

Risks with the welding of stainless steel (2)

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Welding of stainless steel requires the necessary knowledge in order to get quality connections, without unexpected calamities. In Part 1 (MK 6) the metallurgical aspects of stainless steel have already been treated in a restricted way. This article describes the welding aspects and the possible risks that arise when welding stainless steel in an indiscriminate way.

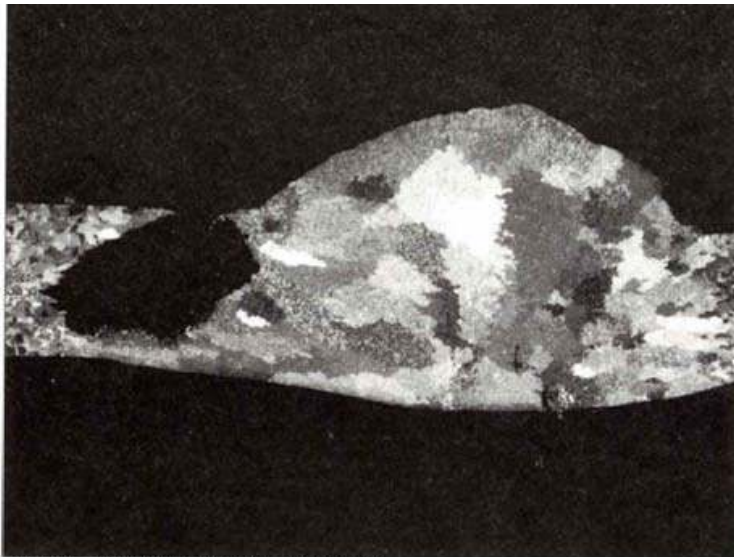
Since this article primarily deals with the welding of stainless steel-types, the metallurgy as treated in MK 6, will not be treated again. It is relevant, though, to mention the different characteristic numbers of stainless steel and also those of unalloyed carbon steel, in order to acquire some knowledge about the differences (table 5).

Stainless steel is an excellent material for welding, provided that the right 'rules of the game' are observed. Here it is also in force that the weakest link in the chain is

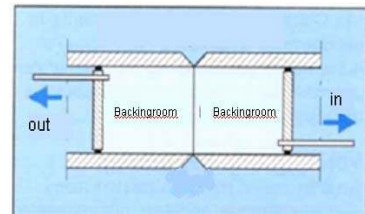
mostly the weld or also the weld area. It is also a fact that these weak links now don't need to occur anymore with the present welding technology and corrosion knowledge. It is thus often because of ignorance and laziness, that inferior welded joints are made. Besides weak mechanical joints also joints that later will become sensitive to all sorts of corrosion mechanisms can be made. Conversations with expert suppliers of semi- goods (such as for example weld additional material)

can prevent a lot of problems and corrosion damages.

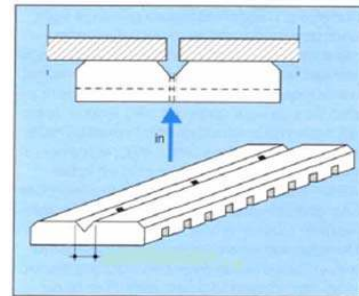
Since the physical properties of austenite stainless steel diverge considerably from carbon steel during welding, this of course has to be considered. In fact, with stainless steel, for example, CO₂ – or autogenous welding can not be used.



7. Severe pitting corrosion just beside the weld



Flushing with backing gas



Backing device with groove and holes

Table 5: Fysical properties

properties	Ferritic stainless steel type 430 (1.4016)	Austenitic stainless steel type 304 (1.4301)	Austenitic stainless steel type 316 (1.4401)	Duplex stainless steel type 1.4462	Unalloyed carbonsteel
Density (kg/m ³) (x10 ³)	7,7	7,8	7,8	7,9	7,85
Linear expansion rate (K ⁻¹) (x10 ⁻⁶)	10,6	17,25	16,7	13,0	12,3
Heat conductivity (W/m-K))	284,6	175,6	159,6	272	480
Electrical resistance at 20 °C (Ωmm ² /m)	0,56	0,71	0,73	0,83	0,1
Melting point (°C)	1490	1440	1420	1430	1420

