Work Item Number	2360
Title of Work Item	Stress relief of cold-worked ends
Ballot Revision Level	4th Ballot (January 2024)
Type of Ballot (Initial, Comment, Comment resolution (reference API ballot#), 1st Re-ballot, 2nd Re-ballot, etc.)	4th Ballot
Submitter Name(s)	Gustavo López Turconi
API Document Modified	API 5CT
API Document, API Modifying Document(s) and Revision Level(s)	11th. Ed.
Revision Key	Text in 11th Ed. for reference (not to be modified) changes from 3rd Ballot text including resolution of comments.

Work Item Charge: The ends of PE pipe require cold work (swage and expand) in preparation for some special end finish connections. For Q&T product, this cold work requires stress relief to restore the material properties to the pre-cold worked condition. The stress relief process needs to be precise to relieve the stress and not exceed the original final tempering temperature. The FTT reported per SR15 may not be the actual pipe body temperature, but the set furnace temperature, not knowing this could cause inadvertent re-tempering of the material during SR. The intent of this WI is to 1) evaluate the industry stress relief capability and determine the best relationship between the reported FTT and the SR temperature and 2) propose any necessary revisions to the standard to make the SR requirements clear.
Ballot Rationale: This WI was initiated back in 2008 to address the stress relief of cold worked (swaged & expanded) pipe ends prior to machining certain SF connections. The intent is to create an industry standard to determine the appropriate stress relief temperature, how that temperature is measured, the allowable temperature tolerances, and how the process is verified.

4th Ballot changes:

Main technical changes are aligned with:
a. Introduction of alternative validation and control methods, as long as still meet the material requirements of this Annex.
b.Limitation of Annex Z to sizes larger or equal to 7”. In the case that the size of the deformed area does not allow to perform the testing required, the approval will be with the partial testing that can be performed.
c. Acceptance criteria for stress relief is based on differences with unaffected area of same joint and minimum yield strength of the grade.
d. Reduction of the requirements for control during production, on mechanical properties to be verified and in verification frequency during the production run.

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3 Terms, Definitions, Symbols, and Abbreviations

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3.1.14 end sizing

An operation that plastically deforms pipe ends by swaging, expansion, or rounding, to adjust dimensions by reducing or increasing OD and potentially changing wall thickness and ovality in the deformed area to allow threading of SF or API 5B connections.

NOTE Depending on the level of cold plastic strain, the mechanical and/or sulfide stress cracking properties of the original material may change.

3.1.31 nascent strain area

Area of pipe body adjacent to the deformed area that may be heated during thermal recovery but has experienced minimal plastic deformation (essentially elastic) during the end sizing process (see Figure Z.1).

3.1.48 thermal recovery (stress relieving)

Process on pipe ends previously end sized that is intended to relieve stresses and recover mechanical or other properties by heating.

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4 Information to be Supplied by the Purchaser

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4.2 Casing

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4.2.2 When applicable in a purchase order, the optional requirements in Table 2 shall apply.

Table 2 – Optional Requirements Specified by the Purchaser (Casing)

Requirement	Reference
SSC test method(s) in strained area during production for Annex Z	Z.4

4.2.3 Upon agreement between the purchaser and the manufacturer, the additional casing requirements in Table 3 shall apply.

Table 3 – Purchaser / Manufacturer Agreement (Casing)

Requirement	Reference
Various end-sizing testing and acceptance criteria	Z.2 to Z.4

4.3 Tubing

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4.3.2 When specified in a purchase order, the optional requirements in Table 5 shall apply.

Table 5 – Optional Requirements Specified by Purchaser (Tubing)

Requirement	Reference
SSC test method(s) in strained area during production for Annex Z	Z.4

4.3.3 Upon agreement between the purchaser and the manufacturer, the tubing requirements in Table 6 shall apply.

Table 6 – Purchaser / Manufacturer Agreement (Tubing)

Requirement	Reference
Various end-sizing testing and acceptance criteria.	Z.2 to Z.4

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5 Process of Manufacture

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5.5 Process Requiring Validation

5.5.1 Final operations performed during product manufacturing that affect attribute conformance as required in this standard (except chemical composition and dimensions) shall have their processes validated.

