CHAPTER 10: BRITTLE FAILURE ASSESMENT

In terms of risk, catastrophic storage tank failure stands as one of the costliest events that can ever happen. It happens with no warning. It can have huge consequences of everything related to your plant: living beings, property, compliance, stakeholders, processes and finances. It is not something you would want for your facility.

Catastrophic tank failure is usually a consequence of brittle fracture, which is not always understood and is underestimated when making tank repairs and inspections. Given that in some locations aboveground tanks have been in service for more than a few decades, and that is not uncommon to build a tank from parts used in other tanks, catastrophic tank failure is a real concern.

Several questions in the exam will be taken from chapter 5 of API 653, so, be sure to read it.

*References for Tables and figures taken from API 650, twelfth edition, Addendum 1, 2014

BRITTLE FRACTURE

Definition of fracture: Fracture is the separation of an object into pieces due to stress, at a temperature lower than the melting point. In pipes, pressure vessels and tanks, fracture can be ductile or brittle. Both are bad, but brittle fracture is very bad, given that cracks in the stressed material travel so fast that there´s usually no chance to react.

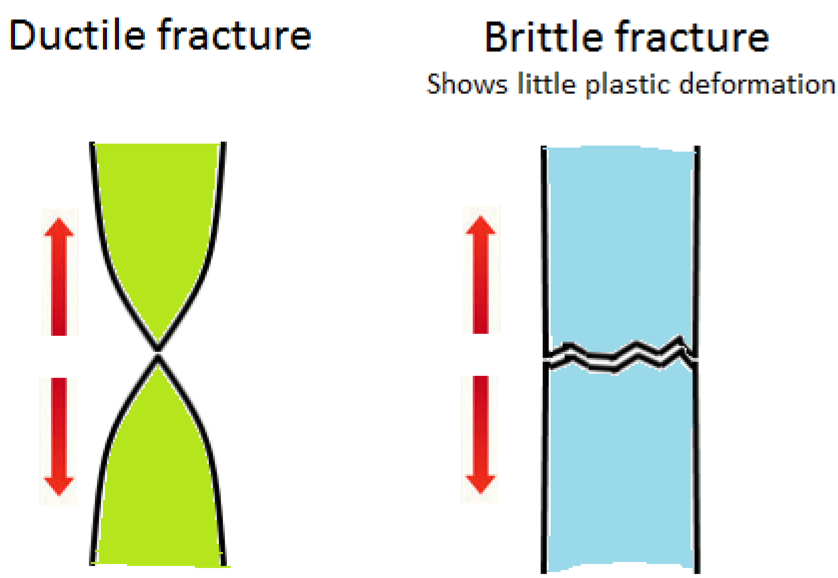


FIGURE 29 DUCTILE AND BRITTLE FRACTURE

Brittle fracture shows no plastic deformation and rather happens if temperature is low, there are tensile stresses applied and if there are stress concentrators as gouges or flaws in the material. Failure is usually catastrophic.

Brittle fracture is more common shortly after erection during hydrostatic testing or on the first filling in cold weather, or in operation, after a change to lower temperature service, or after a repair/alteration. Special care should be taken to not cause overfilling of an old tank. If an old tank has sharp corners or inserts, it could be wise to remove these stress concentrators.

Brittle fracture risk in tanks is minimal if the tank´s shell thickness is no greater than 0.5in. Besides, brittle fracture is very rare if shell metal temperature is over 60°F (Section 5). Older thanks are more susceptible, because manufacturing techniques were deficient.

Sharp cracks and large defects both lower the fracture strength of the material. If a brittle fracture should occur, cracks run almost perpendicular to the applied stress, and with little plastic deformation.

Chapter 5 of API 653 provides a procedure for the assessment of existing tanks for suitability for continued operation or change of service with respect to the risk of brittle fracture.

