditions of the structures.

4. At the level of the choice of the parent metal, by imposing a minimal value of the reduction in a measured in a short transverse tensile test. The literature survey, taken from |9| and summarized on figure 20, shows that this minimal value is a function of the type of welded joint. It seems that a safe valeur for T joint (figure 20 a, b) is 15 % of reduction in area and for cruciform joint (figure 20) this safe value is 30 %

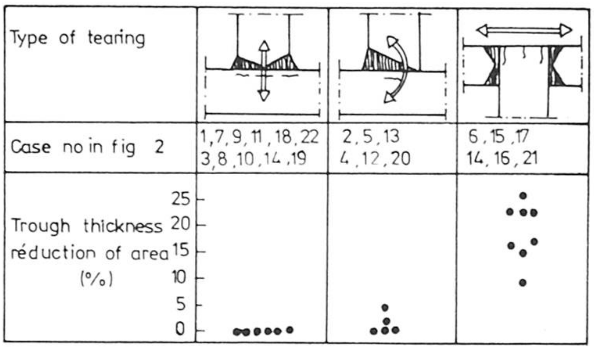


Figure 20

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