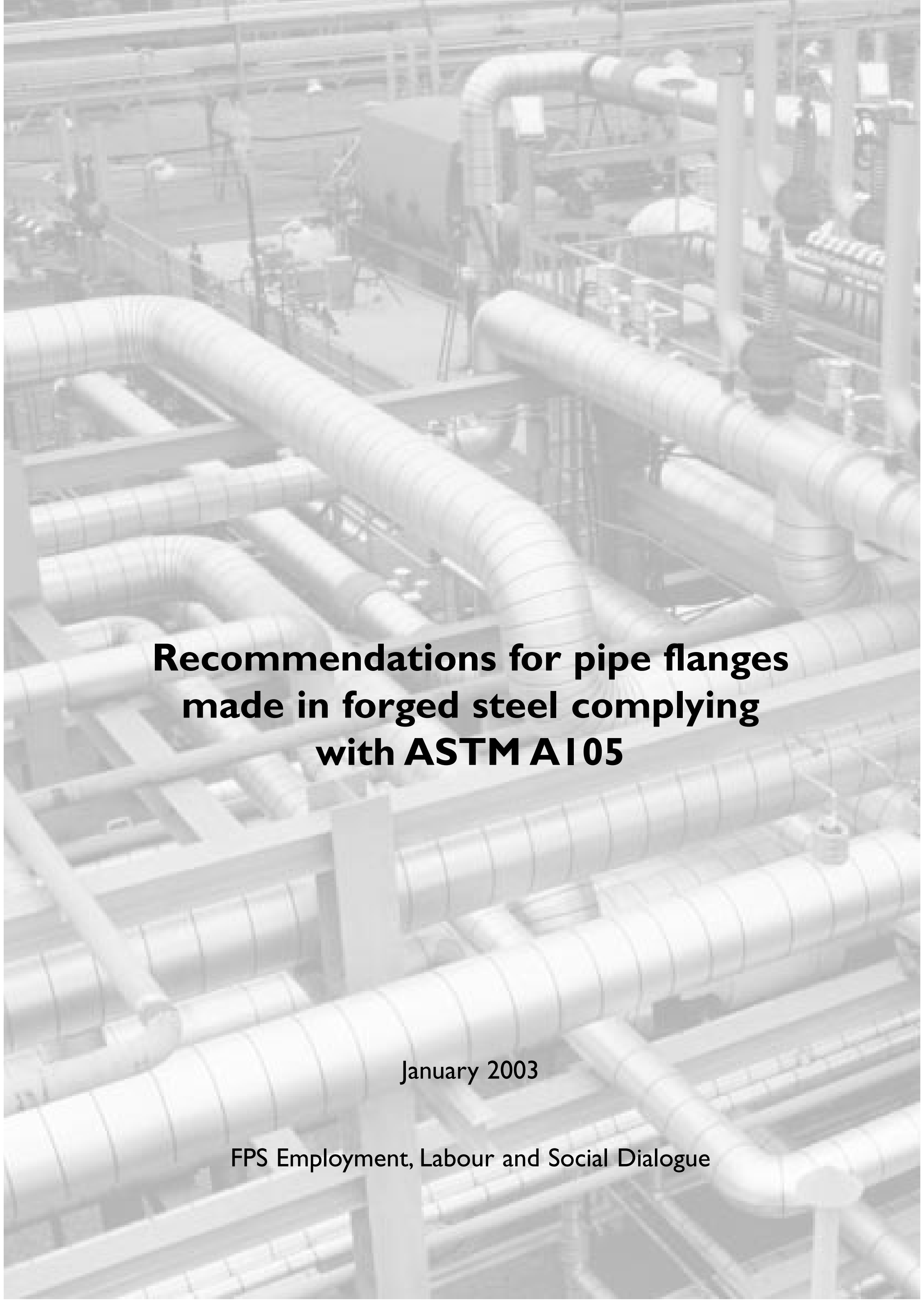

Recommendations for pipe flanges made in forged steel complying with ASTM A105

January 2003

FPS Employment, Labour and Social Dialogue

This brochure is available free of charge at:

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This brochure is also available on the website: www.meta.fgov.be (look for "Prevention of major accidents").

Communication

The standard 'ASME section VIII, division 1' allows the use of steel of type ASTM A105 at temperatures down to -29°C without any form of control of its resistance to brittle fracture.

In 1999, however, during an upset in a High Density Polyethyleen Reactor, a brittle fracture occurred on a ASTM A105 steel flange (diameter 24") at -16°C only.

As part of the investigation following the incident, the operator conducted a metallurgical analysis on several other flanges made of ASTM A105 steel and identical to the one that failed. This analysis revealed that half of these flanges had a similar metallurgical structure (micro structure and grain size) as the one that failed and consequently had a similar susceptibility to brittle fracture.

Since ASTM A105 steel is widely used in the (petro)chemical industry, the Chemical risks directorate initiated in September 2000 a scientific research project to investigate the susceptibility of ASTM A105 steel to brittle fracture.

The research was conducted by the Research Center of the Belgian Welding Institute. It included a study of literature, an experimental research on 24 flanges made of ASTM A105 steel and a fitness-for-purpose analysis. In June 2002 the research project resulted in practical recommendations for new flanges and flanges in service. These recommendations were presented during a seminar in Brussels on the 19th of September 2002 and are entirely included in this brochure.

Introduction

The present guide describes the recommendations concluded from an extensive research project CRC/WPS/11/00 "Susceptibility to brittle fracture of flanges in steel ASTM A105" for the use of such flanges at sub-zero temperatures. In principal the recommendations are only valid for pipe flanges (i.e. flanges mechanically attached or welded to a steel pipe allowing to make so called flanged joints) manufactured from forged steel complying with ASTM A105 "Standard Specification for Carbon Steel Forgings for Piping Components", delivered in the untreated, annealed or normalised condition and designed according to the welding neck type described in ANSI B16.5 "Pipe Flanges and Flanged Fittings" (for a short description of both standards, see end of this guide). Welding neck ASTM A105 steel flanges ordered to dimensions other than those mentioned in ANSI B16.5 but within the investigated nominal thickness range of 32 mm to 102 mm should also be treated as explained in the following chapters. Furthermore, it is recognised that other types of pipe flanges (for instance so called threaded, slip-on-welding or lapped types) are equally liable to brittle fracture so a similar treatment is advised for these components as well.

The incentive for the former project was a brittle fracture indeed that occurred in a 102 mm thick 24" welding neck flange of Class 600 according to ANSI B16.5. This component, made from carbon steel conforming to ASTM A105, was installed since 1990 in a high-density polyethylene (HDPE) reactor and failed in January 1998. Due to a power dip in the plant, the product in the reactor boiled at atmospheric pressure, resulting in cooling of the reactor and the loop to about -16 °C. The line was partly plugged with solid product at the location of the failed flange, which was assumed to be at a temperature of +60 °C and which therefore caused uneven cooling of the component. This steel flange cracked at the transition between the conical and cylindrical part of the welding neck at a location coinciding with the cold area.

The abovementioned research work included the verification of chemical analyses, thorough replica and metallographic examinations with hardness and grain size measurements, room temperature tensile testing but also low temperature notch impact and CTOD fracture toughness testing on pipe flanges extracted from the failed reactor and on new flanges (especially ordered for the project). The research work has permitted to formulate the recommendations for existing and for new flanges separately. These are summarised in the following paragraphs.