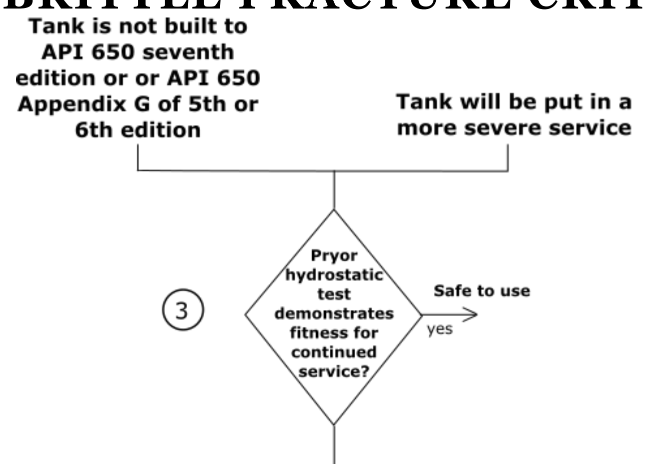
Be sure to study chapter 5 of API 653 thoroughly. Several questions in the exam are about this subject.

In the following lines, I summarize the decision tree found in Figure 5.1 of API 653. That decision tree gives a step by step assessment procedure. The most important outcome of this decision tree is to check if the tank needs a hydrotest or not, or, if considered necessary, be rerated.

If you are making an internal inspection and the tank will be in the same service than before, and you have the certainty that the tank was built to API 650 seventh edition, then you don´t have to enter the decision tree.

If any of the 2 conditions I just mentioned is met, you enter the decision tree.

BRITTLE FRACTURE CRITICAL FACTORS.



The hydrostatic test is the ultimate check of the overall integrity of a tank. API 571 says: "Most processes run at elevated temperature so the main concern is for brittle fracture during startup, shutdown, or hydrotest/tightness testing". Hydrostatic testing accounts for the stress component out of the 3 things needed for brittle fracture to occur: <u>a low-toughness material, a crack or flaw, and some amount of stress</u>. During hydrotest, the hydrostatic head of the water causes the cracks to separate and grow. The tips of the cracks are placed in tension, and plastically deformed. After the water is removed, the crack (which never failed)

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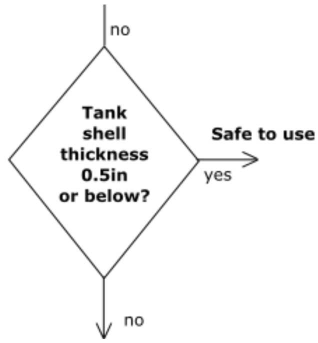

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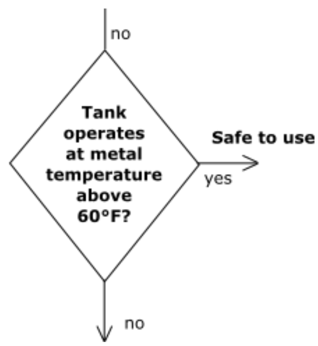


close, placing the tip in a state of residual compression. The sharp tip has been "blunted." After hydrotest, the crack will not grow the same. It can continue to operate.

Toughness measured for a particular sized sample of a given material is not valid for a thicker or thinner sample of the same material (notch-toughness is not intrinsic to the material). Check figure 26 to see a graphic comparing absorbed energy vs thickness: the more thickness, the less toughness. The original nominal thickness for the thickest tank shell plate shall be used for this assessment.

In steel, temperature drops can decrease in a very sharp way the ductility of the material. There is a temperature in which the material stops being ductile and becomes fragile. The transition temperature is actually a temperature **RANGE**. Check figure 27 to understand this issue better. Assurance against brittle fracture can be gained by increasing metal temperature, heating the tank.