Those processes requiring validation are as follows

a) for seamless, as-rolled product: final reheating practice and hot sizing or stretch-reducing. If applicable, upsetting, cold-working, end sizing with or without subsequent thermal recovery unless validation is not required per 7.12.6 or Annex Z.1;

b) for seamless, heat-treated product: heat treatment. If applicable, end sizing with or without subsequent thermal recovery unless validation is not required per 7.12.6 or Annex Z.1;

c) for electric-welded, as-rolled product: sizing and seam welding. If applicable, seam heat treatment and upsetting, end sizing with or without subsequent thermal recovery unless validation is not required per 7.12.6 or Annex Z.1; and

d) for electric-welded, heat-treated product: seam welding and full-body, full-length heat treatment. If applicable, end sizing with or without subsequent thermal recovery unless validation is not required per 7.12.6 or Annex Z.1.

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7 Dimensions, Masses, Tolerances, Product Ends, and Defects

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7.12 Product Ends

7.12.6 Special End-finish

Pipe with end-finish not specified in this standard may be furnished if specified in the purchase agreement. This pipe shall have the body of the pipe manufactured in accordance with the requirements of this standard. If pipe is end-sized, the modified area shall be free of defects as described in 7.13. When threaded by the pipe mill or processor, the pipe shall be marked as specified in 10.5.2.

For products with OD greater than or equal to 177.8 mm (7 in) when pipe ends are subject to end sizing, with or without subsequent thermal recovery, the product shall conform to the requirements of Annex Z or other methods as agreed between purchaser and manufacturer.

Product shall meet the material requirements in Table Z.1 or Table Z.2 for validation and Table Z.3 or Table Z.4 for control during production.

If the size of the deformed area does not allow for machining the minimum small-size test specimen indicated in ISO 6892 or ASTM A370 for tensile test, those of Table C.8 or Table E.8 for impact test or those of NACE TM0177-2016 for SSC tests, the process shall be considered validated through the partial

testing that can be performed (e.g. metallographic examination, hardness testing) and the corresponding requirements of Table Z.1 or Z.2.

If the size of the deformed area does not allow for machining the minimum small-size test specimen indicated in ISO 6892 or ASTM A370 for tensile test, those of Table C.8 or Table E.8 for impact test or those of NACE TM0177-2016 for SSC tests, the product shall be considered approved during manufacture through the partial testing that can be performed (e.g. metallographic examination, hardness testing) and the corresponding requirements of Table Z.3 or Z.4.

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Annex Z
(normative)

Requirements for Validation of End Sizing with or without Thermal Recovery Processes of Pipe Ends

Z.1 General

The process validation requirements in this annex pertain to the operations needed for products with threads as specified in 8.12.2 or special end-finishes as specified in 8.12.6. The pipe ends shall be manufactured to meet the design requirements of the proprietary thread and this annex.

When end sizing is applied to pipe in preparation for threading (with or without thermal recovery), the process shall be validated if any of the following circumstances are true:

a) the manufacturer's process or procedures have not demonstrated validation based on the maximum strain or

b) for Grades L80 and P110 when the maximum compressive or tensile strain in the deformed area prior to thermal recovery exceeds that previously validated by the manufacturer for the same target composition or

c) for Grades C90, T95, C110, P110, and Q125, a specific process validation is mandatory for the particular combination of grade, size, pipe end deformation process and connection geometry, unless a previous validation is available.

The manufacturer shall demonstrate that the manufacturing route selected is validated for the particular combination of size, weight, grade, special end-finish geometry, and maximum strain in the deformed area.

The manufacturer may demonstrate that the process for a particular combination is covered by previous validations performed on metallurgical and deformation equivalences. The manufacturer shall provide objective evidence that cases validated are the worst case for process design. Justification for extrapolation to other products or connection design shall be provided.