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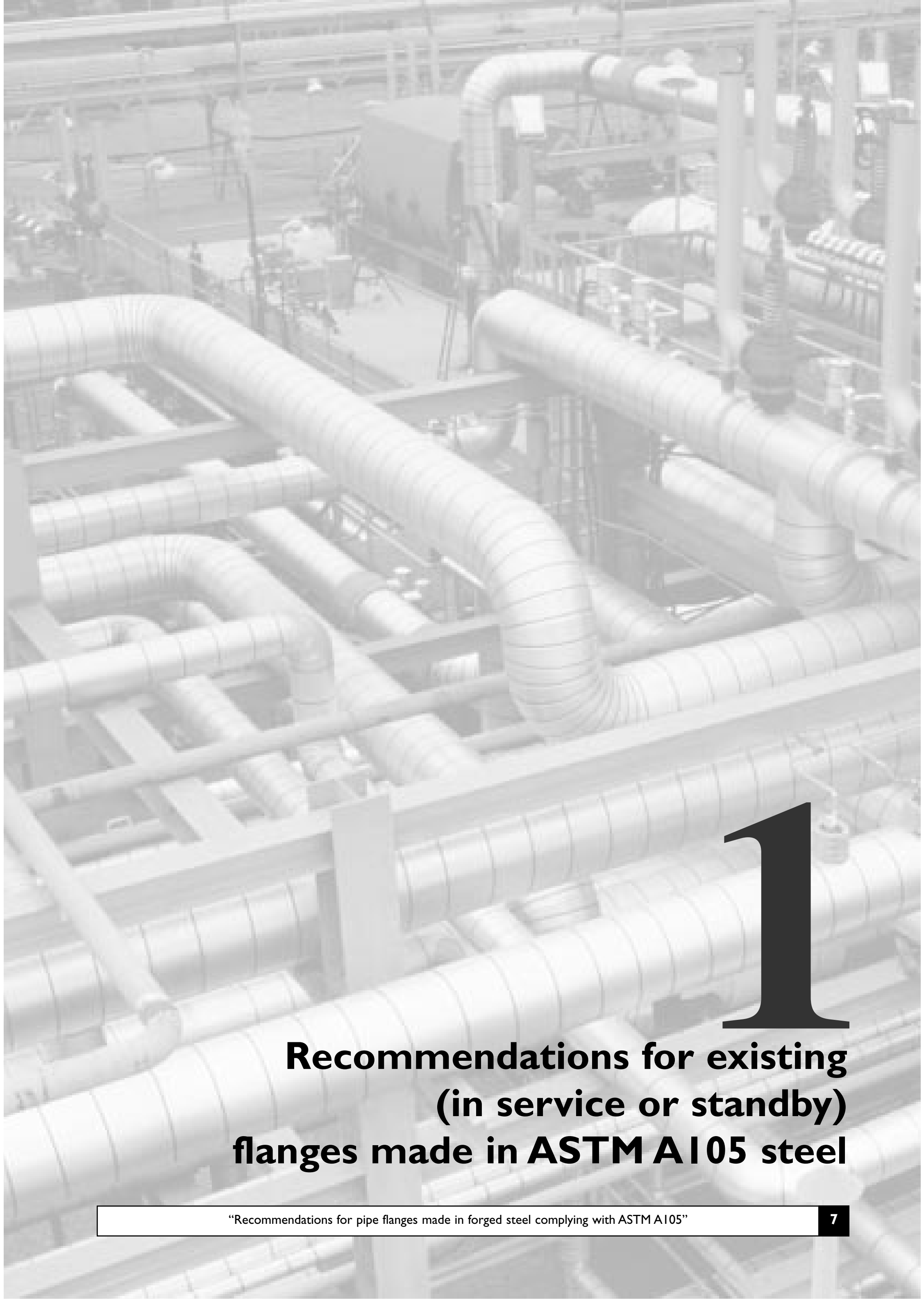

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Recommendations for existing (in service or standby) flanges made in ASTM A105 steel

The low temperature range at which steel flanges complying with ASTM A105 may be used without imposing further requirements according to the abovementioned Standard ANSI B16.5 but also according to ASME B31.3 "Chemical Plant and Petroleum Refinery Piping - Chapter III: Materials" (for a short description of this part of the Code, see end of this guide) is limited to -29 °C (-20 °F).

The recent but broad investigation has shown rigorously that the Charpy V-notch impact toughness of such pipe flanges is adequate to operate at internal pressures indicated in the relevant pressure-temperature ratings tables of ANSI B16.5 only for minimum metal temperatures at or beyond +20 °C.

In view of the material's ability to extensively deform beyond the elastic regime during instrumented but stringent CTOD fracture toughness testing, it is though considered that these flanges should be fit for metal temperatures down to 0 °C. Also the fact that the criterion concerning the minimum required level of impact toughness accepted throughout the investigation was more stringent than that prescribed in ASME B31.3 (for exact figures, see end of this guide) also argues in favour of a relaxation. Moreover "Regels voor Toestellen onder Druk", which are under final development in The Netherlands, will also allow the use of such materials at temperatures certainly below +20 °C. Last but not least, decisions concerning the acceptance or rejection of pipe flanges containing hazardous substances will be taken in due time as it is advised to identify these with first priority.

Because of all this, it is recommended that critical ASTM A105 pipe flanges, i.e. components containing hazardous substances and operating at temperatures lower than 0 °C, should not be used as intended without taking further precautions because of insufficient toughness due to the eventual presence of ferritic-pearlitic microstructures with a large grain size.

The user company should urgently evaluate the failure consequence of all existing ASTM A105 pipe flanges containing hazardous substances. If failure of a critical pipe flange can involve, directly or indirectly, a major accident (according to the Seveso definition), then this should be classified as a critical situation and the following approach should be applied. The verification detailed hereafter is based mainly on the determination of grain sizes by means of replicas (non destructive method) or exceptionally through metallographic sectioning (destructive method) as it has been established that toughness is strongly related to microstructure and grain size.

Anyhow, if cracks are detected through non-destructive testing or NDT (visual, radiography, ultrasonics, magnetic particle, liquid penetrant, ...) then the corresponding flanges creating a critical situation should be removed and/or rejected although guidance to tackle the exceptional occurrence of an isolated crack is given in paragraph "Other important items".

A first step is to gather all possible information about critical pipe flanges by means of a manufacturer's EN 10204: 3.1.B certificate (preferably even an EN 10204:3.1.C

certificate) or any other document and to obtain an idea about the capability (especially concerning heat treating and avoidance of hydrogen cracks) and reliability of the manufacturer. The best method to evaluate the manufacturer's competence is to perform a profound audit on his quality system and capabilities or to have proof of a valuable qualification awarded by an independent, authorised body. Also earlier experience with and service obtained from the same manufacturer can compliment the opinion about the company's competence. This initial and important evaluation will probably be difficult to realise for pipe flanges already in service for a considerable duration but the ideas behind the recent European Pressure Equipment Directive or PED based on the verification through Notified Bodies of delivered products against certification should improve beyond any doubt the identification of capable and reliable manufacturers.