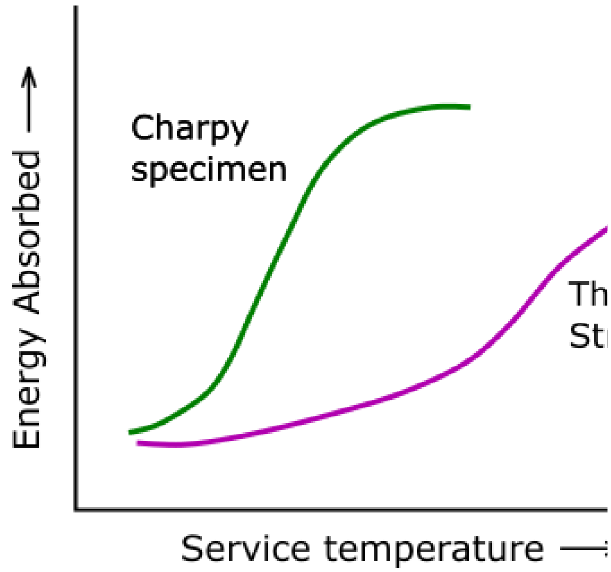


Figure 30 Effect of thickness in DBTT

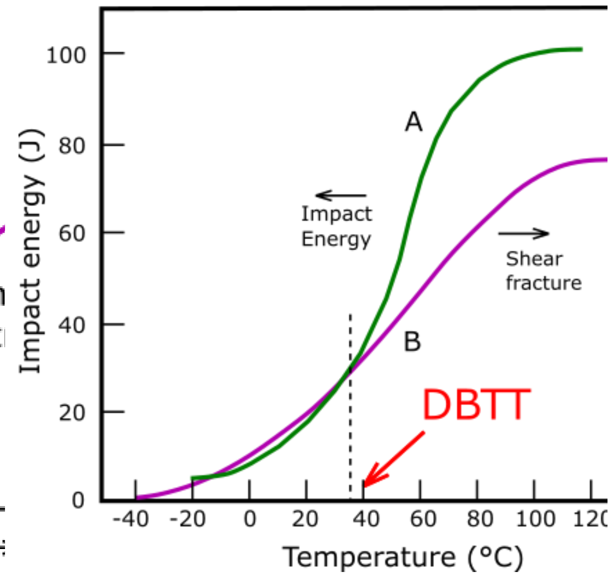
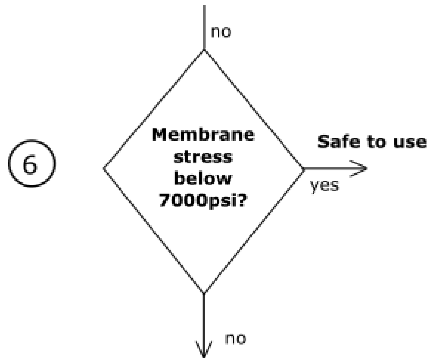


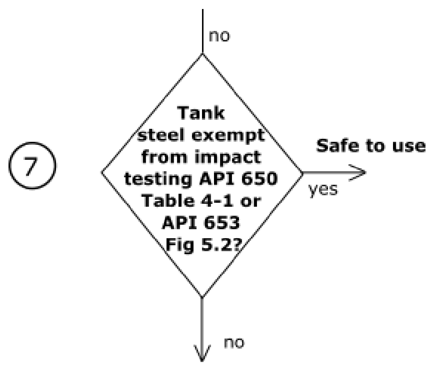
Figure 31 DBTT of A283 steel



Industry experience and laboratory tests have shown that a membrane stress in tank shell plates of at least $7ksi$ is required to cause failure due to brittle fracture. Membrane stress is proportional to Diameter D and Liquid Level H. You can calculate stresses from the following equation:

$$S = \frac{2.6DHG}{t}$$

Where t = is the shell thickness at area of interest in inches



API 650 Table 4-1 is for KNOWN materials and API 653 Fig 5.2. is for UNKNOWN materials. Materials listed in API 650 can be used in accordance with their exemption curves, provided that an evaluation for suitability of service in conformance with Section 4 of API 653 has been performed. The test shall be performed on three specimens taken from a single test coupon or test location. The average value of the specimens (with no more than one specimen value being less than the specified minimum value) shall comply with the specified minimum value. If more than one value is less than the specified minimum value, or if one value is less than two-thirds the specified minimum value, three additional specimens shall be tested, and each of these must have a value greater than or equal to the specified minimum value. For UNKNOWN materials, assess using Figure 5.2 of API 653.

