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The effect of specimen type on tensile test results and its implications for linepipe testing

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The effect of specimen type on tensile test results and its implications for linepipe testing

Der Einfluss des Probentyps auf Zugversuchskennwerte und die Auswirkungen auf die Prüfung von Leitungsrohren

In recent years, EPRG has carried out several projects to quantify the effect of the Y/T ratio on pipeline safety against yielding, bursting, plastic elongation and crack growth. It is known that the yield strength and the Y/T ratio may vary with the type of the tensile specimen used. The objective of this work was to give an overview of the effect of the type of the tensile specimen used on YS, TS and Y/T ratio of linepipe. A comparison has been made of the yield and tensile strength values determined on flattened strip specimens with those determined on non-flattened specimens, for different pipe manufacturing processes, pipe geometries, material grades and specimen orientations.

Based on the results it can be said that for material grades up to X 70 the current practice of giving general preference to the flattened rectangular specimen in acceptance testing for transverse direction can be continued. For the tensile testing of materials in grades higher than X 70 and in all those cases where the true strength and deformation properties of pipe are required, the use of transverse round bar specimens should be prescribed, except in cases where the use of flattened rectangular specimens is proven prudent. The gauge diameter of the round bar specimen should be as large as possible, e.g., equal to 2/3 pipe wall thickness. As the seamless pipe appears to be nearly isotropic with respect to yield and tensile strength, longitudinal strip specimens can be used to characterise its tensile properties.

Die EPRG hat in der Vergangenheit in einer Reihe von Projekten die Auswirkung des Streckgrenzenverhältnisses auf die Rohrleitungssicherheit mit Blick auf Fließen, Bersten, plastische Dehnung und Risswachstum untersucht. Es ist bekannt, dass die im Zugversuch bestimmte Streck- bzw. Dehngrenze YS und damit auch das Streckgrenzenverhältnis Y/T von der Wahl des Probentyps abhängen kann. Ziel der vorliegenden Arbeit war es, einen Überblick über den Einfluss des gewählten Probentyps auf die Ermittlung von Dehngrenze, Zugfestigkeit und Streckgrenzenverhältnis bei Leitungsrohren zu geben. Für unterschiedliche Rohrherstellungsprozesse, Rohrgeometrien, Werkstoffgüten und Probelagen wurden Ergebnisse aus Zugversuchen an gerichteten und nicht gerichteten Proben verglichen.

Die erzielten Ergebnisse zeigen, dass die bestehende Praxis, bis zur Festigkeitsstufe X70 zur Abnahmeprüfung in Umfangsrichtung vorzugsweise die gerichtete Flachprobe einzusetzen, beibehalten werden kann. Für Zugversuche an Rohren oberhalb der Festigkeitsstufe X70 und in allen Fällen, in denen die wahren Spannungs- und Verformungseigenschaften erforderlich sind, sollte in Umfangsrichtung die Verwendung der Rundprobe vorgeschrieben werden. Ausnahme hiervon können Fälle sein, in denen der Einsatz von Flachproben als sinnvoll nachgewiesen werden kann. Der Durchmesser der Rundproben sollte dabei so groß wie möglich sein, z.B. 2/3 der Wanddicke. Mit Blick auf die nahezu isotropen Eigenschaften von Dehngrenze und Zugfestigkeit bei nahtlosen Rohren, sind für diesen Rohrtyp Flachproben in Längsrichtung zur Charakterisierung der Zugversuchseigenschaften geeignet.

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Background and objective

In recent years, the European Pipeline Research Group (EPRG) [1] has carried out several projects to quantify the effect of the Y/T ratio determined in tensile tests on pipeline safety against yielding, bursting, plastic elongation and crack growth. It is known that the yield strength and the Y/T ratio determined may vary with the type of the tensile specimen used.

Only sparse information is available in the standards [2-8] as regards specimen preparation and instrumentation to be adopted to determine the tensile properties of linepipe. While a full size flattened rectangular specimen taken in transverse direction is generally specified or considered as the common type of specimen, the use of a transverse round bar specimen is either at the pipe manufacturer's option or up to the agreement between the pipe manufacturer and the purchaser.

