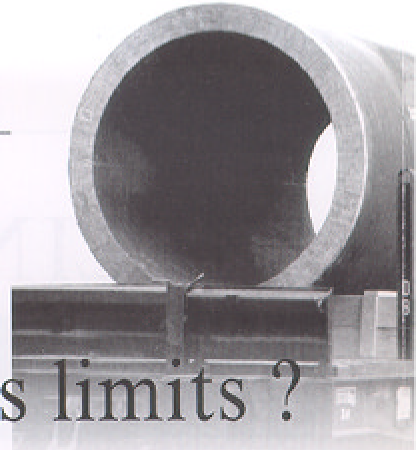
DILLINGER offshore LETTER



Plates for Offshore - Thickness limits ?

The marketing of steel for the oil and gas industries has become more complicated. Larger jackets and greater wall thickness are needed. The use of high strength steels becomes more attractive. In recent years the TMCP rolling technique was developed. It makes possible the production of high strength offshore steels in greater thickness and with lean chemical composition and good weldability. We likewise supply normalized (up to Grade 355) and quenched and tempered plates.

What are the limiting factors for plate thickness ?

BS 7191, as one of the major specifications for offshore steels, calls for a minimum through thickness reduction of 4 (3 for piles) during plate rolling. As the maximum slab thickness of our concast slabs is 300 mm maximum plate thickness of 75 mm, respectively 100 mm, can be supplied using this standard. PrEN 10225 is not setting limits as long as the mill can demonstrate that material complies with the quality requirements.

DILLINGER HÜTTE produces plates up to 450 mm thick. Such plates are rolled form heavy ingots and subsequently pass a separate heat treatment. They are used for applications other than offshore. Plates for offshore (normalized Grade 355 EM) are feasible in a plate thickness of approximately 200 mm, but normally 120 mm or 150 mm (some single plates) is the maximum ordered.

What is particular in rolling thick plates ?

It requires very high rolling forces and thickness reduction per pass to produce an effective grain refinement in the core of thick plate. This is particulary important if through thickness reduction is small. The technique is called „high shape factor rolling" and was already adressed in the last issue of DILLINGER Offshore Letters.

When thick plates are produced by TMCP rolling it really becomes a job for specialists. Special rolling schedules are needed to produce excellent toughness throughout the plate thickness and powerful rolling equipment is needed to assure sufficient core deformation in the final step. Sufficient speed in the subsequent cooling can only be obtained by accelerated cooling, if plate thickness exceeds about 40 mm.

Most specifications allow for a „natural" digression in yield strength for thicker plates, but some like NORSOK do not. If so, the influence of plate thickness on yield and tensile strength has to be compensated by the rolling process or by modified chemical composition with increased carbon equivalent. Careful alloying is however needed to maintain excellent weldability (preheat and HAZ toughness).

The geometry of the impact specimens is the same for all plate thickness (except subsize). The impact values therefore simply reflect the local material toughness at testing temperature. For CTOD-tests the geometry however changes with the plate thickness. Specimen thickness equals plate thickness and so does crack length („preferred geometry" according BS 7448). This size effect leads to effectively higher constraints and hence shifts the transition from brittle to ductile fracture to higher temperatures (Figure 1). Therefore, it is more difficult to fulfill CTOD requirements the thicker the plate. Some specifications even ask for higher CTOD values for greater thickness (e.g., API RP2Z 0.38 mm instead of 0.25 mm if plates exceed 75 mm).

TABLE 1: Weldability in terms of carbon equivalents for 80 mm thick Offshore Grades

Steel grade	supply condition	CE % (typ. average)	Pcm % (typ. average)
355 EM	normalized	0.42	0.23
355 EM	TMCP	0.35	0.17
API 2W-50	TMCP	0.35	0.18
420 EM	TMCP	0.39	0.19
450 EM	TMCP	0.41	0.21

Table 1 shows that the powerful TMCP rolling and accelerated cooling, as performed by DILLINGER HÜTTE, makes for a lean chemical composition even for 80 mm plate thickness. It can be seen that, despite the higer tensile properties, Grade 450 EM can be produced with lower CE and Pcm values than normalized Grade 355 EM.

Increasing demands for toughness in CTOD testing

With increasing yield and thickness greater concern is given to brittle fracture. Weldability qualifications, therefore, usually have to be performed on the thickest material to be supplied. As part of these tests toughness is characterized by impact and CTOD-tests on welds.

Experience with thick plates in material qualification

The status of qualification attained by DILLINGER HÜTTE for the different offshore grades is shown in Table 2. Tests performed recently are shown in with an asterisk. The CTOD results are summarized in the following Tables 3 and 4.