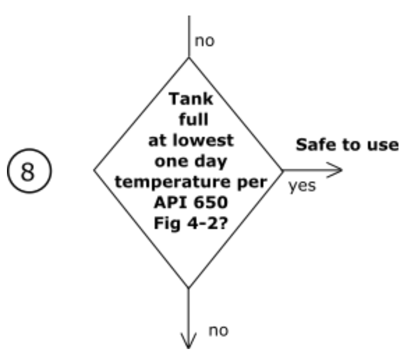


Figure 4-2 of API 650 (you can find a version of that in figure 12 in the following page) gives the Lowest One-Day Mean Temperature in the United States. As an example, we see that Houston, Texas, has a Lowest One-Day Mean Temperature of 15°F. If the tank is not heated, as an inspector, you should try ask for the temperature and liquid level records for every day of operation, and, if the 15°F LODT happened at least one time when the tank was full, then it is safe for use. (Don´t forget to check the calibration of the measurement instrument)

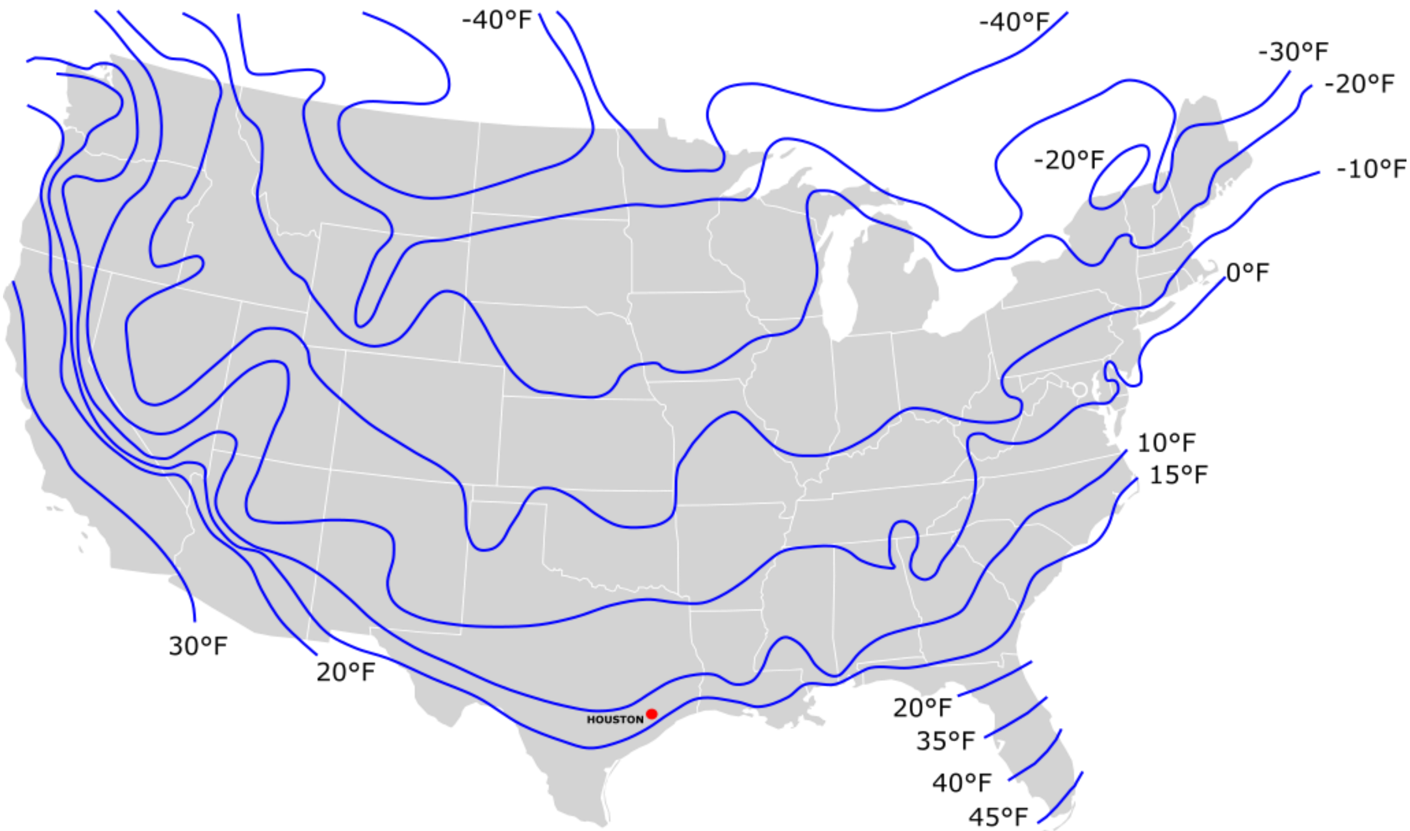


FIGURE 32 LOWEST ONE DAY MEAN TEMPERATURES IN THE UNITED STATES

BRITTLE FRACTURE ASESSMENT BY TYPE OF TANK

Whenever there is doubt about the capabilities of some steel to withstand all the loads present in a tank, maybe because the material is old, or the tank is of unknown steel, or if it is going to operate at low temperatures, impact tests are recommended, and sometimes mandatory according to the standards, to rule out the possibility of brittle fracture.

