Properties of Low Carbon Steel Sheets and Strip and Their Relationship to Formability – SAE J877

Handbook Supplement

PROPERTIES OF LOW CARBON STEEL SHEETS AND STRIP AND THEIR RELATIONSHIP TO FORMABILITY - SAE J877

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PROBLEMS ASSOCIATED WITH EVALUATION of formability or drawability of sheet steel have, for many years, received a great deal of attention and creative thought on the part of scientific metallurgists, sheet steel producers, and fabricators. By nature, these problems are complex and difficult to solve because of the number of involved variables.

In the mid-1930's, when drawability started to become an important factor in the performance of sheet steel, the tests available were Rockwell hardness, Olsen or Erichsen ductility, and standard tension tests. Investigators accumulated masses of data based on the available tests and had varying degrees of success in attempting to correlate them with the fabricating performance. Sheet processing at this time was not as sophisticated as we think it is today. Sheets were either hot rolled, normalized and second annealed, or cold reduced and box annealed. The metallurgists were further burdened with calibration of testing equipment and reproducibility of results on rimmed steel, a material of known nonuniformity.

As long ago as 1940 the AISI Technical Committee on Sheet Steel reviewed this problem extensively. The ASM Committee on formability of steel published the results of an excellent severity classification in Metal Progress in August of 1955 and has since produced sections in the 1961 edition of Metals Handbook on "The Selection of Low Carbon Steel Sheets for Deep Drawing," "The Selection of Low Carbon Steel Sheets for Formability," and "Low Carbon Steel Sheet." The last is replete with mechanical properties and their expected ranges for the various types and qualities of sheet steel.

TRADITIONAL MECHANICAL PROPERTIES

The mechanical properties of low carbon steel sheets are not accurately related to their performance in fabrication, and are not ordinarily used in specifications unless special strength properties are required in the fabricated product. As a matter of general interest, Fig. 1 (which is abstracted from "Low Carbon Steel Sheet") gives typical ranges of mechanical properties of sheets manufactured by three representative mills. With this amount of overlap in the bar charts, it is obviously difficult to separate even killed steel from rimmed steel on the basis of mechanical property data from a limited testing program. It will be noted that the ranges are broader for hot rolled sheets than for the more tailored cold rolled sheets and that cold rolled special killed has the narrowest range. It is true also that the range covered by each bar is considerably restricted by eliminating the effects of gage or thickness and segregation. In hot rolled sheets the heavier gages, that is 10 and 12 gage, will be considerably softer and more ductile than 16 gage. This is because the method of manufacture necessitates finishing and coiling at higher temperatures; hence, a tendency towards more complete annealing after coiling or piling. Likewise, cold rolled sheets in the heavier gages are softer than lighter gage sheets because, in general, they are cold reduced less before annealing.

In rimmed steel, to a large extent, and in killed steel, to a somewhat smaller degree, segregation plays a large part in the distribution curves or charts of mechanical test data when sampling is done at random. The metalloids - carbon, sulfur, and phosphorus - are the elements which are most prone to segregate in a rimmed steel ingot. These elements are from two to five times greater in the top center (core) of the ingot than they are in the skin material which solidifies first. The segregation of these elements causes increased hardness and strength and decreased ductility. For instance, in hot rolled sheets there may be as much as five, or even seven, points variation in Rockwell B from edge to center of a sheet taken from the top portion of the ingot and the same difference between center readings on sheets taken from the top and bottom of the same ingot. In cold rolled sheets this effect of segregation may amount to as much as twelve points Rockwell B. If we superimpose on these the effects of variation from heat to heat through chemistry and variations in finishing and annealing temperatures, it becomes obvious that the selection of the test specimen becomes very important.

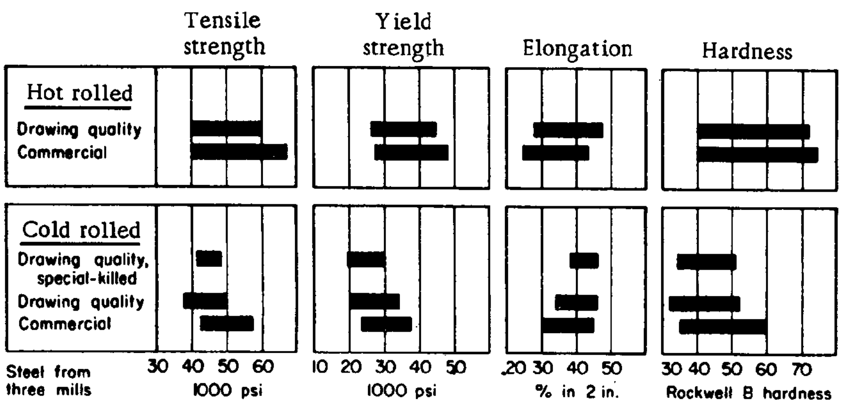

Fig. 1 - Typical range of mechanical properties of 1008 steel furnished by three mills. Hot rolled sheet thicknesses from 0.0958 to 0.1345 in. (16 to 10-gage inclusive); cold rolled from 0.029 to 0.059 in. (22 to 16-gage inclusive). All cold rolled grades include a temper pass. All grades rolled from rimmed steel except the one labelled special killed.