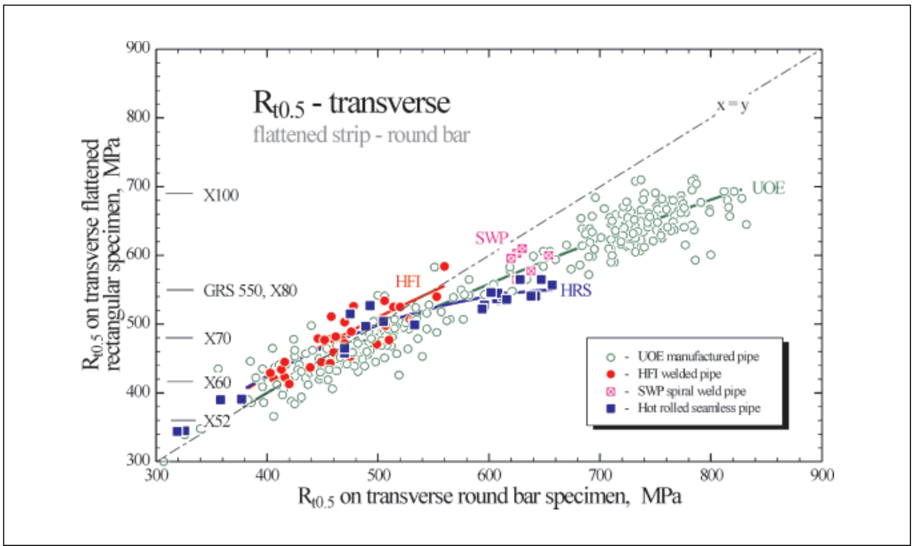

Fig. 1: Comparison of the yield strength values measured on transverse flattened rectangular specimens with those measured on transverse round bar specimens for different pipe types

Bild 1: Vergleich von Dehngrenzenwerten aus Zugversuchen in Rohrumfangsrichtung an gerichteten Flachproben und Rundproben für Rohre verschiedener Herstellungsverfahren

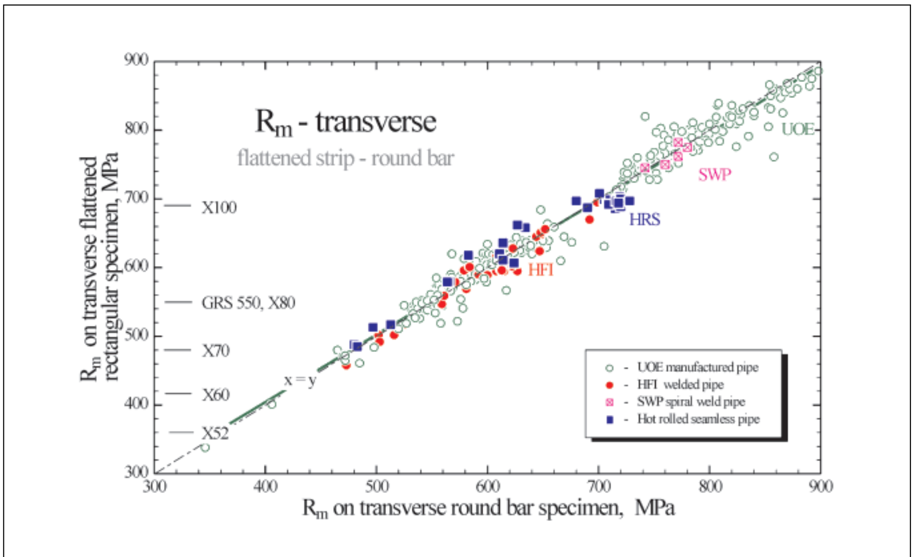

Fig. 2: Comparison of the ultimate tensile strength values measured on transverse flattened rectangular specimens with those measured on transverse round bar specimens for different pipe types

Bild 2: Vergleich von Zugfestigkeitswerten aus Zugversuchen in Rohrumfangsrichtung an gerichteten Flachproben und Rundproben für Rohre verschiedener Herstellungsverfahren

API Spec. 5L requires that the specimen should be flattened at room temperature. According to ASTM E8, the specimen flattening may be either before or after separating the specimen from the test ring taken from the pipe. EN 10002-1 simply mentions that special precautions should be taken in flattening transverse test specimens. Practicable requirements for specimen flattening are not included in the codes and standards.

Generally, it is assumed that the results of tensile tests on round bar specimens represent the yielding behaviour of pipe more closely than those obtained from flattened strip specimens. This is because of the fact that the preparation of the round bar specimen does not involve plastic deformation and hence does not alter the deformation history of the pipe material, in contrast to the preparation of the flattened strip specimen. On the other hand, the round bar specimen enables only a part of the pipe wall to be evaluated.