WHAT THE BOK SAYS

For people studying the API 653 exam, have in mind what the Body Of Knowledge says.

The inspector should understand the importance of tank materials having adequate toughness. The inspector should be able to determine:

a) Tank design metal temperature (API-650, 4.2.9.3 & Figure 4-2)*

b) Material Group Number for a plate (API-650, Tables 4-3a and 4-3b)*

c) If impact testing is required (API-650, Figure 4-1)

d) If impact test values are acceptable (API-650, Table 4-4)*

*References for Tables and Figures taken from API 650, twelfth edition, 2013

When deciding upon the re-use of an existing tank, the first thing you will take into account will be the exemption curve given in Figure 5.2 of API 653. Existing tanks fabricated from steels of unknown material specifications, thicker than 1/2 in. and operating at a shell metal temperature below 60 °F, can be used if the tank meets the requirements of Figure 5.2. The original nominal thickness for thickest tank shell plate shall be used for the assessment.

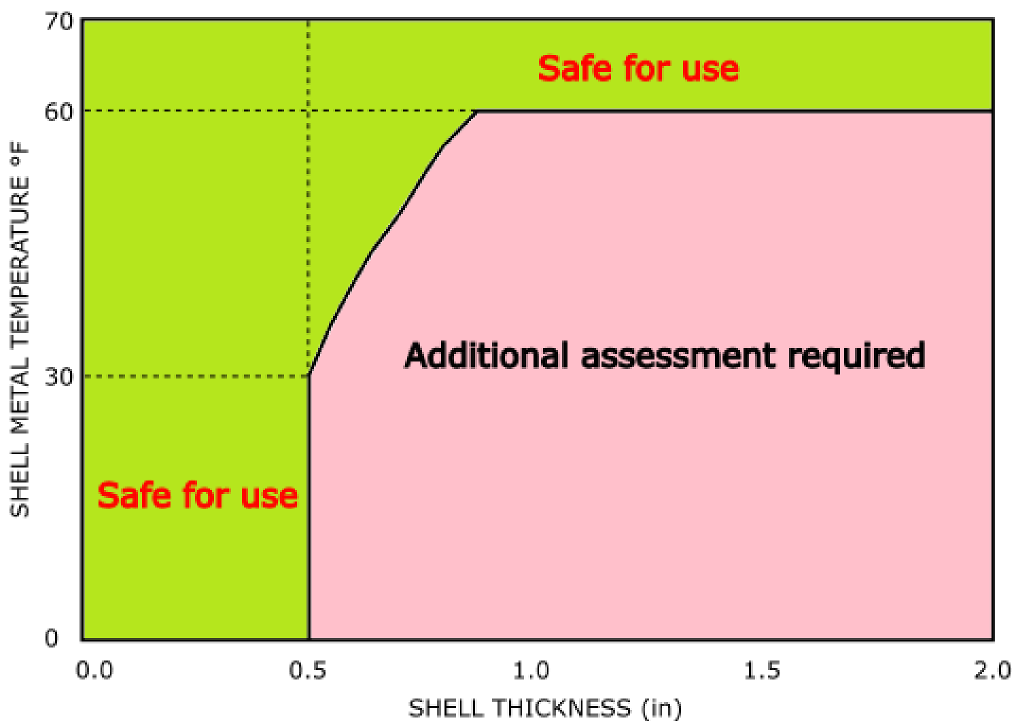


FIGURE 33 EXEMPTION CURVE FOR TANKS CONSTRUCTED FROM CARBON STEEL OF UNKNOWN MATERIAL SPECIFICATION

IMPACT TESTING FOR RECONSTRUCTED TANKS

When a tank is being reconstructed, each individual plate for which adequate identification does not exist shall be subjected to chemical analysis and mechanical tests as required in ASTM A6 and ASTM A370 including Charpy V-notch. Impact values shall satisfy the requirements of API 650

IMPACT TESTING FOR PREHEATED WELDS

Impact testing is required if you are going to apply preheating as an alternative to PWHT, as found in 11.3.1.