The manufacturer shall document the validation process and parameters, the procedures, the evaluation data, and the technical analysis conducted to demonstrate compliance with the requirements of this annex. This information shall be available upon request to the purchaser.

Temperature sticks or paints shall not be used for temperature measurement.

When thermal recovery is applied at pipe ends only and temperature is above the limits specified in 10.4.1 for stress relief temperature, the process shall not be considered "heat treatment".

When thermal recovery is applied full-length after end sizing and the thermal recovery temperature is above the limits specified in 10.4.1 for stress-relief temperature, the lengths shall be considered to have undergone heat treatment and shall be tested as new lots.

NOTE Thermal recovery is a process depending on both temperature and exposure time; when thermal recovery is applied only to pipe ends, the combination of time and temperature does not allow metallurgical changes associated with tempering to occur; in the case that the process is applied full-length, the time at elevated temperature is longer and initiation of metallurgical changes associated with tempering may occur.

Context on the threader's responsibility on acceptance criteria

- When mother pipe is verified to have properties at the unaffected area not meeting the requirements of the grade, the threader shall notify the purchaser prior to threading.
- When pipe is threaded by a facility other than the original pipe manufacturer, the threader is only responsible to ensure the mechanical properties results meet the allowed maximum differences shown in Tables Z.1 to Z.4 between the sized end and the unaffected pipe area and is not responsible for conformance to the specified requirements for the grade.

Z.2 Test Specimens

The tensile test specimens shall be round bars as indicated in ISO 6892-1 or ASTM A370. All tensile specimens shall be the largest applicable round bar. Specimens with diameter below 8.9 mm (0.350 in.) are acceptable. Sub-size round bar specimens shall only be used when comparing results with other sub-size round bar specimens.

NOTE: Sub-size round bar test specimens have been demonstrated to incorrectly represent full wall thickness mechanical properties. Care is recommended when assessing conformance to maximum yield strength using sub-size round bar specimens.

The tensile test specimen location shall be selected so that the gauge section incorporates the strained area and particularly as near as possible to the maximum strain area. In the case of round bar specimens, all specimens shall be of the same diameter.

The hardness test specimens shall be prepared as specified in Figure D.10 utilizing one quadrant testing with 9 indentations

The impact test shall consist of a set of three test specimens with the largest possible test specimen listed in Table C.8 or Table E.8 and the hierarchy of test specimen size and orientation in accordance with Table C.9 or Table E.9.

For Grades C90, T95, and C110, sour service tests shall be performed on either NACE TM0177-2016 Method A and/or Method D specimens. When applicable, the test specimen sizes, method, and acceptance criteria shall be in accordance with 7.14 and 10.10.

Z.3 Process Validation Requirements

Z.3.1 Sample location

Test specimens for process validation shall be taken from a test pipe from the following sections of the test pipe, defined in Figure Z.1:

a) for tensile, hardness, and impact tests, and SSC test (as applicable), take section as close as possible to the area of maximum strain;

b) when thermal recovery is applied, and the temperature is at or above the minimum tempering temperature for the product, take section for tensile test from the area of nascent strain;

c) for tensile and impact tests, take section from the adjacent area of the mother pipe that is unaffected by deformation or heating.

Z.3.2 Test requirements for Grades L80, P110, and Q125

For the cases described in Z.1 where process validation is mandatory, unless other acceptance criteria is agreed between purchaser and manufacturer, the following requirements shall be met (also see Table Z.1 or Table Z.2).

a) Tensile Testing per Z.3.1

Tensile testing shall be performed following 10.4.7 and 10.4.8, except that sub-size round bar specimens may be used when comparing the results from the same size round bar specimen.

The yield strength shall meet the minimum requirement in Table C.5 or Table E.5 except that the yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer. Alternative specimen size, geometry may also be agreed between purchaser and manufacturer.