The EPRG initiated and sponsored a study with the objective to give an overview of the effect of the type of the tensile specimen used on the tensile test results, namely the YS, TS and Y/T ratio. Based on the data made available by the EPRG member companies [1], a comparison was made of the yield and tensile strength values determined on flattened strip specimens with those determined on non-flattened round bar specimens. The data assessed included transverse and longitudinal tensile properties and a wide range of pipe geometries and material grades for UOE, spiral welded, HFI welded and seamless pipe, thereby covering all the pipe types made by the EPRG member companies. The results of tests on tensile specimens were compared with the results of burst tests on pipes to make recommendations for the selection of an appropriate specimen type.

Factors affecting the results of tensile tests on specimens taken from linepipe

The essential factors that affect the tensile test results, particularly the YS and Y/T values, and that may lead to differences between the values determined on the round bar tensile specimen and those determined on the flattened rectangular specimen include the method of pipe manufacture, specimen preparation and the general conditions of testing and evaluation.

Depending upon the method of pipe manufacture, the deformation history in the pipe wall and ultimately that in the specimen cross-section varies with the type of the tensile specimen used as a result of different manifestations of the Bauschinger effect.

In the case of hot rolled seamless (HRS) pipe, the material sampled experiences no cold deformation until the test specimen is flattened. In the case of spiral / helical seam weld pipe (SWP), the material, which was subjected to bending during forming of the plate or strip into pipe, undergoes reverse bending during flattening of the specimen. The manufacture of high frequency induced (HFI) welded / electric resistance welded (ERW) pipe involves an additional deformation step, namely reduction in the course of sizing of the pipe by compression. This reduction tends to decrease the transverse yield strength of the pipe material. In the case of longitudinal seam submerged-arc welded UOE pipe, the sequence of O-ing and expanding involved in the pipe manufacture and the reverse bending involved in the flattening of the specimen increases or decreases the yield strength by turns. In all cases, the increase or decrease in the yield strength depends on the material grade, strain hardening behaviour and processing parameters.

When determining the tensile properties of the pipe using full size transverse strip specimens, it is necessary to flatten the specimen before testing. The flattening operation, consisting of, e.g., straightening between two parallel plates or straightening by over-bending, can lead to different stress-strain curves and therefore especially different yield strength values. The remaining curvature and the residual stresses of the flattened specimen may result in an incorrect shape of the stress-strain curve and hence in a smaller value being measured for the yield strength. Also the variation in the deformation across the specimen cross-section may result in such differences between flattened and non-flattened specimens.

In this context, the method of determining the elongation in the tensile test on a flattened specimen, particularly the location of the extensometer on the specimen, plays an important role. The effect of reverse bending on the stress-strain curve is the smallest when the measurements are made with a double averaging extensometer on the neutral lines in the machined side faces (using pointed knife ends), or on the rolled faces, of the specimen. The effect of specimen flattening is expected to increase with the decreasing D/t ratio. The flattening operation on the strip specimen may result in a reduction of the yield strength in the case of expanded pipe because of the Bauschinger effect and in an increase of the Rt0.5 in the case of non-expanded pipe because of cyclic strengthening.

When machined transverse round bar specimens are used to determine the tensile properties, only a part, but not the full wall is sampled. On the other hand, the pipe material sampled is tested in its unchanged original condition, because the specimen is not subjected to flattening and hence additional cold deformation. The yield strength measured on such specimens may deviate from the integral yield strength of the full pipe wall thickness, if the yield strength across the pipe wall is not uniform. Material grade or the pipe forming operation may be the reason for the yield strength variation across the pipe wall. It is therefore essential to use a gauge cross-section as large as possible for the specimens. In this regard, use of specimens having a gauge diameter equal to about 2/3 pipe wall thickness is practicable in most cases and suitable to describe the actual pipe behaviour closely.

Additional factors that may have an effect on the tensile test results include the definition of the yield point (e.g. at 0.5 % total strain or 0.2 % proof stress), the rate of specimen stressing, specimen length as well as its gauge length and, in the