IMPACT TESTING TO AVOID HYDROTEST

If you are repairing a tank, and you are short of water for hydrostatic test, make sure to include impact testing in your PQR´s before commencement of work, to make it easier to avoid hydrotest.

12.2.3.2.1 of API 653 says "welds to existing metal, develop welding procedure qualifications based on existing material chemistry, including strength requirements. Welding procedures shall be qualified with existing or similar materials, and shall include impact testing. Impact testing requirements shall follow appropriate portions of API 650, Section 9.2.2 and shall be specified in the repair procedure."

Of course, there are many other requirements to hydrotest exemption, which are described in detail in 12.3.2 of API 653

IMPACT TESTING IN NEW TANKS

Brittle fracture concerns are more critical when dealing with the following parts of a tank shell plates, shell reinforcing plates, shell insert plates, bottom plates welded to the shell, plates used for manhole and nozzle necks, plate-ring shell-nozzle flanges, blind flanges, and manhole cover plates. Bottoms are usually thinner and don´t get as much affected by brittle fracture as the mentioned parts.

If you know the material specification, experience has shown that some materials don´t need impact testing. How to know if you need impact test for a new material? When you have your new plates in location, use figure 4.1a or 4.1b of API 650*. Plates less than or equal to 40 mm (1.5 in.) thick may be used at or above the design metal temperatures indicated in Figure 4.1a and Figure 4.1b without being impact tested.

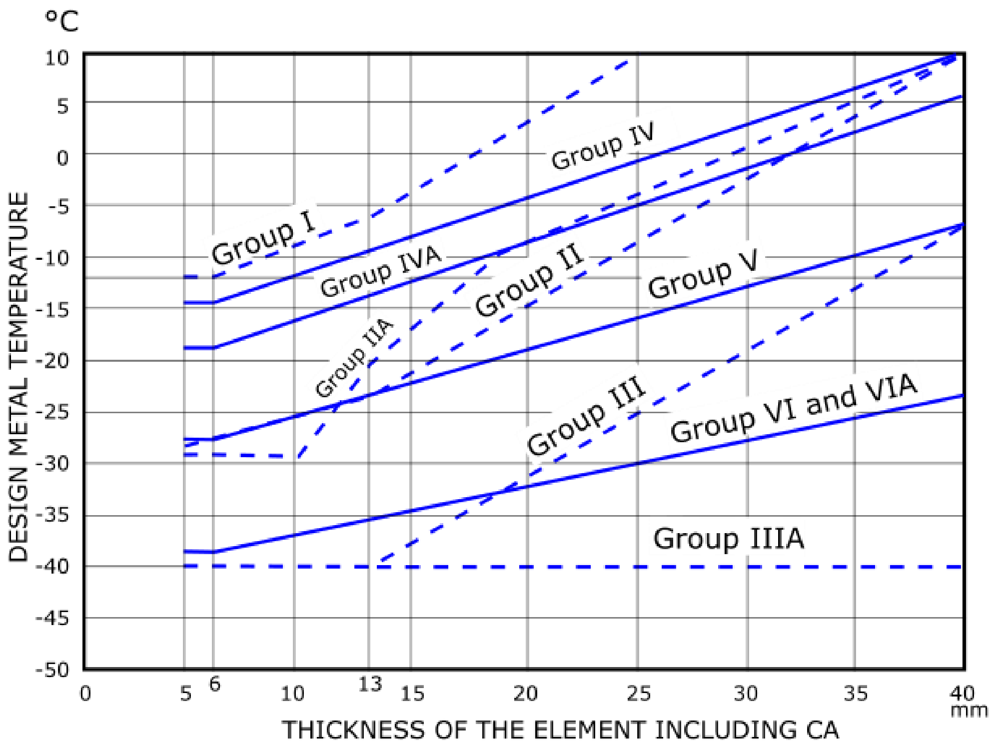


FIGURE 34 MINIMUM PERMISSIBLE DESIGN METAL TEMPERATURE FOR MATERIALS USED IN TANK SHELLS WITHOUT IMPACT TESTING (SI). (USE THIS FIGURE FOR KNOWN MATERIAL SPECIFICATION)

EXAMPLE:

For example, let´s consider an ASTM A36 As Rolled, Semi-Killed plate for a shell 12,5mm thick with a design metal temperature of 10°C. Will it be safe for use?