The yield strength from the deformed and nascent strain (when applicable) areas shall not differ by more than 10 % or 69 MPa (10 ksi), whichever is larger, from the properties of the unaffected area.

a) Hardness Testing per Z.3.1:

If the maximum hardness is required by the grade, the hardness tests shall be performed in accordance with 10.6.9 through 10.6.13 and shall meet the applicable maximum hardness requirement specified in 7.7.1 a), Table C.5 or Table E.5 for the grade.

b) Impact Testing per Z.3.1:

The impact tests shall be performed in accordance with 7.3.7, 10.7.5 and 10.7.6 and shall meet the requirements for the pipe nominal wall and grade in accordance with 7.3.1, Table C.18 and Table C.19 or Table E.18 or Table E.19, when applicable. The average energy of the deformed area shall be greater than 75 % of the average energy of the unaffected area.

Z.3.3 Test requirements for Grades C90, T95, and C110

For the cases described in Z.1 where process validation is mandatory, unless other acceptance criteria is agreed between purchaser and manufacturer, the following requirements shall be met (also see Table Z.1 or Table Z.2).

b) Tensile Testing per Z.3.1

Tensile testing shall be performed following 10.4.7 and 10.4.8, except that sub-size round bar specimens may be used when comparing the results from the same size round bar specimen.

The yield strength shall meet the minimum requirement in Table C.5 or Table E.5 except that the yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer. Alternative specimen size, geometry may also be agreed between purchaser and manufacturer.

The yield strength from the deformed and nascent strain (when applicable) areas shall not differ by more than 5 % or 34 MPa (5 ksi), whichever is larger, from the properties of the unaffected area.

a) Hardness Testing per Z.3.1

The hardness tests shall be performed in accordance with 10.6.9 through 10.6.13 and shall meet the applicable hardness variation requirement specified in 7.7.1 a), Table C.5 or Table E.5 for the grade.

b) Impact Testing per Z.3.1

The impact tests shall be performed in accordance with 7.3.7, 10.7.5 and 10.7.6 and shall meet the requirements for the pipe nominal wall and grade in accordance with 7.3.1, Table C.18 and Table C.19 or Table E.18 and Table E.19, where applicable. The average energy of the deformed area shall be greater than 75 % of the average energy of the unaffected area.

c) SSC Testing per Z.3.1

The sulfide stress-cracking tests shall meet the minimum requirement specified in 7.14.5. If NACE TM0177-2016 Method D sub-size or alternative specimens are used, the acceptance criteria shall be agreed between purchaser and manufacturer.

Z.3.4 Retest

If the unaffected area round bar test results do not meet the minimum yield strength requirements in Table Z.1 or Table Z.2, then full-wall strip specimens may be used to verify the unaffected area meeting requirements in Table C.5 or Table E.5. However, the yield strength difference verification with the unaffected area shall be with round bar test specimens.

Any test specimen that shows defective preparation or material imperfections unrelated to the intent of the test, whether observed before or after testing may be discarded and be replaced by another specimen from the same length. Specimens shall not be judged defective simply because they failed to exhibit the requirement.

Unless the test execution is reported as invalid, no retests shall be allowed. Assignable cause shall be recorded. If these requirements are not met, the thermal recovery process parameters shall be modified.

Z.3.5 Documentation

The manufacturer shall document all test results.

The documentation shall identify the specified diameter, wall thickness, material grade, maximum percentage of deformation applied, range of maximum temperature of heated ends, location of the temperature measurement instruments used, thermal recovery temperature setup, and total exposure time.

Z.4 Thermal Recovery Operations—Control during Production

Z.4.1 Sample Location

The test specimens for process control during production shall be taken from the following sections, as defined in Figure Z.1:

a) for tensile, hardness, impact testing and SSC testing (as applicable), test specimen sections shall be as close as possible to the area of maximum strain; and

b) for tensile testing, test specimen sections shall be taken from the adjacent area that is not affected by deformation or heating.

The test specimens shall be taken from a pipe end corresponding to the beginning of the production run without changes to the set points for controlled variables.