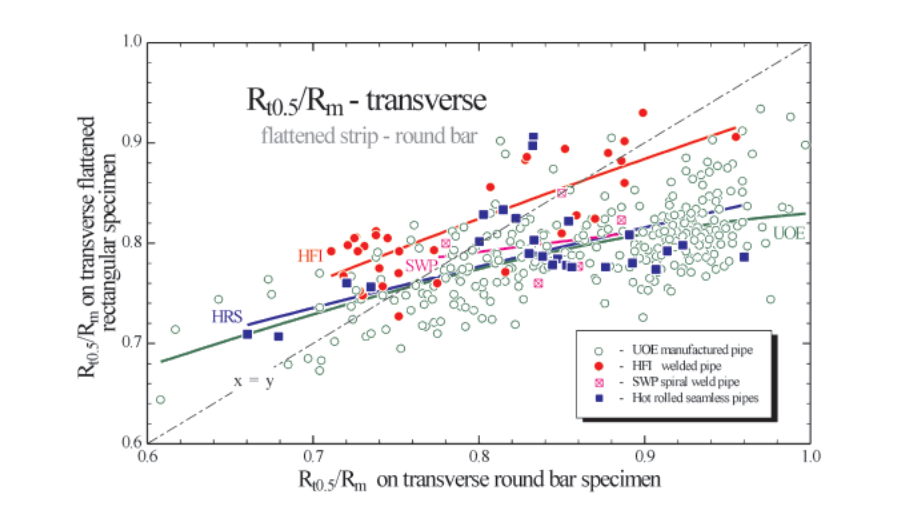

Fig. 3: Comparison of the yield-to-tensile ratios determined on transverse flattened rectangular specimens with those determined on transverse round bar specimens for different pipe types

Bild 3: Vergleich von Streckgrenzenverhältnissen aus Zugversuchen in Rohrumfangsrichtung an gerichteten Flachproben und Rundproben für Rohre verschiedener Herstellungsverfahren

case of rectangular strip specimens also the ratio of specimen width to specimen thickness.

Tensile test results obtained from round bar and strip specimens in the transverse direction

In **Figures 1-3**, the Rt0.5, Rm and Y/T values determined on flattened rectangular specimens are plotted against those determined on non-flattened transverse round bar specimens. The diagrams show the data points as well as the mean curves fitted to them by regression analyses, differentiating between the pipe types. When considering the scatter of the data, particularly the YS and Y/T values, it should be noted that the factors affecting tensile test results as discussed above, despite the different sources from which the data were received, result in noticeable scatter. The present data do not enable the effects of strain hardening, processing parameters, D/t ratio, method of specimen flattening and general test conditions to be separated from one another.

It can be seen in Figure 1 that the Rt0.5 data points for all the pipe types are scattered about the 1:1 line for YS values up to about 500 MPa. The range of the scatter is up to ±50 MPa. The deviation of the data points from the 1:1 line increases, as the yield strength increases above 500 MPa. In this regime, the values measured on the round bar specimens are consistently higher than those measured on flattened rectangular specimens. In contrast, no significant difference in the Rm values (Figure 2) is found between the two specimen types.

The scatter of the Y/T ratio data (Figure 3) is large, compared to that of the Rt0.5 values. This can be attributed to the fact that for a given Y/T ratio, data from pipes of different grades with pronounced differences in yield strength between the round bar and flattened rectangular specimens overlap. Despite this large scatter, clear trends can be noticed in the figures, namely that the Y/T values determined on the round bar specimens are larger than those determined on the transverse rectangular specimens and that the difference increases as the Y/T value increases. The mean curves (best fit curves) for the hot rolled, spiral weld and UOE pipes intersect the 1:1 line at a low Y/T value of 0.75 and the best fit curve for the HFI welded pipe intersects at 0.85.

Comparison of the tensile test results in the transverse direction with full-scale test results

From Figure 1 it can be seen that there is a significant difference in the measured yield strength between round bar and flattened rectangular specimens. The difference increases as the strength level increases. The question as to which of the two specimen types represent the pipe behaviour more closely can only be answered by a comparison of the tensile test results with the yielding behaviour of the full size pipe subjected to internal pressure.

The comparison of tensile test results with full-scale test results was made only for HFI welded and UOE pipe types, because no relevant data were available for the other pipe types. In **Figure 4**, the Rt0.5 values measured on transverse round bar and flattened rectangular tensile specimens are compared with the $\sigma_{vt0.5}$ values measured on pipes. The yield strength values measured on round bar specimens agree better with the pipe yield strength than those measured on