The number and type of the following steps depend on the conclusions made in the first step. In the method described further, very often it is advised to examine a "limited", a "moderate" or a "reasonable" number of components. The exact number of flanges covered by these terms should be selected for each group of similar forgings separately (same manufacturer, manufacturing route, nominal pipe size and rating class) on the basis of common sense. It is proposed that the inspection of a "limited" number of components should incorporate about 2% to 5% of the group. The verification of a "moderate" number of flanges instead should be realised on 10% tot 20% of the set of forgings under consideration. Finally it is suggested that the inspection of a "reasonable" number of flanges should be done on about 20% to 40% of the group.

A very severe failure consequence (which endangers directly or indirectly human life or environment) should force the interpreter to perform more examinations than a less severe failure consequence (no threat of human life or no huge costs because of shut-down or repair).

A summary of the developed approach is given in table I. It is the intention to start at the appropriate cell of column A in the table and to continue to the right (and so to the relevant cell of column B, column C, ...), taking account of the result of the required examination, unless the reader is guided to another row. The different cases which can possibly occur are described in the following paragraphs and, as mentioned before, should be examined for each group of similar pipe flanges separately.

It is understood that the recommendations for installed pipe flanges should not necessarily cause a deliberate shut-down of the plant but may be scheduled at the next maintenance period or any other preventive control. The maximum delay for the approach outlined hereafter should be based on the above mentioned criticality assessment performed by the user company and should therefore depend on the severity of the situation. It is also clear, when established criteria can not be met, that process conditions may be relaxed so that a re-assessment can be done which may avoid the rejection of the relevant component(s).

1.1 Case I of Table I

If according to the certificate of a capable and trustworthy manufacturer an annealing or normalising (yielding microstructures with a similar morphology) heat treatment complying with ASTM A105 has been realised, then critical components may be used above -29 °C without further inspection.

A replica examination may be done to determine the corresponding grain size on a limited number of flanges (2% to 5% of the group, depending on the severity of the failure consequence) and so to verify whether the heat treatment was appropriate for the material but ample evidence has been provided showing that the microstructure of the forged ASTM A105 steel is easy to refine by normalising over a wide time and temperature range.

The eventual replica examination should be realised at the conical part of the flanges and at locations evenly distributed over the flange circumference. Grain size criteria depending on the minimum metal temperature and on the number of replicas removed per flange have now been established quantitatively and are valid for the untreated, annealed or normalised condition, see later.

If the detected grains are small enough (thus having an ASTM E112 grain size number beyond the required level), then the group of similar flanges is regarded as acceptable with a high degree of confidence as the verification has shown that the heat treatment was appropriate for the material. The investigation then has also confirmed the capability and reliability of the manufacturer.

On the other hand, when the uncertainty concerning the heat treatment of the group of similar flanges still exists after performing the replica examinations, then Column C of Case V should be applied (or process conditions relaxed). Such a situation certainly raises questions about the capability and/or reliability of the selected manufacturer.

1.2 Case II of Table I

If following the certificate of a capable and reliable manufacturer no annealing or normalising heat treatment or a heat treatment other than that stipulated in ASTM A105 (for instance for flanges up to ANSI Class 300) has been executed, then these flanges should not be used or, if already in service, should not be exposed to any pressure unless the degree of grain refinement has been examined.

This again can be realised by extracting replicas from a moderate number of flanges (10% to 20% of the group, depending on the severity of the failure consequence), the outcome of which again should entirely satisfy (i.e. for all flanges examined) the stipulated criterion applicable for replicas in order to permit the use of this group of components.

If one or more of these arbitrarily selected components have a coarse microstructure (outside the acceptable range, depending on the minimum metal temperature) then Column C of Case V should be applied as the grain size is not appropriate for at least those flanges already investigated (or process conditions relaxed).

1.3 Case III of Table I

In case where, according to the certificate of an unqualified and/or unreliable manufacturer, an annealing or normalising heat treatment as stipulated in ASTM A105 has been executed, then these flanges should not be used unless an additional examination has been executed. This should consist of an initial replica investigation on a reasonable amount of components (20% to 40% of the group, depending on the severity of the failure consequence) after which the grain size criterion for replicas given hereafter is applied.

If all flanges comply with the said requirements, then it is suggested to accept these forgings to be installed and/or used down to the relevant temperature. It also has demonstrated the capability and reliability of the manufacturer, despite the information already gathered or the assessment already made.

If instead, one or more flanges prove to have a too coarse microstructure, then it is proposed (besides a possible relaxation of process conditions) to apply Column C of Case V. The lack of reliability and capability of the manufacturer is then confirmed.

1.4 Case III of Table I

In case where there are reasons to doubt about the capability and/or reliability of the manufacturer and when no annealing or normalising heat treatment or a heat treatment other than that stipulated in ASTM A105 has been done (Case IV) or if no or insufficient information about the flanges or the manufacturer is available (Case V), a control of grain size should be initiated on the basis of a non destructive replica examination on all flanges under consideration.

In case where all flanges meet the grain size criterion applicable for replica examinations, then it is supposed that this group of components has proper grain sizes and is therefore considered as fit for working at the relevant minimum metal temperature.

If one or more components fail to meet the requirement, then a reasonable number of non-complying flanges (20% to 40% of the group, depending on the severity of the failure consequence, and with the largest grain size) should be removed and/or examined metallographically to measure the grain size on radial cross sections. This involves the removal of the flange(s) being in service but may avoid the loss of other components. Replacing all of the non complying flanges or relaxing the process conditions though may finally be more attractive than initiating the proposed metallographic investigation.

More relaxed grain size criteria for rejection or acceptance based on the inspection of extracted metallographic samples are given further in this guide.

In case where all metallographically inspected flanges prove to have a sufficiently fine grained microstructure, then these should be replaced by appropriate components (which may be taken from stock but should comply with this guide or may be ordered according to the recommendations for new flanges given further in this guide) and the remaining still installed or available flanges may be accepted.

When one or more flanges instead yield coarse grained microstructures (beyond the tolerable range), then all flanges not complying with the earlier replica criteria should be rejected, i.e. removed and/or regarded as not being fit for working under the envisaged temperature conditions, unless relaxed.

In order still to recover doubtful flanges, it may also be useful before removal and/or metallographic examination to further increase the number of replicas per flange to permit the application of a more relaxed grain size criterion so that some flanges can still be classified as acceptable.

1.5 Criteria about grain sizes detected on replicas for untreated, annealed or normalised pipe flanges

From a practical point of view, the minimum required ASTM E112 grain size numbers detected by replica or metallographic examination (not the so called target values which are directly related to the minimum metal temperature) have been rounded to the nearest 0,5. This is because ASTM E112 grain size numbers can not be rigorously determined as the accuracy relies on the exact recognition of grain boundaries and may therefore depend somewhat on the experience and interpretation of the investigator.

For a minimum metal temperature of -29 °C, the relevant microstructure should have a maximum grain size corresponding with an ASTM E112 grain size number of 8,1 (target value) based on a minimum required impact toughness of 27 J. It has been shown through a statistical analysis that this maximum grain size can only be assured with a confidence level of 95% in case one replica yields an ASTM E112 grain size number of at least 9,5 (target value plus 1,4 and rounded off). This requirement can be relaxed by increasing the number of replicas per flange up to four,

in which case the mean ASTM E112 grain size number should be 9,0 (target value plus 0,8 and rounded off) or higher. If, exceptionally, the grain size of the component is measured on eight replicas then the mean ASTM E112 grain size number should be minimum 8,5 (target value plus 0,6 and rounded off).