Welding of stainless steel

Since in practice quite a bit of austenite qualities are welded, the consideration hereunder will primarily relate to these stainless steel types. Because the physical properties of austenite stainless steel, in contrast with the chrome steels, diverge considerably from those of the carbon steel, it will be clear that these differences have a considerable influence on the ultimate welding process. The linear coefficient of expansion, for example, is 1,5 times bigger than that of carbon steel, which means that after a thermal strain a much higher stress remainder is left in the material. Fastened joints have to be put much closer than with carbon steel. The relatively bad heat conduction capacity of austenite stainless steel causes that the heat in the welded area gets discharged much worse. Because of this, welding in position is obstructed by the slow coagulation. The chance to get inter-metallic separations on the granule borders is increased because of the role which is played by the time factor. There is also the danger that the melting bath gets overheated. The worse conductivity can cause that the feed electrode gets overheated quicker. Because of these facts it is recommended to use the MIG-welding process of electrode welding with thicker sheets because of the relatively low thermal stress. With thinner sheets (until about 3 mm) and pipes, the TIG-welding process is mostly recommended. With TIG-welding the heat is obtained from an electrical arc between an infusible tungsten electrode and the piece of work. Because of this the TIG-welding process is well suited for the welding of thin stainless steel and pipe joints, and this in each desired state. Also for the placing of ground joints with thick sheets the TIG-welding process is often used. The welding under dust cover is in some cases also applied.

For all the stainless steel qualities it is important that the preparation be optimum. Attention should especially be given to the cleaning and the pre-processing of areas that have to be welded. The welds should be dry, clean and especially grease-free. Especially grease and pencil marks contain carbon steel which would very much like to penetrate into the material (diffuse), since the urge to absorb carbon steel is so high. Grease dissociates



9. Stress-corrosion cracking



10. Trans-crystalline cracking caused by stress-corrosion

at increased temperatures in carbon and hydrogen and it will be clear that this carbon steel will enormously corrode the weld quality (formation of chromium calcium carbides). The joints ought to be flat and undamaged (free from burrs). The shape is dependant on the product that has to be welded.

As general guideline it applies to all stainless steel qualities that additional weld materials need to have, as much as possible, the same chemical composition of the parts that have to be welded.

What is practically still a misunderstanding, is that the so called 'L'-qualities are specifically meant for welding. This is not the case, because 'L' stands for 'low-carbon', and therefore not for 'welding'.

It is possible to weld stainless steel both with coated electrodes and with wires (TIG/MIG-welding

process). Coated electrodes are used on behalf of hand welding. Advantages of hand welding are that there is access to all the positions and that the heat supply is relatively low. Furthermore it works quickly and the investments are low. The slag also gives protection at the back of the weld. Disadvantages of hand welding are that the chance on slag rests, slag occlusions, spatters and start colors are big, because of which staining will always be necessary. The process also progresses quite slowly. Attention should be paid to the insulating cover of the electrodes which has to be very dry.

With regard to the wire joints (TIG and MIG) in general it can be stated that the advantages are: no slag- and splatter formation and the weld is protected very well. With the MIG-process the welding speed is high and the process is easily

mechanized and automatized. The disadvantages are that both processes are sensitive to wind (therefore operate inside) and that no correction of the weld bath is possible. Care for a good backing should also be taken.

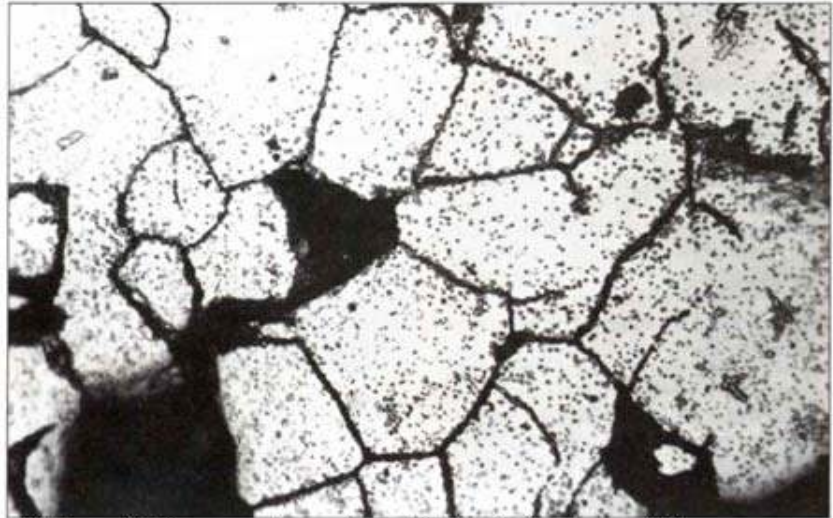
Table 6: Necessary groove width for a backing device								
Thickness	0,3	0,5	0,8	1	1,25	1,5	2	2,5
Width	1	2	2	3	3	3	3	3