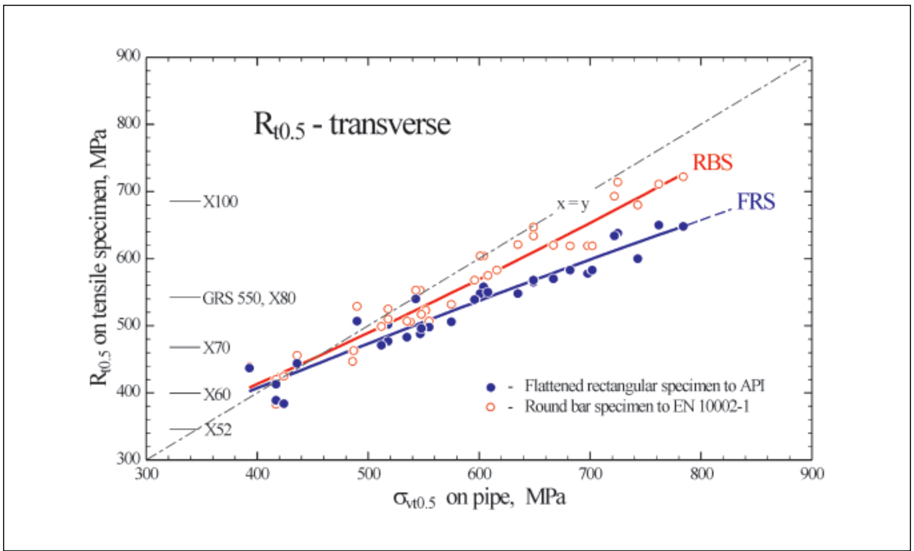

Fig. 4: Comparison of the yield strength values measured on transverse flattened rectangular and round bar specimens with yield strength values measured in burst tests on pipes

Bild 4: Vergleich der Dehngrenzenwerte aus Zugversuchen in Rohrumfangsrichtung an gerichteten Flachproben und Rundproben mit Dehngrenzenwerten aus Berstversuchen an Rohren flattened rectangular specimens do. Up to a specified minimum yield strength corresponding to that of grade X 70, the scatter bands of the results on both the tensile specimens overlap. The divergence between the two scatter bands increases as the strength increases. Similar trends can also be noticed for the corresponding Y/T values.

Longitudinal-To-Transverse Anisotropy

In the case of pipes with small diameters, extraction of standard size transverse specimens (both flattened rectangular and round bar) may not be practicable. Therefore, the pipe standards permit longitudinal specimens to be used for testing small diameter pipes. Furthermore, determination of longitudinal tensile properties is commonly specified for pipe intended for use in offshore applications.

Hot rolled seamless pipe can be presumed to be essentially isotropic with respect to YS and TS. Because of the effects of the plate rolling process and the pipe forming operations associated with the manufacturing of UOE pipe, the tensile strength values measured in the longitudinal direction are expected, in majority of the cases, to be lower than those measured in the transverse direction [9]. In the case of the HFI welded pipe, the sizing operation carried out after pipe forming and welding is anticipated to increase the YS, without altering, or only slightly reducing, the TS in the longitudinal direction

In **Figures 5-6**, the $R_{t0.5}$ and R_m values determined on longitudinal round bar specimens are plotted against those determined on transverse round bar specimens. The data on the seamless pipe are distributed about the 1:1 line, while the UOE pipe exhibits anisotropy with respect to yield strength. For this pipe type, the yield strength in the longitudinal direction is smaller than that in the transverse direction. The anisotropy increases as the yield strength increases. HFI welded pipe shows the opposite trend. Spiral weld pipe shows a tendency to slightly higher yield strength in the longitudinal direction than in the transverse direction. This trend is however vague because of the small database available for this pipe type. Dependent on the pipe type, little, or hardly any, anisotropy is noticeable in the Rm values (Figure 6).

The general trends for the Y/T ratio can be seen from the data points for the different pipe types included in Figure 6. While the seamless pipe is nearly isotropic with respect to the Y/T ratio, anisotropy is clearly noticeable with UOE and HFI welded pipes. In round bar tests, UOE pipe exhibits on average higher Y/T values in the transverse direction than in the longitudinal direction. The anisotropy increases as the Y/T ratio increases. HFI welded pipe tends to exhibit a higher Y/T ratio in the longitudinal direction than in the transverse direction, but the anisotropy disappears in the upper range of Y/T values.

The plots of the data determined on strip specimens in the longitudinal and transverse directions are shown in **Figures 7-8**. They are in general analogous to those made for the round bar specimens. But, it should be noted that unlike the longitudinal strip specimens, the transverse strip specimens are flattened. It is remarkable that the influence on $R_{t0.5}$ of the Bauschinger effect resulting from the flattening of the strip specimen is such that the experimental data become nearly uniform for all the pipe types. The large scatter of the data however suggests that anisotropy must be anticipated in the case of individual pipes, here also in the case of seamless pipe. As regards