The research work on which the present recommendations have been based, has also permitted to determine the target ASTM E112 grain size numbers for minimum metal temperatures between -29 C and 0 °C (see table III) but again the limited number of replicas should always be taken into account appropriately for guaranteeing these target values.

No differentiation in evaluation has been made for components subjected to internal pressures lower than the allowable values given in ANSI B16.5 for the lower temperature range as the conditions are very seldom accurately known for the whole temperature range to which a pipe flange may be exposed, including start-up, shut-down or upset conditions. So it is assumed in general throughout this guide that the maximum pressure-temperature ratings according to ANSI B16.5 or any other standard are not only respected but also applied.

For those rare cases where the exact conditions (or so called envelopes of temperature and pressure) are known, it is allowed to adjust the minimum metal temperature and so to relax the grain size criterion to take account of pressure conditions which are less severe than those tolerated by ANSI B16.5 or, for pipe flanges ordered to dimensions specified by the purchaser, less than the equivalent pressures (invoking the same allowable stresses). For these cases it is proposed to accept the same temperature correction as described in prEN 13445 "UNFIRED PRESSURE VESSELS" (for a short description of this standard, see end of this guide), which is summarised in table II and which is less relaxing than for instance the Recommended Practice 579 "Fitness-for-Service" issued by the American Petroleum Institute (API). All combinations of metal temperature and internal pressure should be considered for each pipe flange and the minimum corrected temperature should be retained for assessing the maximum grain size.

It is clear, when for instance a minimum metal temperature below 0 °C may be converted, after correction according to table II, into a temperature at or above 0 °C, that no further actions should be undertaken to safeguard against initiation of brittle fracture unless other combinations of metal temperature and internal pressure yield to sub-zero temperatures after adjustment. It also means that critical pipe flanges made in ASTM A105 steel which are exposed to internal pressures above 25% but less than or equal to 50% of the ANSI B16.5 rating, may be used down to -25 °C (because -25 °C + 25 °C = 0 °C) without further precautions according to the present recommendations.

Table II: Adjustment on minimum metal temperature			
Maximum internal pressure (relative to pressure-temperature rating of ANSI B16.5 applicable for the lowest temperature range or equivalent rating)			
> 75 % and ≤ 100 %	> 50 % and ≤ 75 %	> 25 % and ≤ 50 %	≤ 25 %
0 °C	+10 °C	+25 °C	+50 °C

1.6 Criteria about grain sizes detected on metallographic samples for untreated, annealed or normalised pipe flanges

Imposing maximum grain sizes detected by metallographic samples in order to assure a minimum toughness should only take account of the variation in grain size across the flange. When three samples are prepared from only one radial cross section and when three individual measurements of ASTM E112 grain size number are executed per sample, then the mean ASTM E112 grain size number should be 8,5 (target value plus 0,2 and rounded off) or higher for a minimum metal temperature of -29 °C. If instead four radial cross sections are extracted and prepared from the same flange then the mean ASTM E112 grain size number should only be 8,0 (target value plus 0,1 and rounded off) or higher.

The same relaxations as before may be applied when pressure conditions are less stringent than those mentioned in ANSI B16.5 for the lowest temperature range or equivalent pressures for pipe flanges ordered to other dimensions.

As illustration, the following table III summarizes the minimum required ASTM E112 grain size numbers for different combinations of minimum metal temperature and amount of replicas taken or metallographic sections extracted. For reasons explained earlier, actions should only be taken effectively for so called critical situations, i.e. pipe flanges with severe failure consequences, operating below 0 °C and containing hazardous substances.

Table III: Minimum required ASTM E112 grain size number for various combinations of minimum metal temperature and type and extent of examination

Min. metal temp. [°C]	Target ASTM E112 grain size number	Minimum ASTM E112 grain size number on replicas			Minimum ASTM E112 grain size number on metallographic samples	
		for 1 replica	for 4 replicas	for 8 replicas	for 1 radial sect.	for 4 radial sect.
≥ 0	Not required	Not required	Not required	Not required	Not required	Not required
-5	7,1	8,5	8	7,5	7,5	7
-10	7,3	8,5	8	8	7,5	7,5
-15	7,5	9	8,5	8	7,5	7,5
-20	7,7	9	8,5	8,5	8	8
-25	7,9	9,5	8,5	8,5	8	8
-29	8,1	9,5	9	8,5	8,5	8

"Not required" means that no verification of grain size should be done (note that ASTM E112 grain size number increases with decreasing grain size).

The indicated target ASTM E112 grain size number guarantees a 27 J impact transition temperature not above the corresponding minimum metal temperature for forged steel complying with ASTM A105 with a ferritic-pearlitic microstructure.

1.7 Applicable thickness range for pipe flanges made in ASTM A105 steel

As already mentioned before, the previous recommendations strictly are only valid for pipe flanges with a nominal thickness of 32 mm to 102 mm. It is strongly discouraged to extrapolate the present findings to larger thicknesses as it is generally known that larger dimensions tend to lower the fracture toughness due to effects of increased constraint (constrained yielding caused by plastic zones which are small relative to the dimensions of the component). For the same reasons, a relaxation on the evaluation of forgings of smaller thickness can be made as these should behave more ductile because of reduced constraint. Unfortunately, it is impossible at present to quantify the degree of relaxation appropriate for smaller flanges.

This may put stringent limitations on the applicability of the present recommendations, but ASTM A105 flanges with a thickness above 102 mm (and so for the large diameter pipe flanges above ANSI Class 600) are quite rarely used. On the other hand flanges with a thickness below 32 mm, for the reasons explained above, should not easily give raise even at -29 °C to initiation of brittle fracture provided the internal pressure is kept below the ANSI B16.5 limit or equivalent value.

1.8 Other important items

The following important items have been observed during the basic research work, some of which call for great caution.

- Non destructive testing can be used for tolerating exceptionally the application of ASTM A105 pipe flanges containing imperfections for temperatures below 0 °C. Indeed, an Engineering Critical Assessment or ECA based on BS7910:1999 has shown that when an isolated surface defect for instance of 1,5 mm deep and 7,5 mm long or an extremely long defect of 0,7 mm deep located at the intersection of the hub and the pipe section can be detected with a high degree of confidence in a pipe flange of 24" diameter and of ANSI Class 300, then this component can be safely used down to -29 °C without further restrictions on grain size.

Tolerating exceptionally an ASTM A105 flange at temperatures down to -10 °C instead requires the unconditional detection of an isolated surface flaw with a maximum depth of 2,0 mm and a maximum length of 10,0 mm or an extremely long flaw of maximum 0,85 mm deep. Sizes of surface or embedded defects with other aspect ratios (ratio of crack depth to crack length) can be determined by means of an identical fitness-for-purpose assessment.

It should be strongly emphasised that defects of these sizes may not be considered as tolerable levels for good workmanship so that the occurrence of even smaller flaws in several flanges can not be accepted but instead should stimulate necessary actions to improve the production quality. Moreover, the above defect sizes do not take account of crack extension due to fatigue. So if loading conditions of a component can vary rapidly in time then NDT should be done at regular intervals to assure that the size of any extended defect is still smaller than the tolerable flaw size.