Corrosion

Many devices of stainless steel fail prematurely because of corrosion damages that have arisen through unprofessional welding. In general it counts that the same additional weld material must always be used as the basic material. In practice the corrosion damages mentioned here below, occur mostly as a consequence of incomplete welding:

- well shaped corrosion;
- stress (crack) corrosion;
- inter-crystalline corrosion;
- weld decay;
- knife-line attack;
- crack corrosion.

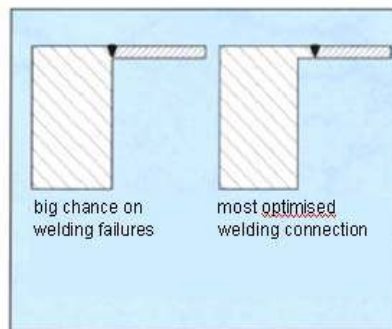
These forms of corrosion and the measures to prevent these as much as possible are hereafter further discussed.



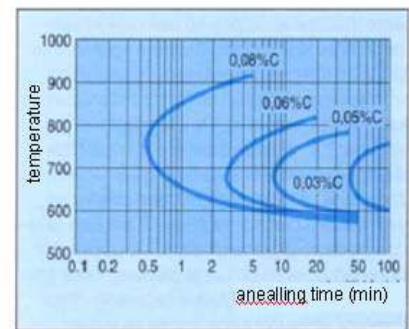
11. Inter-crystalline corrosion and precipitation of chromium carbides

Pit shaped corrosion

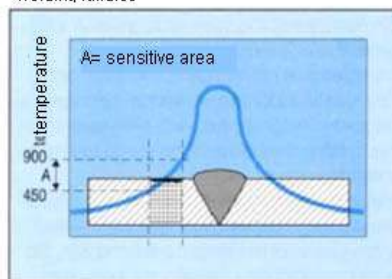
This form of corrosion is very feared because a strong corrosion takes place merely locally. The stainless steels without molybdenum are the most sensitive to this form of corrosion. On average this corrosion form shows up mainly where halogen-ions appear, such as fluorine-, iodine-, bromine- and especially chlorine ions. The cause of this corrosion must always be searched in the damage or interruption of the passive layer of chromic oxide. An extra sensitive place where this corrosion appears, especially takes place next to the welded joint. Start colours are the evidence of that, because they indicate a strong local oxidation. This oxidation usually leads to a porous layer of oxide which allows the electrolyte to go through. Especially the relatively small chlorine ion, which is so necessary in order to keep the object passive, often penetrates deeper than the larger oxygen atom. It is therefore very important that similar start colours are removed with staining or polishing, possibly followed by another passivation. This staining happens mostly through a suitable pickle paste, because an immersion in a pickling bath is often not possible. In practice, it is than often thought, that everything is all right, but it is



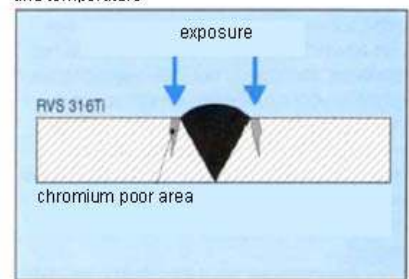
12. Using the right method prevents welding failures



13. TTT-diagram (time, transformation and temperature)



14. Temperature in the welding crack



15. Knife-line attack

forgotten that the invisible insides can also have these start colours. In pipe systems such kind of problems appear regularly, even with the use of backing-gas. The reason is that there is still too much oxygen in the backing-gas and/or that the heavier backing-gas (also called formation gas) allow the lighter oxygen to stay above in the pipet, because of which it still starts

local oxidation. This form of corrosion has already prematurely completely destroyed a lot of channel systems. Even conduits, through which for example, chloride containing cooling water flows can after one or two years be completely full of leaks just next to the welded joints. Effective washing with backing-gas and the use of the right sealing tools will offer a good

solution. Internal and external welding are also used simultaneously on the same spot, because of which the backing becomes superfluous. Normally a little hydrogen (+/-2%) is added to the backing-gas, in order to allow the oxygen to react with it, so that the stainless steel is spared.