TABLE 2: Status of qualification for Offshore steels

Steel grade	casting route	plate thickness	procedure
355 EM (N)	concast	75 mm (100mm)[1])	BS 7191
355 EM (N)	ingot	120 mm	BS 7191
355 EMZ (TMCP)	concast	70 mm	BS 7191
355 EMZ (TMCP)	ingot	90 mm	BS 7191
S 420 (TMCP)	concast	100 mm	BS 7191*
450 EMZ (TMCP)	concast	80 mm	BS 7191
450 QT	concast	60 mm	BS 7191
450 QT	ingot	100 mm	BS 7191
API 2W-50 (TMCP)	concast	90 mm	API RP2Z*

N = normalized, TMCP = thermomecanically rolled, QT = quenched and tempered

[1]) PWHT only

For the API 2W-50 qualification the full set of welds required by API RP2Z were tested with heat input of 1.5, 3.0 and 4.5 kJ/mm. All tests were performed in the as welded condition. Excellent results were obtained all showing maximum load behaviour, hence fully ductile. S 420 was welded with heat input of 3.5 kJ/mm according to BS 7191. Again, fully ductile tearing was observed but for one specimen only. CTOD results are indicated in Tables 3 and 4. The clip gauge capacity was smaller in some sets of tests. As the CTOD values at maximum load could not be determined exactly, these test results are indicated as „>„ with CTOD values at the limit of measurement. Actual results at maximum load were essentially higher and had to be in the same range (2.10-2.60 mm) as for the other set of tests.

TABLE 3: CTOD results of API 2W-50

API 2W-50, 90 mm concast
CTOD specimenSENB, BxB specimen, full size
as welded

welding	SAW	1.5 kJ/mm, HV-prep.			
crack position	single values at -10°C (mode)				
CG-HAZ	2.61 (max)	2.35 (max)	2.50 (max)	2.37 (max)	2.31 (max)
	2.55 (max)	2.16 (max)			
IC/SC-HAZ	2.29 (max)	2.49 (max)	2.50 (max)	2.15 (max)	
welding	SAW	3.0 kJ/mm, HV-prep.			
crack position	single values at -10°C (mode)				
CG-HAZ	2.07 (max)	2.46 (max)	2.16 (max)	2.46 (max)	
IC/SC-HAZ	2.08 (max)	2.63 (max)	2.18 (max)	2.29 (max)	
	2.25 (max)	2.46 (max)			
welding	SAW	4.5 kJ/mm, HV-prep.			
crack position	single values at -10°C (mode)				
CG-HAZ	2.49 (max)	2.45 (max)	2.49 (max)		
	>0.78 (max)	>0.80 (max)	>0.71 (max)	>0.74 (max)	>0.77 (max)
	>0.81 (max)	>0.79 (max)	>0.79 (max)	>0.81 (max)	>0.80 (max)
	>0.74 (max)	>0.72 (max)	>0.71 (max)	>0.79 (max)	>0.80 (max)
IC/SC-HAZ	2.29 (max)	2.49 (max)	2.50 (max)	2.15 (max)	

TABLE 4: CTOD results of S 420 (Norsok)

S 420, 100 mm concast,
welding SAW 3.5 kJ/mm, HV-prep.,
CTOD specimenSENB, BxB specimen, full size

as welded				
crack position	single values at -10°C (mode)			
weld metal	>0.78 (max)	>0.78 (max)	>0.77 (max)	
CG-HAZ	>0.77 (max)	0.24 (u)	>0.79 (max)	>0.78 (max)
	>0.78 (max)	>0.75 (max)		
IC-HAZ	>0.76 (max)	>0.77 (max)	>0.77 (max)	
PWHT				
crack position	single values at -10°C (mode)			
weld metal	>0.78 (max)	>0.78 (max)	>0.77 (max)	
CG-HAZ	>0.82 (max)	>0.81 (max)	>0.81 (max)	>0.81 (max)
	>0.76 (max)			
IC-HAZ	>0.77 (max)	>0.79 (max)	>0.79 (max)	

It was demonstrated, that good CTOD values can be achieved even for thick welds provided the steel is optimized with regard to HAZ toughness. Nevertheless, I would like to comment on actual requirements. The thickness effect in CTOD testing seems to me very conservative compared to actual cases. For welds from 30 to 100 mm thick approximately the same defect size can be detected in ultrasonic inspection. Normally it may show the size of a single welding pass. How would such a certain defect affect safety for different plate thicknesses? A crack of a particular size will head to lower stress concentrations the larger the ligament. Hence, it can be expected to be less harmful for fatigue crack growth, less prone to instability by ductile tearing and less likely to initiate fracture. Could that mean a thick plate would usually behave in a more tolerant manner to a certain defect? In the proposal of Eurocode 3, it is estimated that initial defect would only increase in a logarithmic scale to the plate thickness. A linear increase of crack length as being the case for the CTOD geometry (SENB) is absolutely unlikely.

In the actual specifications the gap between conditions in CTOD testing and those likely in a steel structure certainly grow with increasing plate thickness. The reluctance against high wall thickness that results from the CTOD testing conditions should be reconsidered for an economical use of thick plates.

Dr. Frank Hanus
(Manager Welding Laboratory)

Note: Eurocode 3, Design of steel structures, Annex C „Design against brittle brittle fracture". Ideas and actual status of Eurocode 3 - Annex C „Prevention of brittle fracture" will be presented in one of the next issues of DILLINGER Offshore Letter.