- The large grain size of some of the investigated flanges but also the significant variation within one same flange proved that no proper heat treatment had been applied before supply to the customer, although mentioned on the accompanying EN 10204: 3.1.B certificate. Because of a now established quantitative correlation between grain size and toughness the risk of brittle fracture occurring in an inappropriately heat treated component is intensively increased for exposure temperatures below 0 °C. The earlier mentioned precautions should allow to cope with this inconvenience. Also tensile properties may be below the ASTM A105 requirements even for flanges with a fine microstructure.

  Therefore, it is advised that the Authorities should directly or indirectly through Notified Bodies verify (according to the European Pressure Equipment Directive or PED) whether the information concerning chemical composition, heat treatment and mechanical properties is true for the accompanying product. This emphasises the importance of selecting capable and reliable manufacturers maintaining an approved quality control system.

- These statements also prove that if the manufacturer indeed is able to guarantee that the flange is correctly heat treated as specified on the certificate, then a sufficiently fine grained microstructure may be assumed excluding any risk of fracture initiation within the flange at temperatures at or above -29 °C. This actually should be the case for flanges above Class 300 as these need to be heat treated following ASTM A105.

- It has been shown that hardness measurements cannot give proper indications about the material's toughness or grain refinement. Also account should be taken during replica examinations for the depth of decarburisation (of about 0,4 mm) caused by the heat treatment.

Table I:

RECOMMENDATIONS (FIVE CASES) APPLICABLE FOR EACH EXISTING GROUP OF SIMILAR PIPE FLANGES (SAME MANUFACTURER, MANUFACTURING ROUTE, SIZE AND RATING CLASS) WITH SEVERE FAILURE CONSEQUENCES, MADE FROM FORGED ASTM A105 STEEL, CONTAINING HAZARDOUS SUBSTANCES AND OPERATING AT TEMPERATURES (*) BETWEEN 0 °C AND -29 °C

Only valid for pipe flanges with a nominal thickness between 32 mm and 102 mm

A	B	C	D	E	F	G
Manufacturer	Normalised or annealed according to certificate ?	Initial replica examination necessary ?	Result	Further examination necessary ?	Result	Conclusion
Capable and reliable	Yes and as stipulated in ASTM A105 (irrespective of Rating class) **Case I**	No, eventually on a limited number of flanges to verify whether heat treatment was appropriate for material	All flanges complying with grain size criterion applicable for replicas	No		Heat treatment most surely was appropriate, so all flanges acceptable (capability and/or reliability of manufacturer is confirmed)
			One or more flanges not complying with grain size criterion applicable for replicas	Yes, apply as for Case V, Column C, because heat treatment was not appropriate for material		See applicable row of Case V (capability and/or reliability of manufacturer is questionable)
	No or Yes, but other than stipulated in ASTM A105 (in principal only possible for flanges up to ANSI Class 300) **Case II**	Yes, on a moderate number of flanges to verify the degree of grain refinement	All flanges complying with grain size criterion applicable for replicas	No		All flanges most surely have proper grain size and therefore are acceptable
			One or more flanges not complying with grain size criterion applicable for replicas	Yes, apply as for Case V, Column C, because grain size is not appropriate		See applicable row of Case V

- A limited number of flanges = 2% to 5% of the set of components under consideration depending on the severity of the failure consequence.
- A moderate number of flanges = 10% to 20% of the set of components under consideration depending on the severity of the failure consequence.
- A reasonable number of flanges = 20% to 40% of the set of components under consideration depending on the severity of the failure consequence.

(*) Temperatures may differ from minimum metal temperature by applying a correction factor when maximum internal pressures at these minimum metal temperature are lower than the maximum allowable pressure according to ANSI B16.5 indicated for the lowest temperature range or the equivalent maximum allowable pressure for flanges ordered to other dimensions.

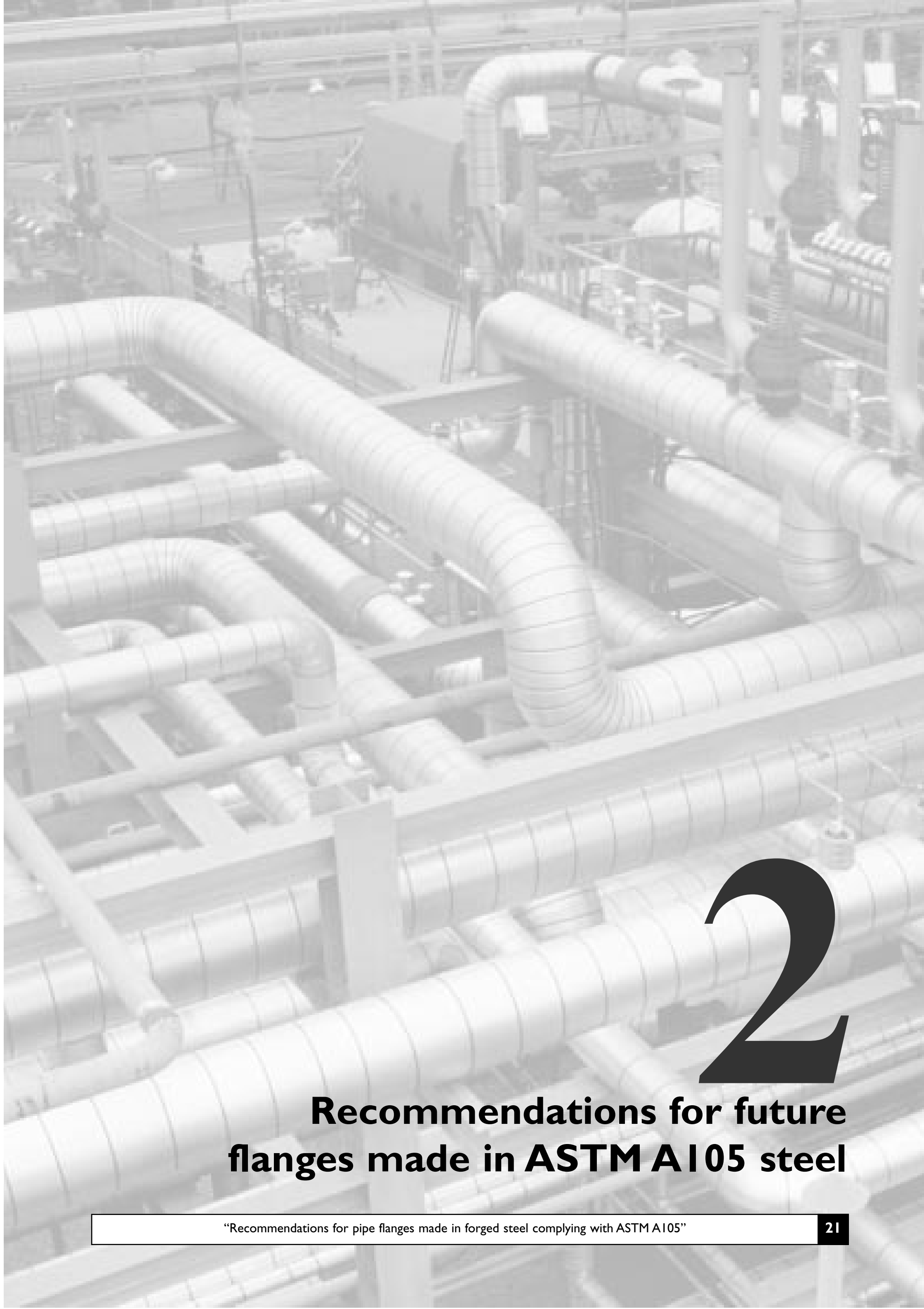
(**) It is understood that selection of part of a set of non-complying components for further examination should be done on the basis of detected grain sizes (coarsest microstructure)
In some cases, flanges which do not fulfil the grain size criterion after initial replica examination can be further examined by increasing the number of replicas so that a more relaxed criterion for grain size can be applied. Unjustified removal and rejection of flanges can so be avoided as these can still be classified as acceptable.