However, in practice it seems that the effect of the hydrogen addition often does not give the completely desired result. Helium can also be added to the backing-gas, in order to chase away the oxygen at the top of the pipe. In order to make a good welding process the welding chamber must first be washed with formation gas according to the formula in fig. 6. Empirically it is also stated that the time of flowing must be in such an extent that the total volume of the backing space is replaced about 20 times.

Since, from practice, it often appears that the complete formation, in regards to quality, is far from satisfactory, it can not be sufficiently emphasized how important this is. It is actually only prudent to start with the welding process if the amount of oxygen in the formation gas has come under the 50 ppm. If this critical aspect is adequately recognized, a lot of corrosion, like for example the well corrosion as reproduced in figure 7, can be prevented. It is also possible to weld sheets by backing them with the help of a so called 'bearing', out of which the protection gas constantly flows at the bottom of the welded joint (fig. 8). The groove width which is necessary for this bearing is reproduced in table 6.

Slag rests can also further increase the risk of corrosion. Therefore these must always be thoroughly removed. In conclusion, it is worth mentioning that after the application of the first welding layer, the backing gas has to continue flowing when the second filling layer is applied, because the first welding layer will become very hot again (big chance for oxidation). After welding, it is also strongly recommended carry on rinsing until the surface has come under 250°C.

Corrosion from contamination

A variant of pit shaped corrosion is the so called contamination corrosion, caused because strange metal particles have ended up on the stainless steel. Lack of oxygen under these particles results in activation of the surface, through

Flushing time

$$t = 4 \cdot 10^4 \cdot D^2 \cdot L / F$$

- t = flushing time
- D = diameter
- L = length backingroom (mm)
- F = backinggas output (dm³/min)

which pit corrosion will arise. The most serious form is caused by the contamination (infection) of carbon steel particles, which can initiate intense pit corrosion. Also metal particles of all sorts of tools and wrong wire brushes can give origin to this form of corrosion. Therefore, it is important that the processing of carbon steel and stainless steel happens separately and that the tools are handled very consciously. If there is still uncertainty about a possible contamination, than staining is the best solution.

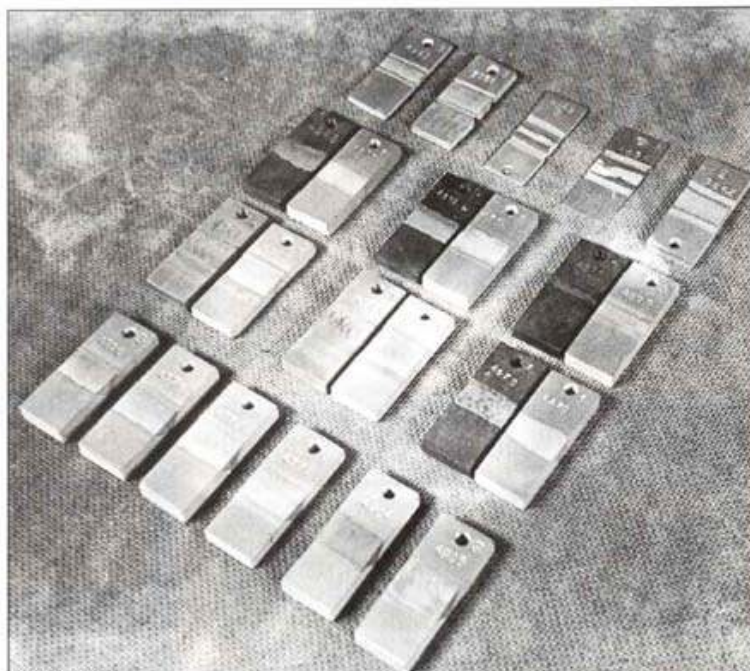
Stress (crack) corrosion

Stresses often give origin to corrosion and therefore the point is to hold these as low as possible. Stress areas in an electrochemical system are always anodic and similar spots sacrifice themselves on behalf of the cathode, which, as for surface, is usually many times bigger: this accelerates the corrosion process even more. The corrosion phenomenon which arises is the trans-crystalline

corrosion, which means that the corrosion propagates across the metal crystals (fig. 9 and 10). This is in contrast with the inter-crystalline corrosion, where the corrosion propagates around the granules (fig. 11).