Z.4.2 Test Requirements for Grades L80, P110 and Q125 during Production

Production shall proceed within the parameters of the previously validated process, unless agreed between manufacturer and purchaser.

Unless other acceptance criteria for control during production is agreed between purchaser and manufacturer, the following requirements shall be met (also see Table Z. 3 or Table Z. 4).

c) Tensile Testing per Z.4.1

Tensile testing shall be performed following 10.4.7 and 10.4.8, except that sub-size round bar specimens may be used when comparing the results from the same size round bar specimen.

The yield strength shall meet the minimum requirement in Table C.5 or Table E.5 except that the yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer. Alternative specimen size, geometry may also be agreed between purchaser and manufacturer.

The difference of yield strength between the deformed and nascent areas (when applicable) versus unaffected pipe body shall be less than or equal to 69 MPa (10 ksi) for L80, 77 MPa (11 ksi) for P110 or 83 MPa (12 ksi)for Q125. If the difference is greater than 69 MPa (10 ksi) for L80 76 MPa (11 ksi) for P110

or 83 MPa (12 ksi) for Q125 and less than or equal to 86 MPa (12.5 ksi) for L80 , 93 MPa (13.5 ksi) for P110 or 100 MPa (14.5 ksi) for Q125, two additional confirmation tests on the same pipe end or three additional tests on other pipe ends representative of equipment start-up conditions may be performed to verify the product and the process. If the results meet the acceptance criteria, then the verification is acceptable. All additional tests shall show a difference between affected areas and pipe body lower than 69 MPa (10 ksi) for L80, 76 MPa (11 ksi) for P110 or 83 MPa (12 ksi) for Q125.

a) Hardness Testing per Z.4.1

If the maximum hardness is required by the grade, then hardness testing shall be performed in accordance with 10.6.9 through 10.6.14 and shall meet the requirement for maximum hardness specified in 7.7.1 a), Table C.5 or Table E.5 for the grade.

Z.4.3 Test requirements for Grades C90, T95 and C110 during production

Production shall proceed within the parameters of the previously validated process, unless agreed between manufacturer and purchaser.

Unless other acceptance criteria for control during production is agreed between purchaser and manufacturer the following requirements shall be met (also see Table Z.3 or Table Z.4).

d) Tensile Testing per Z.4.1

Tensile testing shall be performed following 10.4.7 and 10.4.8, except that sub-size round bar specimens may be used when comparing the results from the same size round bar specimen.

The yield strength shall meet the minimum requirement in Table C.5 or Table E.5 except that the yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer. Alternative specimen size, geometry may also be agreed between purchaser and manufacturer.

The difference of yield strength between the deformed and the unaffected pipe body shall be less than or equal to 34 MPa (5 ksi) for C90 and T95 or 41 MPa (6 ksi) for C110. If the difference is greater than 34 MPa (5 ksi) for C90 and T95 or 41 MPa (6 ksi) for C110 and less than or equal to 52 MPa (7.5 ksi) for C90 and T95 or 59 MPa (8.5 ksi) for C110, two additional confirmation tests on the same pipe end or three additional tests on pipe ends representative of equipment start-up conditions may be performed to verify the product and the process. If the results meet the acceptance criteria, then the verification is acceptable. All additional tests on deformed and nascent areas (when applicable) shall show a difference with unaffected pipe body lower than 34 MPa 5 ksi for C90 and T95 or 41 MPa (6 ksi) for C110.

e) Hardness Testing per Z.4.1

Hardness testing shall be performed in accordance with 10.6.9 through 10.6.15 and shall meet the requirement for maximum hardness specified in 7.7.1 a), Table C.5 or Table E.5 for the grade.

f) SSC Testing per Z.4.1

When specified in the purchase agreement, sulfide stress-cracking testing shall be performed. The tests shall meet the minimum requirement specified in 7.14.5. When NACE TM0177-2016 Method D sub-size or alternative specimens are used, the acceptance criteria shall be agreed between purchaser and manufacturer.