Table I (cont.):

RECOMMENDATIONS (FIVE CASES) APPLICABLE FOR EACH EXISTING GROUP OF SIMILAR PIPE FLANGES (SAME MANUFACTURER, MANUFACTURING ROUTE, SIZE AND RATING CLASS) WITH SEVERE FAILURE CONSEQUENCES, MADE FROM FORGED ASTM A105 STEEL, CONTAINING HAZARDOUS SUBSTANCES AND OPERATING AT TEMPERATURES (*) BETWEEN 0 °C AND -29 °C

Only valid for pipe flanges with a nominal thickness between 32 mm and 102 mm

A	B	C	D	E	F	G
Manufacturer	Normalised or annealed according to certificate?	Initial replica examination necessary?	Result	Further examination necessary ?	Result	Conclusion
Not capable and/or not reliable	Yes and as stipulated in ASTM A105 (irrespective of Rating class) Case III	Yes, on a reasonable number of flanges to verify the degree of grain refinement	All flanges complying with grain size criterion applicable for replicas	No	-	All flanges most surely have proper grain size and therefore are acceptable (capability and/or reliability of manufacturer is better than assessed)
			One or more flanges not complying with grain size criterion applicable for replicas	Yes, apply as for Case V, Column C	-	See applicable row of Case V (lack of capability and/or reliability of manufacturer is confirmed)
	No or Yes, but other than stipulated in ASTM 105 (in principal only possible for flanges up to ANSI Class 300) Case IV	Yes, apply as for Case V, Column C	-	-	-	See applicable row of Case V
No or insufficient information about manufacturer and flanges	– Case V	Yes, on all flanges	All flanges complying with grain size criterion applicable for replicas	No	-	All flanges have proper grain size and therefore are acceptable
			One or more flanges not complying with grain size criterion applicable for replicas	Yes, remove and/or examine metallographically a reasonable number of non-complying flanges (**), although replacing all non-complying flanges may be more economically attractive	All flanges now complying with grain size criterion applicable for metallography	Replace extracted flanges and accept all other flanges
					One or more flanges not complying with grain size criterion applicable for metallography	Replace flanges not complying in Column D (thus including removed flanges)



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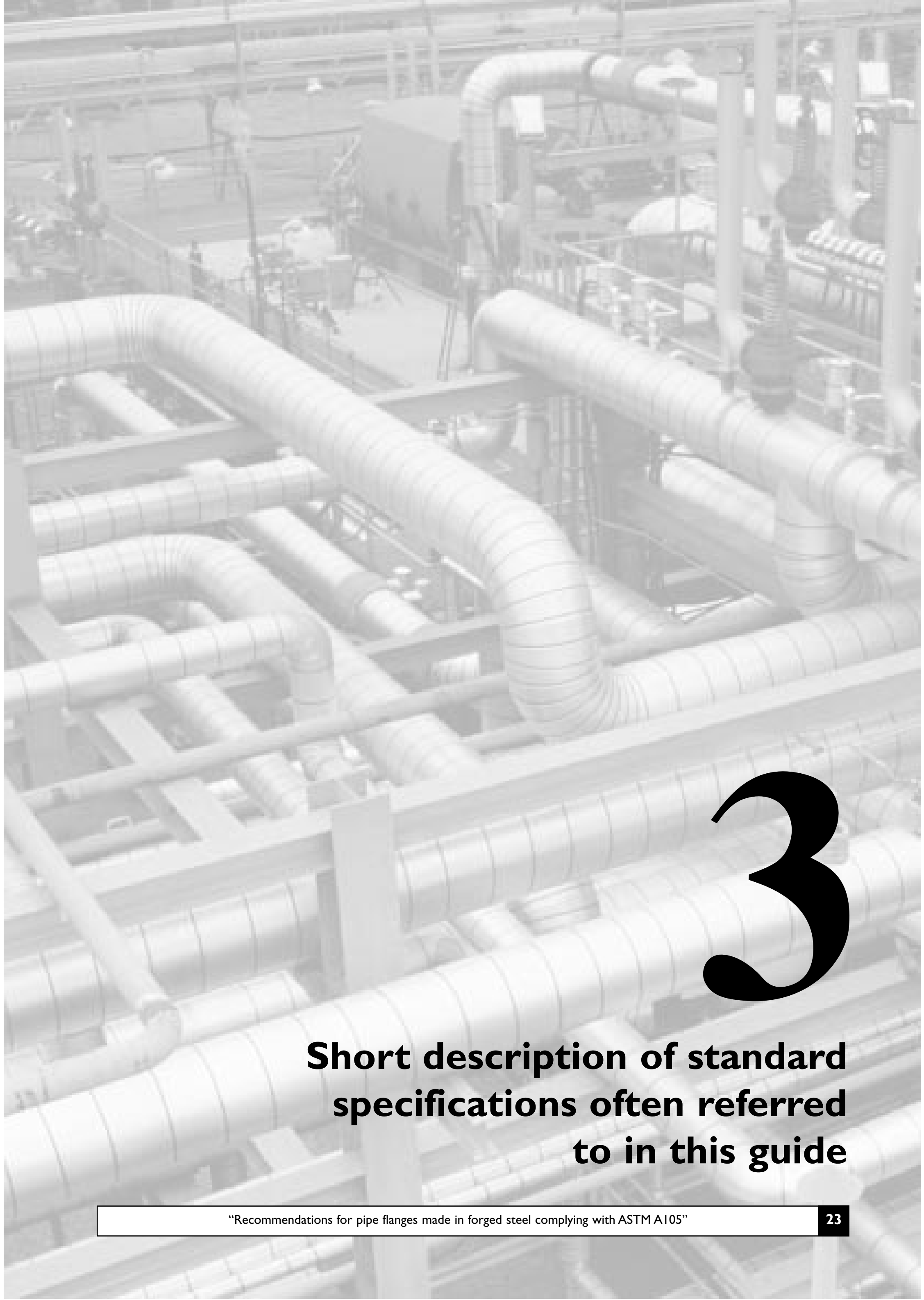
Recommendations for future flanges made in ASTM A105 steel

If critical ASTM A105 pipe flanges (which per definition are components for installation at temperatures between -29 °C and 0 °C and containing hazardous substances) with severe failure consequences (to be evaluated by the user company) are to be ordered in the future, then it is recommended to follow the procedure explained hereafter.