Small micro cracks on the surface cause a stress rise in that specific area, so that this spot poses itself anodic and corrodes. During corrosion the hydrogen ion takes an electron from the electrolyte of the ion metal which has come into the solution, so that there is formation of hydrogen. This hydrogen diffuses locally into the surface of the stainless steel, which leads to local brittling. This brittling makes that the small seam propagates easily, through which the trans-crystalline seam (crack) can form itself quite quickly. This serious corrosion, in principle, appears only with halogen-ions (especially fluorine- and chlorine ions).

In order to prevent stresses in stainless steel as much as possible, it is advised to weld the parts as much as possible in a cold state with the current density as low as possible and the weld speed as high as possible. There care should also be taken that the welds are not layed too closed to each other and that the welds do not cross each other. Attaching must therefore be done as small as possible, so the use of attach strips is always dissuaded. Since, because of



15. Weld-decay

shrinking, the welds also cause an extra stress it should be looked at that these welds have a minimum content, without this happening at the expense of the strength of the connection. When welding unequal thicknesses the chance to keep higher remainder stresses is also bigger and therefore, here, the task of the constructor is to prevent it as much as possible (fig. 12).

In practice appears that to glow with low stress at about 1060 °C is the best, this is because first the stresses disappear and then because possible inter-metallic joints and other precipitates dissolve in the matrix. There can also arise stress corrosion if more welded joints are put on each other since the quality of the welds underneath goes backwards because of continually heating. It is advisable to keep the lowest layer on the corrosion loaded side and it if possible to heat.

steel containing less carbon will be much less sensitive to it than the kinds with a higher content of carbon. Empirically, it has been found that the chromium carbides arise only on the granule borders if the carbon content is higher than 0,04 %.

In practice, it also appears that thin-walled stainless steel, generally speaking, does not have problems because of this phenomenon since the cooling time is so short as a result of the thinness of the plate thickness.

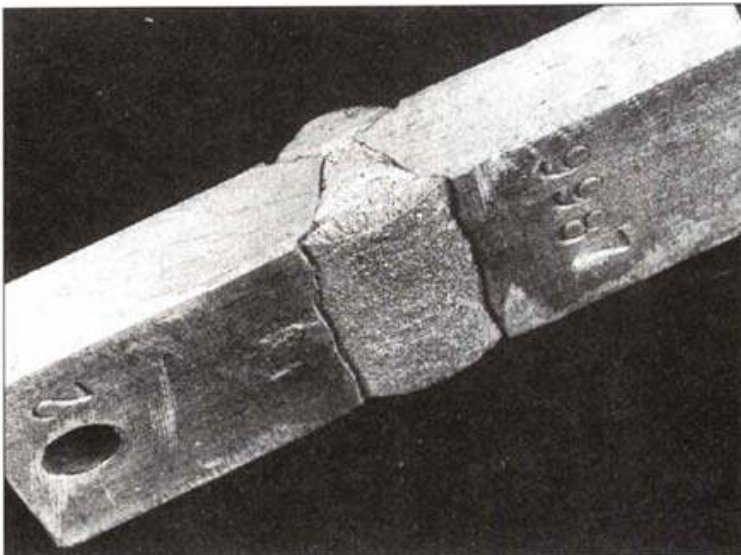
In this last case, therefore, time is not enough to form these carbides. These carbides form themselves especially in the temperature range between 450 and 900 °C. At a certain distance from the weld there will be a so called sensitive area which allows these carbides to arise. Therefore, there is always corrosion at a certain distance from the weld and not immediately next to the weld such as has been the

stresses the corrosion is further intensified.