SOLUTION

API 650 describes three types of steel: Killed, As-rolled and Normalized

KILLED: Killed steel is steel that has been completely deoxidized by the addition of an agent before casting, so that there is practically no evolution of gas during solidification. They are characterized by a high degree of chemical homogeneity and freedom from gas porosity. The steel is said to be "killed" because it will quietly solidify in the mold, with no gas bubbling out. It is marked with a "K" for identification purposes

AS ROLLED: In the event that customers heat-treat their own plates, the product is referred to in as-rolled condition. After being rolled, the plate is cooled in static air. The term as-rolled condition stems from the fact that the product is not heat-treated

NORMALIZED: In this condition, carbon steel is heated to approximately 55 °C above Ac3 or Acm for 1 hour; this ensures the steel completely transforms to austenite. The steel is then air-cooled, which is a cooling rate of approximately 38 °C (100 °F) per minute. This results in a fine perlitic structure, and a more-uniform structure.

In our example, the plate is As-rolled, semikilled material, which makes it a group I, according to Table 4.4a or 4.4b of API 650.

Excerpt of table 4.4a. Material groups (SI)

Group I As Rolled, Semi-Killed	
Material	**Notes**
A283M C	2
A285M C	2
A131M A	2
A36M	2, 3
Grade 235	3
Grade 250	5

Design Metal Temperature is defined as "the lowest temperature considered in the design, which, unless experience or special local conditions justify another assumption, shall be assumed to be 8 °C (15 °F) above the lowest one-day mean ambient temperature of the locality where the tank is to be installed". The values for mean temperatures in any location in the United States can be found in Figure 4.2—Isothermal Lines of Lowest One-Day Mean Temperatures. Maximum design temperature is 93°C for tanks designed to API 650.

Our design metal temperature is 10°C and our shell thickness is 12,5mm for a group I material. This combination of materials, design, and construction features, makes our steel safe for use (See figure 17)