Orders should be placed to reliable manufacturers which can prove (or have already proven through official and independent qualifications) their capability concerning precautions for the avoidance of flakes (or hydrogen cracks) and concerning the performance of heat treatments fast enough to cope with the production rate. As long as PED regulations are not yet fully realised, it is recommended in the mean time that the user himself should identify potential (capable and reliable) manufacturers.

Irrespective of size and rating class but certainly for a flange thickness equal to or above 32 mm, the order should include a compulsory heat treatment according to ASTM A105 of all flanges but also a full non destructive examination to exclude the presence of detectable cracks. Indeed flanges containing cracks initially should not be put into service. In order to avoid the occurrence of hydrogen cracks, it is recommended to require vacuum degassed steel when ordering large diameter flanges.

If again some uncertainty exists concerning the accuracy of a proper heat treatment or concerning the appropriateness of the treatment for the flange material, then a control of grain size should be done similar to that detailed in the earlier described Case I. The same remarks remain valid as those made in the paragraph about the thickness range of pipe flanges.



3

Short description of standard specifications often referred to in this guide

Important items included in ANSI B16.5 and ASME B31.3 but specifically valid for ASTM A105 steel are given hereafter in 'italic'.

3.1 ASTM A105 "Standard Specification for Carbon Steel Forgings for Piping Components"

ASTM A105 "Standard Specification for Carbon Steel Forgings for Piping Components" covers forged carbon steel piping components for ambient and higher- temperature service in pressure systems. Included are flanges, fittings, valves, ... ordered either to dimensions specified by the purchaser or to dimensional standards such as ANSI and API specifications with a maximum weight of 4540 kg (10.000 lb). The ASTM standard specifies the chemical composition for heat and product analyses (for instance for heat analysis C ≤ 0,35%, Si: 0,10 - 0,35% and Mn: 0,60 - 1,05%) and the main mechanical properties of the product (yield strength ≥ 250 MPa, ultimate tensile strength ≥ 485 MPa, strain at fracture ≥ 22% and reduction of area ≥ 30%). Supplementary requirements (for instance concerning hardness, tension tests, hydrostatic testing, repair welding, heat treatment, carbon equivalent, etc...) may be specified by the purchaser.

Heat treatment according to ASTM A105 is not mandatory except for the following piping components:

- Flanges above Class 300 (according to ANSI B16.5);
- Special design flanges where design pressure at design temperature exceeds the pressure-temperature ratings of Class 300, Group 1.1 (according to ANSI B16.5);
- Special design flanges where design pressure or design temperature are not known;

Heat treatment when required shall be:

- annealing (to be done immediately after forging and to consist of cooling, followed by reheating to refine the grain and finally uniform cooling in the furnace); or
- normalising (identical but final cooling in still air); or
- normalising and tempering (the latter consisting of heating between specific temperatures for minimum _h/inch of maximum section thickness); or
- quenching and tempering (either fully austenitizing followed by quenching in a suitable liquid medium or fully austenitizing and rapid cooling, then partially reaustinitize followed by quenching in a suitable liquid medium).

Forgings complying with ASTM A105 shall be free of injurious imperfections, the depth of which, by definition, encroaches on the minimum wall thickness of the finished product. Shallow surface imperfections not classified as injurious in some cases do not need to be removed or, if required, shall be removed by machining or grinding. Repair of defects by welding is also permissible for forgings made to dimensional standards (like ANSI B16.5). All forgings repaired by welding shall be

post-weld heat treated (tempered, or alternatively annealed, normalised and tempered, or quenched and tempered) and the mechanical properties eventually reassessed.

3.2 ANSI B16.5 "Pipe Flanges and Flanged Fittings"

ANSI B16.5 "Pipe Flanges and Flanged Fittings" covers pressure-temperature ratings, materials, dimensions, tolerances, ... for pipe flanges and flanged fittings (forged, cast or made from plate) in sizes NPS _ (Nominal Pipe Size) through NPS 24 corresponding to ANSI B36.10. Flanges and flanged fittings shall be designated as one of the following: Class 150, 300, 400, 600, 900, 1500 or 2500 or corresponding metric designations PN 20, 50, 68, 100, 150, 250 and 420. Ratings are maximum allowable non-shock working pressures, expressed as gage pressure, at the temperature shown for the applicable material. Materials having the same or closely related composition and yield strength have been grouped to provide compatible flanged joint ratings for materials likely to be used together. All materials in ANSI B16.5 are designated by the applicable ASTM Specification and are so called

- "Group 1 Materials", subdivided in Group 1.1 (carbon or C-Mn Si steels, including ASTM A105 and A350-LF2), Group 1.2 (carbon or 2_Ni to 3_Ni steels, including ASTM A350-LF3), ... to Group 1.14 (9Cr-1Mo steels);
- "Group 2 Materials", subdivided in Group 2.1 (18Cr-8Ni stainless steels), Group 2.2 (16Cr-12Ni-2Mo, 18Cr-13Ni-3Mo, ... stainless steels), ... to Group 2.7 (25Cr-20Ni stainless steels); or
- "Group 3 Materials", subdivided in Group 3.1 (Cr-Ni-Fe-Mo alloys), Group 3.2 (Ni alloy 200), Group 3.4 (Ni-Cu alloys 400 and 405), ... to Group 3.8 (Ni-Mo-Cr alloys, Ni-Cr-Mo-Nb alloys, ...).

According to ANSI B16.5, a flange (threaded, blind or welding neck type) made from a material of Group 1.1 (like ASTM A105 steel) with dimensions complying with Class 600 (or in metric units Class PN100) may be exposed to temperatures between -29 °C (which is the minimum allowable temperature for all materials mentioned in ANSI B16.5) and +38 °C at a maximum pressure of 102,1 bar. The maximum allowable pressure gradually decreases with increasing maximum exposure temperature but all (Sub-)Groups of materials have an upper temperature limit above which flanges may never be exposed to. *For the carbon steels of Group 1 for instance (i.e. materials of Group 1.1 to 1.4) this maximum allowable temperature is 540 °C, at which the pressure should be limited to 6,5 bar.*

3.3 ASME B31.3 "Chemical Plant and Petroleum Refinery Piping - Chapter III: MATERIALS"

3. ASME B31.3 "Chemical Plant and Petroleum Refinery Piping - Chapter III: MATERIALS" states limitations and required qualifications for materials based on their inherent properties. Their use in piping is also subject to requirements and limitations in other parts of this ASME Code. The designer shall verify that materials which meet other requirements of the Code are suitable for service throughout the operating temperature range. An important table given in appendix of ASME B31.3 'Allowable stresses and quality factors for metallic piping and bolting materials' summarises the basic allowable stresses in tension for metals (again all designated by the applicable ASTM Specification) between a minimum and a maximum temperature. It includes values for iron castings, carbon steels, stainless steels, copper and copper alloys, nickel and nickel alloys, aluminium and aluminium alloys, … A second table of the same appendix gives a similar overview of design stress values for bolting materials.