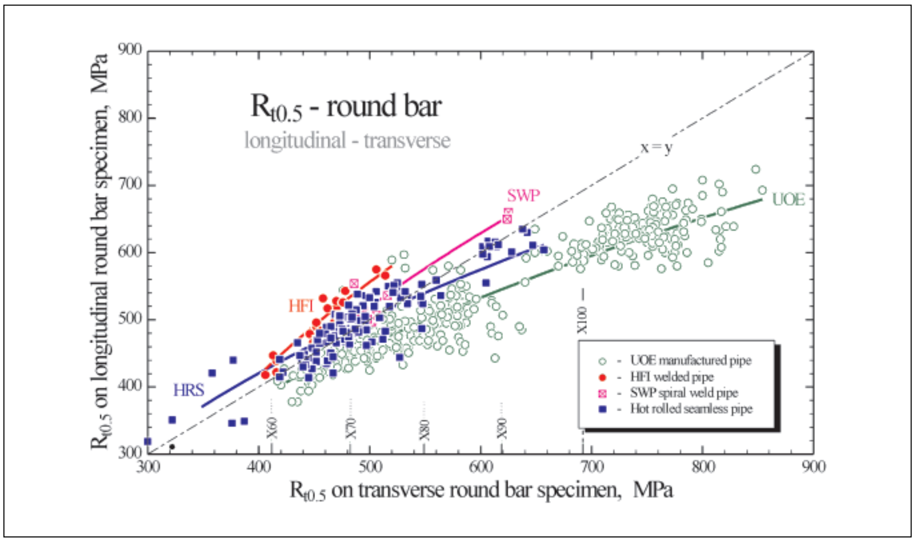

Fig. 5: Effect of strength level on the transverse-to-longitudinal anisotropy with respect to yield strength values as determined on round bar tensile specimens for different pipe types

Bild 5: Einfluss der Festigkeitsstufe auf die Längs-Quer-Anisotropie von Dehngrenzenwerten, ermittelt an Rundproben für Rohre verschiedener Herstellungsverfahren

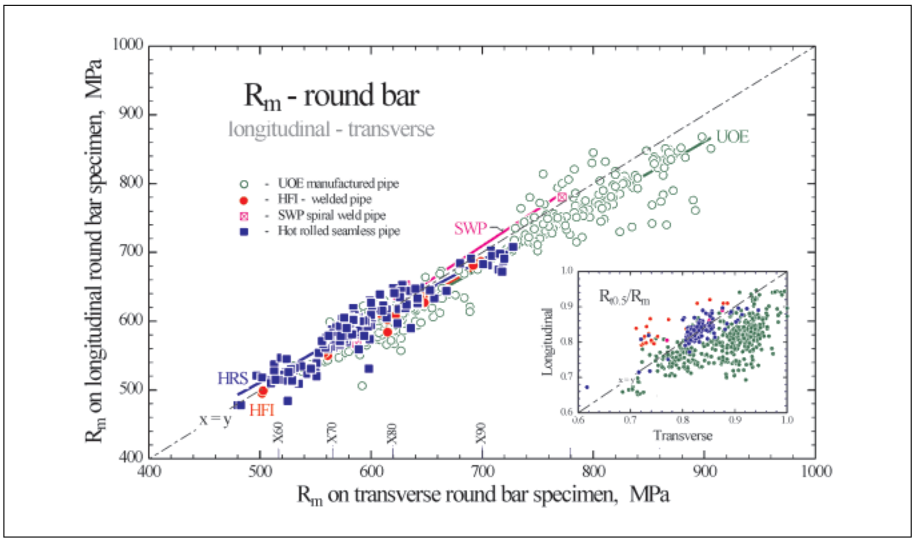

Fig. 6: Effect of strength level on the transverse-to-longitudinal anisotropy respect to tensile strength values, as determined on round bar tensile specimens for different pipe types (insert shows the corresponding plot of Y/T ratios)

Bild 6: Einfluss der Festigkeitsstufe auf die Längs-Quer-Anisotropie von Zugfestigkeitswerten, ermittelt an Rundproben für Rohre verschiedener Herstellungsverfahren (Eingeschobenes Diagramm gibt die entsprechenden Streckgrenzenverhältnisse wieder)