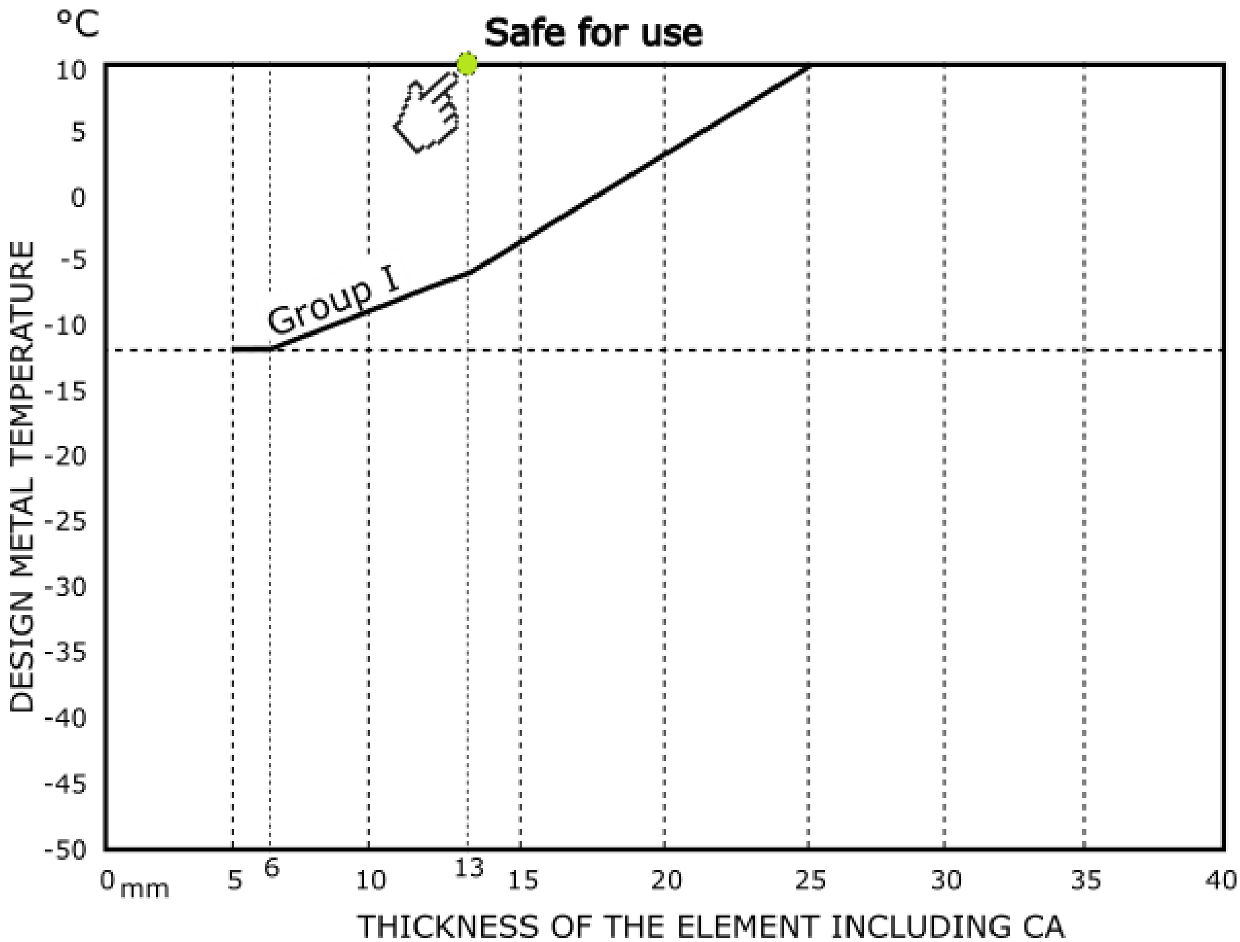


FIGURE 35 EXAMPLE OF ASSESSMENT FOR BRITTLE FRACTURE

WHEN IMPACT TESTING IS DONE

For a new tank, if required by the Purchaser or if the material falls in an area other than "safe for use", a set of Charpy V-notch impact specimens shall be taken from plates after heat treatment (if the plates have been heat treated), and the specimens shall fulfill the stated energy requirements. Three specimens are needed, and the average value of the three tests should be compared against the minimum requirements of Table 4.5a—Minimum Impact Test Requirements for Plates.

For a new tank, the impact test requirements and the definition of "controlling thickness" for pipings and forgings used as shell nozzles and manholes is found in numeral 4.5 of API 650.

IMPACT TESTS FOR WELDING PROCEDURE SPECIFICATIONS

When a new tank is constructed and impact tests are required by 4.2.9, 4.2.10, or 4.5.4, impact test should follow the guidelines found in numeral 9.2 of API 650.

As you can see, impact testing it is not a very difficult subject to understand. The standards are very clear regarding old and new tanks. Notice that the BOK works exclusively with API 650 and not with API 653.

EXAMPLE:

An Aboveground Storage Tank is to be constructed using ASTM A 516 gr 60 plates. The plates are normalized. The plates were tested for impact value and the following were the test results. The test results are presented for 32 mm thick plates (Lot A) and 30 mm thick plates (Lot B).

A) Longitudinal Specimen:
Three specimens failed at 13 ft-lb, 15 ft-lb and 18 ft-lb respectively

B) Transverse Specimen:
Three specimens failed at 12 ft-lb, 14ft-lb and 14ft-lb respectively

Which of the two plates is OK to use in a new tank?

SOLUTION:

The material belongs to Group III A.
The thicknesses are within acceptable limits. (Ref: 2.2.2, 516 gr60 can be used up to 40 mm thickness)

Plate A (Longitudinal):
Average of 3 specimens =3
13 +15 +16 = 14.66 ft. lb.
Average of 3 specimens, 14.66 ft. lb is less than required average of 15 ft. lb.
REJECT.

Plate B (Transverse):
Average of 3 specimens =3

12 +14 +14 = 13.33
Average of 3 specimens, 13.33 is greater than required average of 13 ft. lb.
Also only one specimen (12 ft. lb) is below average and its value is greater than 2/3 x 13, i.e., greater than 8.66. ACCEPT

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