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Investigation of the Drawability of Sheet Metals
(Measurements of r Values of Sheet Steel)

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For assessing the qualities of sheet metal for deep-drawing by the tension test, r value is adopted generally. However, it is difficult and complicated to obtain the precise value of it. In order to obtain the value precisely and easily, the authors have made trialy the devices to measure directly the elongation and the reductions of width and thickness; these devices are transducers to which the electrical resistance strain gauges are applied. By using these devices, precise, continuous, multipoint and quick measurement can be done. It has been clarified by the continuous measurements that r values are not the same relating to the elongations. It is recommended that one uses r value obtained at about 25% elongation.

§ 1. Introduction

For assessing the qualities of sheet metal for deep-drawing by the tension test, as the coefficient of plastic anisotropy, r value, which has been introduced by Lankford, is adopted generally, and defined as the following equation for a rectangular section test piece,

$$r = \ln\frac{W_0}{W}\Big/\ln\frac{T_0}{T} \tag{1}$$

where W_0 and T_0 are the initial values of width and thickness, W and T are the values after the deformation of width and thickness. It has been clarified by many investigations that r value is most suitable to assess the deep-drawing qualities of sheet metals. If r value of any sheet metal is large, the limit of deep-drawing is large. r values in any directions to rolling direction are not unique in a plane of sheet steel. This property depends on the anisotropy of metal crystal in any direction of the plane of sheet steel.

The precise measurement of r values of the sheet metals is considerably difficult, and the calculation is complicated to obtain the precise value of it. Moreover, according to increase of the elongation in tension test, r value varies considerably. Then, in order to decide the method to obtain the most suitable r value, many studies must be carried out. In order to make the measurement more easily and precisely, the authors have made some devices to measure the elongation, and the reductions of width and thickness, applying the electrical resistance strain gauges to them. The behavior of plastic deformation of the test piece is able to be shown continuously during the tension test by these devices with pen writing recorders. Above all, the values of the reductions of width and thickness have been able to be recorded continuously on the X-Y recorder, and r value is able to be obtained easily and precisely for all process of tension test, and the measurement has been extremely quick in comparison with the other methods which are proposed today.

§ 2. Consideration of error

In order to clarify how the errors of r values are not the same concerning with the shape of test piece and to the methods of measurements, the authors have carried out preliminary experiments, and have given the consideration of effects of measuring errors to r value. In the plastic deformation, the distributions of elongation, and the reductions of width and thickness are not uniform in the longitudinal direction, because the width of jawing portion is larger than the width of parallel portion of the test piece, and the plastic deformations of the parallel portion neighbouring the jawing portion are smaller than the deformation at the centre of test piece as shown in fig. 1. In this case elongation of gauge length 50 mm is 30 percent. The uniform deformation is located only within 20 mm at the centre, and deformations at outsides of this range are smaller than those at the centre. Macroscopically, the plastic deformation consists of two directional slip components, one gives the reduction of width and the other gives the reduction of thickness. The slip directions have an angle about 45 degrees to each direction of these deformations, which are the elongation and the reductions of width and thickness. Non uniformity of those deformation is owing to the width of jawing portion, since the slip producing the reduction of width is prevented by the effect of the width of jawing portion which is larger than the width of parallel portion. The schematic explanation is shown in Fig. 2. The right hand region from the line ***ab*** and the line ***cd*** is affected by the width of jawing portion, where ***a*** and ***c*** are the end of parallel portion. According to these phenomena, the measurements of those deformations must be made within the portion excluding the region which is affected by the jawing portion. Those phenomena were investigated by K. Yoshida and his co-workers[1]. The authors have used the shape of test piece as shown in Fig. 3, the length of parallel portion is 70 mm, and the gauge length of elongaton is 20 mm at the centre. It has been confirmed by our many experimental measurements that there is no effect by the width of jawing portion within ± 10 mm from the centre.

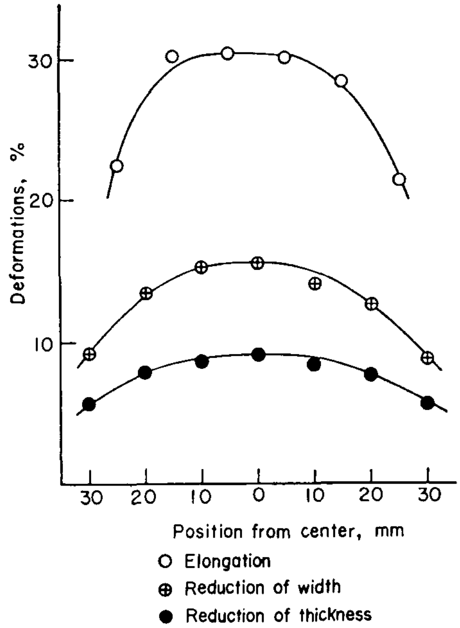

Fig. 1. Preliminary experimental results, 0.08% C steel

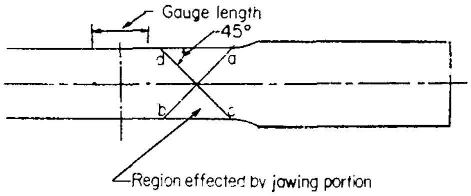

Fig. 2. Effect of jawing portion to the plastic deformation of parallel portion of the test piece.

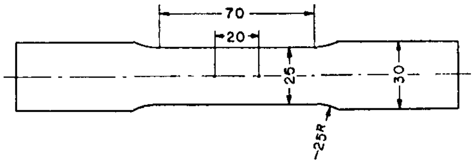

Fig. 3. Test piece.