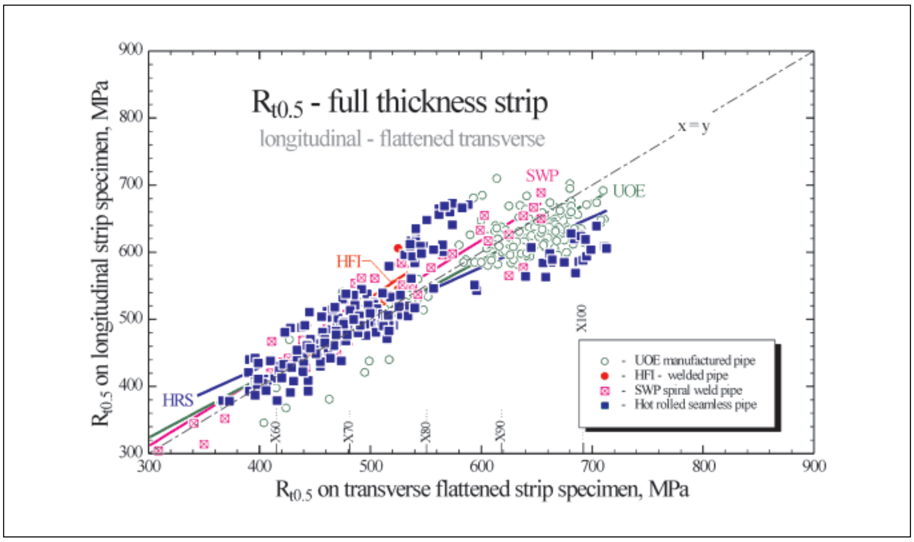

Fig. 7: Effect of strength level on the transverse-to-longitudinal anisotropy with respect to yield strength values, as determined on full size strip specimens for different pipe types

Bild 7: Einfluss der Festigkeitsstufe auf die Längs-Quer-Anisotropie von Dehngrenzenwerten, ermittelt an Flachproben für Rohre verschiedener Herstellungsverfahren

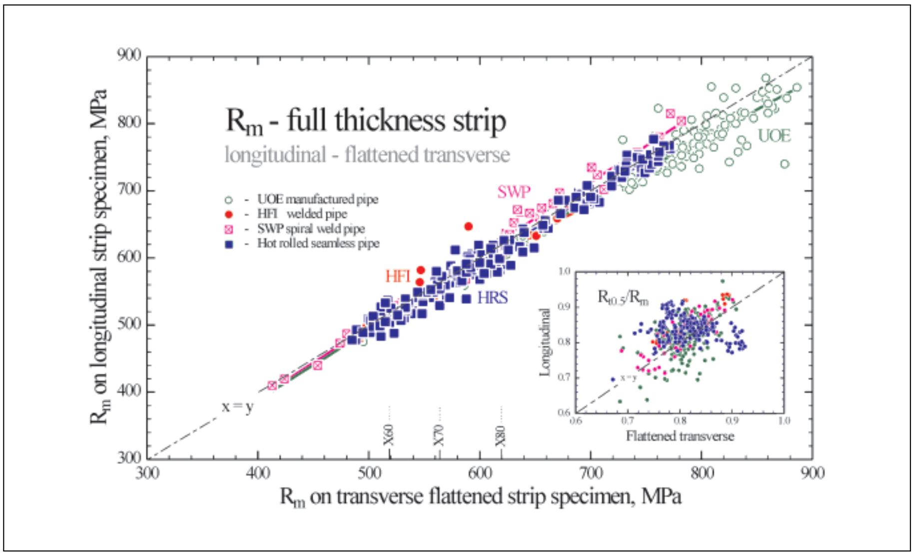

Fig. 8: Effect of strength level on the transverse-to-longitudinal anisotropy with respect to tensile strength values, as determined on full size strip specimens for different pipe types (insert shows the corresponding plot of Y/T ratios)

Bild 8: Einfluss der Festigkeitsstufe auf die Längs-Quer-Anisotropie von Zugfestigkeitswerten, ermittelt an Flachproben für Rohre verschiedener Herstellungsverfahren (Eingeschobenes Diagramm gibt die entsprechenden Streckgrenzenverhältnisse wieder)

the R_m data, there is hardly any difference between the flattened transverse strip specimen and the non-flattened longitudinal strip specimen for seamless pipe. However, for UOE pipe there is a trend towards lower R_m values in the longitudinal direction.

The plot of the Y/T ratios included in Figure 8 indicates that because of the large scatter only rough trends are noticeable which hardly allow any predictions to be made for individual cases.

Discussion

Tensile tests serve to verify the compliance of the pipe to design and product requirements for yield strength, tensile strength and yield-to-tensile ratio as well as for elongation. The objective of this verification is to ensure safe assessment of the integrity of the pipe under elastic and over-elastic loads. Compared to conventional pipeline designs, which are based on specified minimum values for yield strength and tensile strength, the determination, as closely as possible, of the behaviour of the full size component is gaining ever-increasing significance in modern designs, which are guided by the limit state design concepts. Besides this, objective determination of $R_{t0.5}$ and R_m is important in the context of field hydrotests, where the internal pressure applied to the pipe is close to the materials yield strength [10].