Z.4.4 Retest

If the unaffected area round bar test results do not meet the minimum yield strength requirements in Table Z.3 or Table Z.4, then full-wall strip specimens may be used to verify the unaffected area meeting requirements in Table C.5 or Table E.5. However, the yield strength difference verification with the unaffected area shall be with round bar test specimens.

Any test specimen that shows defective preparation or material imperfections unrelated to the intent of the test, whether observed before or after testing may be discarded and be replaced by another specimen from

the same length. Specimens shall not be judged defective simply because they failed to exhibit the requirement.

If a test fails to meet the requirements noted in Tables Z.3 and Z.4, then all lengths produced since the last complete successful testing shall be rejected.

Z.4.5 Thermal Recovery Process Control during Production

Temperature of pipe ends during the recovery process shall be controlled and the final temperature recorded as part of the process control plan.

The manufacturer shall control that recovery temperature and time are consistent with the parameters defined during the validation of the process.

For temperature recording, the temperature shall be measured with a calibrated optical pyrometer, handheld thermometer, contact pyrometer, thermocouple, or other device agreed between purchaser and manufacturer. Temperature sticks and paints may be used for periodic temperature verification but not for acceptance of the product or for recorded values.

Table Z.1—Requirements for Process Validation (SI Units)

Grade	Type	Unaffected Area	Deformed and Nascent [a] Area				Difference between Deformed and Nascent Areas with Unaffected Area	
		Yield Strength [b] (MPa)	Yield Strength [b] (MPa)	Hardness, (HRC)	Impact (J)	SSC	YS [b] (MPa)	Impact (J)
		min	min	max	min		max	min
1	2	3	4	5	6	7	8	9
L80	1	Table C.5 and 7.7.1 a			Table C.18 ,Table C.19 and 7.3.1	7.14	69	75 % of Energy of the Unaffected Area
L80	3Cr						69	
L80	9Cr						69	
L80	13Cr						69	
C90	1						34	
T95	1						34	
C110	—						41	
P110	—						76	
Q125	1						83	

[a] If applicable.
[b] Yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer.

Table Z.2—Requirements for Process Validation (USC Units)

Grade	Type	Unaffected Area	Deformed and Nascent [a] Area				Difference between Deformed and Nascent Areas with Unaffected Area	
		Yield Strength [b] (ksi)	Yield Strength [b] (ksi)	Hardness, (HRC)	Impact (ft-lb)	SSC	YS [b] (ksi)	Impact (ft-lb)
		min	min	max	min		max	min
1	2	3	4	5	6	7	8	9
L80	1	Table E.5 and 7.7.1 a			Table E.18 ,Table E.19 and 7.3.1	7.14	10	75 % of Energy of the Unaffected Area
L80	3Cr						10	
L80	9Cr						10	
L80	13Cr						10	
C90	1						5	
T95	1						5	
C110	—					—	6	
P110	—					—	11	
Q125	1						12	

[a] If applicable.
[b] Yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer.

Table Z.3—Requirements during Production (SI Units)