During the production of both hot rolled and cold rolled sheets, sampling procedures include prescribed test locations. This enables the steel producer to prejudge material with a greater degree of accuracy than can possibly be done with random sampling.

THE TEST SPECIMEN

The selection of the test specimen is as important as the test itself. The specimen should be as representative as possible of the sheet or lift. While it is not possible to establish precise sampling procedures because each situation is somewhat different from any other, some guides may be suggested:

1. Because the severe stretch or draw in a stamping usually takes place well in from the edge of the sheet, test specimens should be taken from the central three-fourths of the width.

2. Because segregation affects the properties in the center of the sheet and has no effect on the edges, any attempt to determine the range or distribution of properties throughout a lift or a coil should include specimens from the center of the sheet.

3. Because the ends of coils are usually not representative of the body, specimens should be taken only after uncoiling 50-100 ft. Coil ends in the hot rolled sheets cool faster after coiling than the center. In cold rolled sheets the outside laps during annealing may be as much as 100 F hotter than the balance of the coil. These conditions produce variations in addition to segregation.

STANDARD TESTS OF FORMABILITY

The Rockwell Hardness and the Olsen cup tests are usually the first, and frequently the only, mechanical tests made to indicate formability. These tests are not an exact measure of formability but they may serve as a guide and are useful for broad applications. In respect to these test values, 0.400 Olsen may be related to about 35-40 Rockwell B for a 20 gage sheet and these are indicative of good drawing quality. Likewise, 0.375 Olsen may be related to about 45-50 Rockwell B and average drawing quality and 0.360 Olsen and 55-60 Rockwell B indicate below average drawing quality or commercial quality level. These tests are easily and quickly made and require a minimum quantity of steel.

Olsen Cup Test - The Olsen cup test value recorded is the height of the cup in thousandths of an inch at the instant the punch load starts to drop. Load values are not otherwise significant. The higher cup draws usually indicate better ductility.

Some laboratories read the cup height at visible fracture which results in recorded values higher by 0.010-0.020 in. Those experienced in using this test can predict the approximate coarsening behavior of the steel after forming by examination of the sides of the cup. With ASTM grain sizes 8 and 9 the sides and top of the cup are smooth; with grain size 7 and larger there is moderate to heavy roughening which becomes progressively coarser as the grain size increases. Ridges across the top of an Olsen cup will indicate the presence of roller leveller or coil breaks previous to testing.

Directionality and brittle fracture may also be detected by examination of the cup fracture.

Rockwell Hardness Test - This test is used as one of the controls in sheet steel production and, as indicated previously, if testing position within the ingot is known, Rockwell hardness is a fairly good indicator of formability. This does not mean that we can set up rigid limits of inspection and rejection on the basis of Rockwell testing even with controlled testing positions, but it does provide the sheet producer with broad limits by which he may prejudge applicability for severe forming as compared to relatively simple forming applications.

There are some restrictions which must be adhered to if hardness testing is to be performed properly:

1. There are minimum thicknesses for various hardness levels which can be tested on the Rockwell B scale. Twenty gage (0.036 in.) can be tested on the B scale if it is no softer than B 40. Thinner and softer sheets must be tested on the F scale or even the proper T scale. These limits are well delineated in ASTM E 18-61T, Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials.

2. To secure the most accurate data for control or investigational work the surfaces of the sheet to be tested must be prepared by touching them to a 180 grit belt sander. Heavy or coarse surface texture (40 Mu in. or rougher) may produce hardness readings as much as 5 Rockwell B points lower than the true hardness of the sheet.

Tensile Tests - When properly interpreted, the full data obtained from properly prepared and performed tensile tests give a somewhat more accurate measure of formability, but even they must be considered inadequate when samples are taken without regard to the nonuniformity in properties across the width of a sheet or length of a coil.

Tension tests should be made on a standard 1/2 in. wide, 2 in. gage length (2-1/4 in. parallel section) specimen if elongation comparisons are to be made. The edges of the gage length should be carefully milled. Blanked or sheared specimens without proper preparation by machining give inaccurate results, particularly elongation and tensile strength. Both parallel milled and center-taper milled specimens are used. The center tapered specimen insures center breaks, but at a slight sacrifice in elongation compared to a parallel milled specimen. See ASTM E 8-61T, Methods of Tension Testing of Metallic Materials, Sections 5(b), 7, and 9(a).