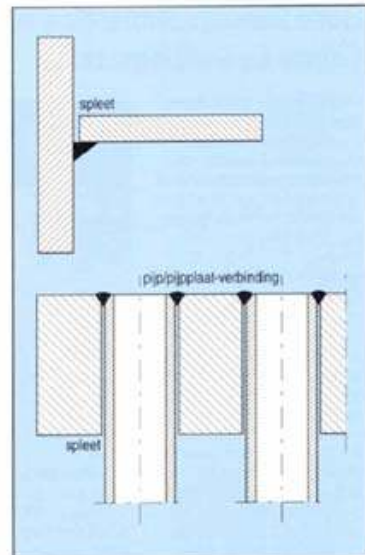
Brittling can also arise because ($Cr_{23}C_3$) the toughness of the material is brought significantly down on account of the hard chromium carbides. This form of corrosion is therefore called inter-crystalline corrosion, because this takes place between the metal crystals (fig. 11). The part will quickly break through because of the present remainder stresses, due to the notch effect which has arisen through the corrosion. Of course this form of corrosion can also be obtained through other thermal strains which last for a certain time.

Weld decay

Weld decay is actually a variant of inter-crystalline corrosion. It is however specifically named, because the inter-crystalline corrosion can also arise from other thermal strains. If the temperature



17. Knife-line attack



18. Crevices between tube/plate due to one-side welding

Inter-crystalline corrosion

At a short distance from the welded joint, because of the influence of the heat on the granule borders and in the rule with a higher content of carbon, chromium carbides can arise if there is enough time for that. More than one things appears from the so called TTT-diagram, which stands for Time, Transformation and Temperature (fig. 13). The diagram shows that these undesired carbides can form themselves if the carbon content, the temperature and the time lead to it. In other words: a stainless

case of the 'knife-line attack'. These carbides arise on the granule borders because there the tendency for similar links to arise is highest. The corrosion can even reach such serious forms that the granules become loose from each other. These precipitates withdraw chromium from their environment and through this the environment is more base than the rest. The environment of the carbides through this becomes active and will quickly corrode in a high measure. If there are also

curve is examined on a weld, a sort of Gauss-curve can be seen (fig. 14). If the TTT-diagram is set next to it, it can be seen a sensitive area arises next to the weld, which with enough time, forms the notorious chromium carbides. At high temperatures the solution pressure is big enough and at lower temperatures the diffusion speed is too low to form the feared carbides. This results in the so called nose form of the TTT-curve. There remains a sensitive area which is rapidly affected as a consequence of this phenomenon. In this case

again solutions are the application of types with a low content of carbon on a heat treatment after welding. On figure 15 the corrosion form is visible. Weld decay luckily does not occur so much in practice anymore, because usually enough measures are taken against it.

Knife-line attack

Because of the relatively high content of carbon, the types of stainless steel which are alloyed to titanium form titanium carbides. These titanium carbides set themselves on the matrix in a disperse way, and prevent the formation of chromium carbides. The reason is that titanium has a higher affinity with regard to carbon than to chromium. Stainless steel is in this way consolidated. However, titanium carbides can be a cause of pit corrosion, because these particles can manifest themselves as a defect on the surface. Next to this problem and to the fact that it cannot be polished so easily, there is another big disadvantage and that is that the titanium carbides will dissociate in the heat influenced area (disintegrate).

Titanium will than burn and the carbon which is given off will on its turn immediately combine with the chromium, with all the disadvantageous consequences. For this reason titanium containing additional weld material is never applied. The consequence is that this area has become active because on a small strip the chromium content has decreased below 12%. It will be clear that locally intense corrosion will arise and it will have the form of a sharp knife. This is also the reason for which it is called knife-line attack (fig. 16 and 17). It is not a simple task to fight against this phenomenon. Next to keeping the heat-input as low as possible and the weld-speed as high as possible, the best remedy is still to always use, instead of a titanium stabilized stainless steel, a type with a low content of carbon (L-quality). The only disadvantage of this is that its mechanical properties are worse.

Niobium-stabilized qualities are obviously less sensitive to this knife-line attack problem. Next to additional low carbon weld materials, niobium-stabilized weld additional materials are also used.

Crack corrosion

Even if this form corrosion as consequence of welding does

occur very little, the constructor has to make sure that no splits will be present when placing the weld.

Mainly in narrow cracks, the discharge of the medium is so small that there will be a lack of oxygen, which is, however, so necessary to keep oxide hide in an optimum form. Especially the chlorine ion will penetrate deeply into the narrow cracks and there destroy the protection layer. This last can mainly happen in pipe/pipesheets-joints which are welded unilaterally (fig. 18).