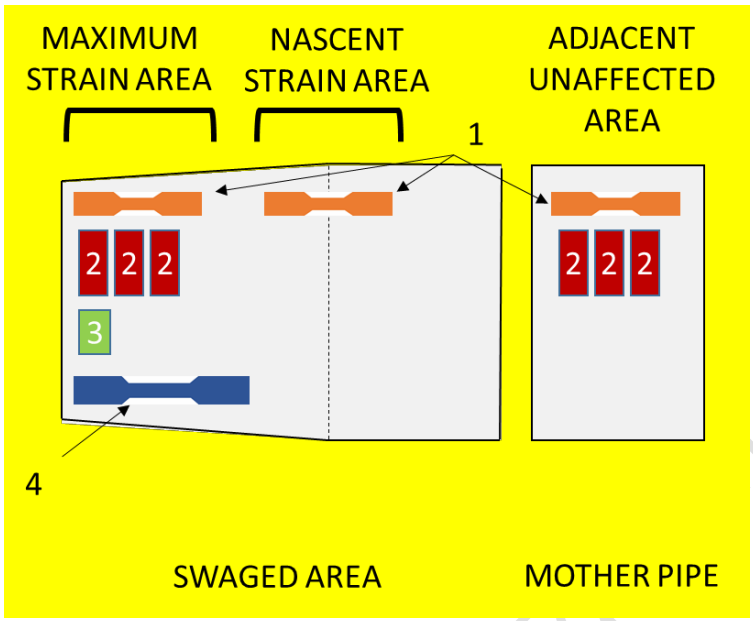
Grade	Type	Unaffected Area	Deformed and Nascent [a] Area			Difference between Deformed and Nascent Areas with Unaffected Area
		Yield Strength [b] (MPa)	Yield Strength[b] (MPa)	Hardness, (HRC)	SSC	Yield Strength [b,c] (MPa)
		min	min	max		max
1	2	3	4	5	6	7
L80	1	Table C.5 and 7.7.1 a			7.14	69 (86)
L80	3Cr					69(86)
L80	9Cr					69 (86)
L80	13Cr					69 (86)
C90	1					34 (52)
T95	1					34 (52)
C110	—					41 (59)
P110	—					76 (93)
Q125	1					86 (100)

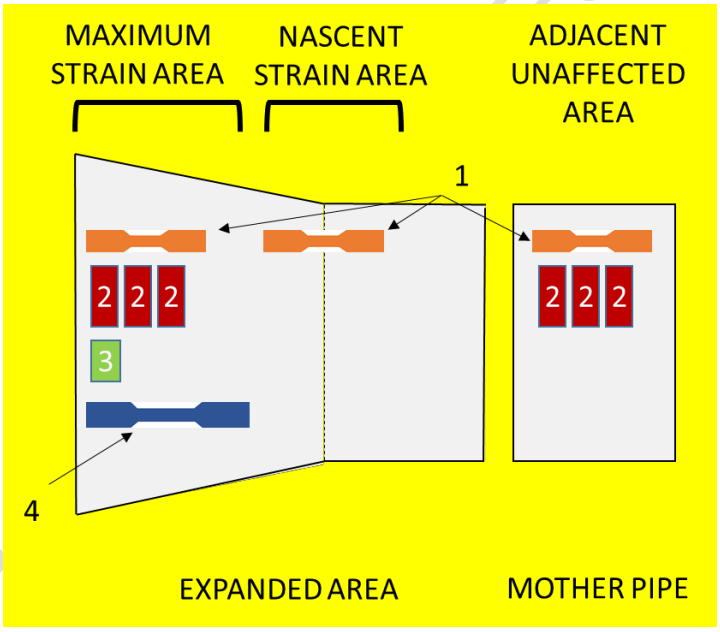
[a] If applicable.
[b] Yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer.
[c] Retesting is allowed on additional samples.

Table Z.4—Requirements during Production (USC Units)

Grade	Type	Unaffected Area	Deformed and Nascent [a] Area			Difference between Deformed and Nascent Areas with Unaffected Area
		Yield Strength [b] (ksi)	Yield Strength [b] (ksi)	Hardness, (HRC)	SSC	Yield Strength [b, c] (ksi)
		min	min	max		max
1	2	3	4	5	6	7
L80	1	Table E.5 and 7.7.1 a			7.14	10 (12.5)
L80	3Cr					10 (12.5)
L80	9Cr					10 (12.5)
L80	13Cr					10 (12.5)
C90	1					5 (7.5)
T95	1					5 (7.5)
C110	—					6 (8.5)
P110	—					11 (13.5)
Q125	1					12 (14.5)

[a] If applicable.
[b] Yield strength shall be determined using the 0.2 % offset method or other method agreed between purchaser and manufacturer.
[c] Retesting is allowed on additional samples.





Key
1 tensile test specimens
2 impact test specimens
3 hardness test specimen
4 sulfide stress cracking specimen (Method A or D)

Figure Z.1—Example Layout of Test Specimens for End Sizing and Thermal Recovery Process