This report discusses the basic dependence of the yield and tensile strengths measured in tensile tests on the method of pipe manufacture, specimen type, specimen size, specimen orientation and the method of testing. The properties determined in tensile tests on flattened and non-flattened transverse specimens are compared with the corresponding properties determined in burst tests on pipes.

Product and design standards use the transverse yield strength (generally $R_{t0.5}$) as the most important quantity to characterise the strength of the pipe. From Figure 1, the mean difference in yield strength between transverse round bar and transverse flattened rectangular specimens can be seen for the different pipe types studied. In the yield strength range above about 500 MPa, the difference in the yield strength between the round bar specimen and the flattened rectangular specimen increases as the yield strength increases. This is particularly evident in the case of seamless pipe and the UOE pipe, where the difference in the yield strength is greater than 100 MPa for grades higher than X 90. As the comparison of the results on tensile specimens with the results of the burst tests on pipes shows, a round bar specimen sampling a sufficiently large portion of the pipe wall in its gauge diameter (e.g. equal to 2/3 pipe wall thickness) closely represents the behaviour of the pipe, particularly in a higher material grade.

Besides the type of specimen, the method of specimen flattening in the case of strip specimens, the remaining curvature and residual stresses of the specimen and the tensile test procedure, particularly the method of the measurement of elongation, may have a significant effect on the test results.

Further investigations directed to studying the effects of specimen flattening and D/T-ratio and to increasing the data base, particularly with regard to the comparison between tensile tests and the pipe behaviour would give more insight into the significance of tensile testing on linepipe.

Determination of the yield strength of the pipe material in a tensile test is of importance not only in the context of safe mechanical design of a pipeline, but also in the context of other tests performed to characterise the material of a pipe consignment. If for instance, in a stress corrosion cracking sensitivity test the level of the stress applied to the specimen shall be a certain percentage of the actual yield strength, but not of the specified minimum yield strength, a change in the type of the tensile specimen used to determine the yield strength in the tensile test would have an effect on the magnitude of the stress applied to the specimen. The resultant increase or decrease of the time to failure of the corrosion test specimen or threshold stress values would not mean any change in the corrosion resistance of the material.

The economic advantages or disadvantages of using the round bar tensile specimen or the flattened rectangular specimen are not discussed in this report. However, it appears that in the context of acceptance and production testing the flattened rectangular specimen is easy to produce and may be less expensive.

Conclusions

The results presented and discussed in this report do not imply that the current testing philosophy needs to be completely revised. Based on the results available for the UOE, HFI weld, spiral weld and seamless pipes, it can be said that for material grades up to X 70 the current practice of giving general preference to the flattened rectangular specimen in acceptance testing and using, where appropriate, the round bar specimen by agreement between the pipe manufacturer and the purchaser can be continued further.

For testing materials in grades higher than X 70, it is recommended that the specifications should prescribe the use of a transverse round bar specimen in order to determine the pipe properties correctly, except in individual cases where the use of flattened rectangular specimens is proven prudent. The gauge diameter of the round bar specimen should be as large as possible, e.g., equal to 2/3 pipe wall thickness. As the seamless pipe appears to be nearly isotropic with respect to yield and tensile strength, longitudinal strip specimens can be used to characterise its tensile properties.

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References

[1] www.eprg.net
[2] API SPEC 5L, Specification for Line Pipe, Forty-second edition, January 2000
[3] EN 10208-2:1998, Steel pipes for pipe lines for combustible fluids – Technical delivery conditions – Part 2: Pipes of requirement class B
[4] ISO 3183-2: 1996, Petroleum and natural gas industries - Steel pipe for pipelines – Technical delivery conditions, Part 2: Pipes of requirements class B
[5] DNV Offshore Standard OS-F101, Submarine pipeline systems, January 2000
[6] DIN 2413:1993, Stahlrohre; Berechnung der Wanddicke von Stahlrohren gegen Innendruck
[7] ASTM E 8: 1999, Standard test methods for tension testing of metallic materials
[8] EN 10002-1, Metallic materials, Tensile testing; Part 1: Method of test at ambient temperature
[9] Bai, Y, Knauf, G. Hillenbrand, H.-G., Materials and design of high strength pipelines, Tenth International Offshore and Polar Engineering Conference (2000), Vol. II, pp. 244-252
[10] VDTÜV-Merkblatt Rohrleitungen 1060: Richtlinien für die Durchführung des Streßtests, August 1977