Yield Point - The determination of the yield point is complicated by the variety of load-extension contours, which depend upon the condition of the steel and the conditions under which it is loaded. If the yield point is sharp and shows yield point elongation, the value recorded when testing cold rolled sheets is known as the lower yield point, and is the lowest stress reached during yield point extension. When tests are made against minimum specification values, the upper yield point is recorded. If the yield point is indefinite, as indicated by a smooth stress strain diagram, the yield point is recorded as the stress at 0.5% extension under load. The yield point is very significant. A low yield point is best if other properties are favorable and if it is not caused by abnormal grain growth. Steels with low yield point deform easily in compression; hence there is less tendency for buckles to form in tension-compression types of shell or cup drawing.

Tensile Strength - Tensile strength is recorded as the stress at the highest load reached during the tensile test.

Elastic Ratio - This is the yield point divided by the tensile strength and is an important consideration in severe stretching. The lower this value, the greater the spread between the yield point and the tensile strength. With low elastic ratios the sheet starts to deform at lower stress levels and continues to deform over a wider stress range. Steels with low elastic ratios stretch more evenly between moderately stressed and highly stressed areas of the stamping rather than by concentrating the stretch in the highly stressed areas.

Total Elongation - A direct measure of ductility in stretching and, therefore, the steel with high elongation will stretch farther before failure. As pointed out previously, if elongation values are to be compared, comparable specimen sizes and methods of sample preparation must be used.

Uniform Elongation - This is correlated closely and directly with the amount of deformation that can occur before localized necking beyond which point forming operations are not readily controllable. Even though uniform elongation is a unidirectional property, it is directly related to the amount of stretch possible in multidirectional stretch. Uniform elongation will vary between 20 and 28%; however, it is possible for sheets to stretch more than 40% in one direction in a biaxial stress field. This is because the tensile test specimen is not restrained and therefore it contracts laterally.

Yield Point Elongation - A direct measure of the depth or intensity of stretcher strains that will develop in lightly formed areas. Even a small amount of yield point elongation is undesirable in exposed parts and must be minimized by properly roller levelling immediately before drawing.

NEW TESTING METHODS

Recently, scientific experimenters have made significant progress in understanding the behavior of sheet metal in a drawing operation. They have even devised some new tests whose applications may reveal some of the specifics we need to know about formability and drawability.

Plastic strain ratio, work hardening exponent, anisotropy, stretch forming, and scribed square (see SAE J863, Method of Determining Plastic Deformation in Sheet Steel Stampings) are already becoming widely accepted terms describing some areas of drawability determination.

Plastic Strain Ratio, R - When a tensile test specimen from a sheet of ductile metal having isotropic mechanical properties is stretched 20%, the width will contract 10% and the thickness will also contract 10%. This is essentially true for a hot rolled or a normalized low carbon steel sheet. If the sheet has been cold reduced and annealed subcritically by conventional methods, it will have a certain degree of preferred crystallographic orientation, resulting in anisotropic mechanical properties. In this case the width contraction of the tension test specimen may be 12% and the thickness contraction 8%. Since the pastic strain ratio, R, is defined as the width strain divided by the thickness strain, R = 1.5 for cold reduced, annealed specimen and R = 1.0 for the normalized specimen.

In the case of an anisotropic sheet the direction of sampling for the tensile test specimen also influences the plastic strain ratio. The results for rimmed and aluminum killed steel sheets shown in Table 1, may be considered typical.

Aluminum killed steel sheets processed for flattened or "pancake" grain characteristically have higher R values in all test directions than rimmed steels. For both grades the maximum R normally occurs in the transverse direction and the minimum in the diagonal direction. As a class, the aluminum killed steels processed to obtain high average R values are capable of producing the most difficult stampings.

Work Hardening Exponent - One of the properties of ductile metals is to increase in hardness and strength as they are plastically deformed. This is demonstrated in a tension test in which the first sections of the test specimen are strengthened sufficiently to stretch plastically by work hardening to prevent further extension until all other sections are equally extended. Local necking begins when the work hardening rate is not great enough to compensate for the increased stress associated with the reduction in area of the cross section. A high work hardening rate is conducive to a high uniform elongation, and usually to a high total elongation. This characteristic is important in drawn parts in which the metal undergoes uniaxial or biaxial stretching.

Cup Drawing Tests - Olsen and Erichsen cup drawing or ductility tests take their place along with hardness tests among the "old-line" methods of evaluating drawing sheets.

Table 1 - Mechanical Properties and Characteristics of Hot Rolled and Cold Rolled Sheet Steel

Tension Test Specimen	R Value Angle with Direction of Rolling		
	0 deg	45 deg	90 deg
Rimmed steel, annealed	1.22	0.95	1.55
Aluminum killed, annealed	1.61	1.21	1.88
Rimmed or aluminum killed, normalized	0.92	0.95	0.98