A listed material, i.e. material that conforms to a listed specification, may be used at any temperature not lower than the minimum shown in the first mentioned ASME table, provided that the base metal (and also the weld deposit and heat affected zone) is qualified as required by ASME B31.3. These toughness test requirements are in addition to tests required by the Material Specification. *For forged steel complying with ASTM A105 the minimum temperature indicated in the said ASME table is -29 °C while no further requirements than those mentioned in the material standard are specified.*

A listed material may be used at a temperature lower than the minimum shown in the first mentioned ASME table, unless prohibited in this Section or elsewhere in this ASME Code, and provided that the base metal (and also the weld deposit and heat affected zone) is qualified as required by ASME B31.3. The allowable stress or component rating at any temperature below the minimum shown in this table shall not exceed the stress value or rating at the minimum temperature of this table or the component standard. *For forged steel complying with ASTM A105 it is required for use below the minimum temperature of -29 ºC to heat treat the base metal per applicable ASTM specification (for forgings the applicable specification is ASTM A350) and then to impact test the base metal (and again the weld deposit and heat affected zone) at the minimum design temperature.*

Impact testing is not required if the design temperature is above -46 °C, the maximum operating pressure does not exceed 25% of the maximum design pressure at ambient temperature and the combined longitudinal stress does not to exceed 41 MPa. Neither is impact testing required when the maximum obtainable Charpy specimen has a width along the notch of less than 2,5 mm.

The acceptance criteria for carbon and low alloy steels with a minimum specified tensile strength of 448 MPa to 517 MPa are an average and an individual energy respectively of at least 20 J and 16 J for 'fully deoxidised steels' and respectively of 18 J and 14 J for

'other than fully deoxidised steels'. No requirements for lateral expansion are included for carbon steels with a minimum specified tensile strength below 656 MPa.

3.4 prEN 13445 - Edition 1999: "UNFIRED PRESSURE VESSELS"

prEN 13445 - Edition 1999: "UNFIRED PRESSURE VESSELS" has been prepared under a mandate given to CEN by the European Commission (EC) and supports essential safety requirements of the EC Pressure Equipment Directive (PED). This European Standard specifies the requirements for materials, design, manufacture, testing, inspection and safety systems for unfired pressure vessels up to being placed on the market and is not applicable to pressure equipment other than stationary, items specifically designed for nuclear use, fired or otherwise heated pressure equipment with risk of overheating intended to the generation of steam or superheated water at temperatures higher than 110 °C, ..., pipelines, ...

Steels shall have a specified minimum elongation after fracture of at least:

- 14%for the transverse direction, or in those rare cases where it is the more critical direction, the longitudinal direction and
- 16%for the longitudinal direction, or where this is the less critical direction, the transverse direction.

Steels shall have a specified minimum impact energy measured on a Charpy-V notch test specimen (EN 10045-1) of at least 27 J for ferritic and 1,5 to 5% Ni alloyed steels and 40 J for other steels at a test temperature according to the prescriptions given hereafter, but not higher than 20 °C.

The materials are divided into groups in accordance with CR TR 15608 (CEN Technical Report 'Welding-Guidelines for a metallic materials grouping system for fabrication purposes'). They have been allocated into these groups in accordance with their chemical composition and properties in relation to manufacture, heat treatment after welding and non-destructive examination.

The relevant paragraphs of prEN 13445 provide criteria for the avoidance of low temperature (including temperatures at pressure tests) brittle fracture of metallic materials, in the form of plate, tubes, fittings, forgings, castings, flanges, … in pressure parts. The criteria are based on impact energy requirements at specified temperatures for the base material, heat affected zone and weld metal. The properties for the base material shall be specified by material standards.

The minimum metal temperature TM is the lowest temperature defined for each of the following conditions :

- temperature during normal operations ;
- temperature during start up and shut down procedures ;
- temperature which may occur during possible process upsets ;
- temperature which may occur during pressure or leak testing.

A temperature adjustment term TS relevant to the calculation of the design reference temperature TR is dependent on the pressure induced principal membrane stress at the appropriate minimum metal temperature. Values of TS are defined in the following table for non welded and post weld heat treated conditions.

Temperature adjustments TS for non welded and post weld heat treated condition

Percentage of maximum allowable stress			Membrane stress (*)
> 75%; ≤ 100%	≤ 75%	≤ 50%	≤ 50 MPa
0 °C	+ 10 °C	+ 25 °C	+ 50 °C

(*) In this case the membrane stress should take account of internal and external pressure and dead weight.

The design reference temperature TR is the temperature used for determining the impact energy requirements and is calculated by adding the adjustment TS to the minimum metal temperature TM. All applicable combinations of the temperatures TM and TS shall be considered and the lowest possible TR-value shall be used for the determination of the required material impact temperature. The impact test temperature TKV is the temperature at which the required impact energy KV has to be achieved.

The reference thickness eB of a component is the thickness to be used in Method 2 (see later) to relate the design reference temperature TR of the component with its required impact test temperature TKV. The reference thickness is based on the nominal thickness (including corrosion allowance). For butt welded components eB is the nominal wall thickness of the component at the edge of the weld preparation.

One of the following three methods shall be used to determine the impact energy requirements to avoid brittle fracture.

Method 1 - Code of practice

The impact energy requirements for ferritic steels and 1,5% to 5% Ni steels are given in the following table.

Impact energy requirements for ferritic and 1,5% to 5% Ni steels			
Impact energy KV	Impact test temperature TKV	Limitation of reference thickness eB	Remarks
27 J	TR	For as welded : ≤ 30 mm	Rp ≤ 310 MPa
27 J	TR	For PWHT : ≤ 60 mm	310 MPa < Rp ≤ 460 MPa

Method 2 - Code of practice developed from fracture mechanics for C, C-Mn, fine grain and low alloyed steels with specified minimum yield strength # 460 MPa.

In this procedure the impact test temperature TKV is not equal to the design reference temperature TR. Parent material, welds and heat affected zones shall meet the impact energy KV (40 J or 27 J) and impact test temperature TKV requirements given in various figures (TKV in function of design reference temperature TR and reference thickness eB). The figure to be used depends on base metal specified minimum yield strength (≤ 310 MPa; > 310 MPa and ≤ 360 MPa; > 360 MPa) and on whether or not a minimum required impact energy of 27 J is specified in the product standard.

Method 3 - Fracture mechanics analysis

A fracture mechanics analysis may be used as a basis for determining the suitability of particular vessels for their intended duty when so agreed between the parties concerned for the following:

a) materials not currently covered by standard product codes;
b) those cases where the requirements for low temperature applications cannot be adhered to;
c) where defects outside the non-destructive testing requirements are detected;
d) where it is proposed to use materials in thickness greater than permitted by the low temperature requirements.

For material not covered by the low temperature requirements of Methods 1 or 2, a similar level of tolerance to fracture can be obtained by specifying, fracture toughness requirements determined from the use of Assessment Procedures such as PD6493 (now BS7910) with a reference defect size as agreed by the parties involved (e.g. a through wall flaw of total length equal to 10 mm, or a quarter wall thickness surface flaw with length six times its depth) and inputs of an equivalent stress (or strain) relating to the hydraulic test condition, for a defect in a region of stress concentration and subject to residual stresses equivalent to the ambient temperature yield strength of the base material for AW components, or 30% of yield for PWHT components.

For materials which are covered by the low temperature requirements for Method 1 or 2, but where the Charpy energy requirements cannot be met, a fitness-for-purpose assessment using representative fracture toughness data and inspection requirements may be employed to determine the integrity of the vessel for its intended use.

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