Now let us consider the range of errors of r values induced by the errors of measurements of width and thickness. If the absolute errors of measurements of the width δ_W and the thickness δ_T are ± 0.01 mm and ± 0.002 mm respectively, when the width is measured with a micrometer which has 0.01 mm scale, and the thickness is measured with a point micrometer which has 0.001 mm scale, and the initial values of the width and the thickness are about 25 mm and 0.8 mm respectively, the dispersion of r values is shown in Table at various elongations. If more precise r values are necessary, for instance, the errors of r values are less than 5%, then the errors of the thickness measurements must be less than ± 0.001 mm. Those measurements are very difficult by using

Table. Dispersion of r values relating to measuring errors.

elongation / mean r value	15%	20%	25%
0.70	0.65～0.76	0.66～0.75	0.67～0.74
1.00	0.92～1.09	0.93～1.07	0.95～1.06
1.30	1.19～1.44	1.21～1.40	1.22～1.38
1.60	1.44～1.78	1.48～1.75	1.49～1.71

$W_0=25.0$ mm, $T_0=0.80$ mm, measuring errors $\delta_W=\pm 0.01$ mm, $\delta_T=\pm 0.002$ mm general tools, because the errors may be larger than ± 0.002 mm.

Let us assume that the volume of the specimen is invariable before and after deformation. Then r value can be obtained by the calculation with measurements of the elongation and the reduction of width of the test piece. In this case the calculating equation is written as follows,

$$r = \ln \frac{W_0}{W} \Big/ \ln \frac{WL}{W_0 L_0} \qquad (2)$$

where L_0 is the gauge length, and L is the length of it after deformation. However, this method is not so convenient, because the complication of precise measurement is not decreased, and the range of errors of r values obtained by this way is not smaller than that obtained with Eq. 1.

If there is one percent error of thickness, in the case where the variation of thickness is 0.1 mm, then the absolute error of measurement is ± 0.001 mm. Thus, by using general tools, such precise measurements are very difficult. However, if we use any devices which can measure only the varied value of deformation of the test piece, more precise measurement of r value can be done by using these devices. The authors have made trially the devices for such purposes.

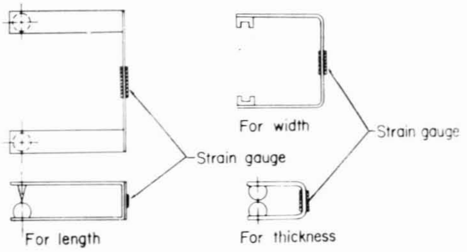

Fig. 4. Structure of the transducers.

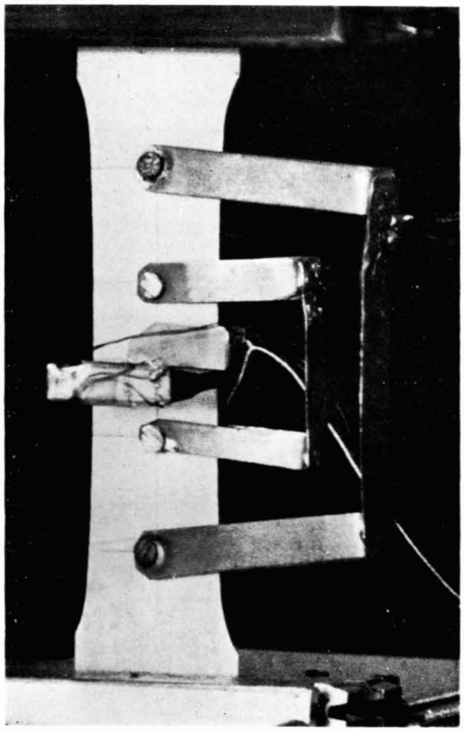

Fig. 5. Transducers set on test piece.

§ 3. Devices for Measurements

The authors have made the devices which can measure directly only the deformation of the test piece precisely and quickly. These devices are transducers which translate the variations as follows: the plastic deformation of test piece → the elastic deformation of transducers → the variation of electrical resistance of strain gauges. The linearity of the relation between the plastic strain and the variation of electrical resistance holds throughout considerably wide range of those variations. The elastic strain ranges of these transducers must be wide enough to measure large plastic deformations of the test pieces with high sensitivity, and a phosphor bronze plate has been used to meet the above demand. The shapes and structures of these transducers are shown in Fig. 4, and the photograph of them is shown in Fig. 5. The extensometer of the transducers has two pairs of a steel needle and a steel ball, and the needles are set in the small punched pits marked at gauge length of the test piece. The reduction-meter of the width has two channels at the holding points, and the channel bottoms are made as having some curvature, then the touch points never move during the tension test. The reduction-meter of thickness has one pair of steel balls at the touch point. This device must have high sensitivity, because the variation of thickness are very small in general cases. For this purpose this device has the property that the strain of the transducer at the strain gauge is very large in proportion to the variation of the distance of the steel balls. This can easily detect the thickness variation of about 0.0005 mm. The transducers for elongation and width have high precision, and their relative measuring errors are within the range of 0.5 percent. Those devices have many excellent properties as follows.

i) Very small, light, and robust

Those devices (the transducers) are smaller in comparison with the other devices which have the same purpose for the measurements. The weight of those devices is extremely small (about 2 or 3 grams) and they do not need any complicated attachments to be mounted on the test piece. Therefore, their structure is very simple and also robust. Treatment of them is easy and does not need care and special technique.

ii) Quick measurement

If all test pieces are made same size within an error range of one percent, one needs not measure each test piece before and after tension test. Because, those devices can measure directly only the deformations. If the measurements are carried out by using a pen writing recorder, the all data are able to be obtained from the recorded paper after the all tests. Therefore, the measurements can be carried out very quickly with those devices and instruments. Only 3 minutes is necessary for one test piece, this period is very short in comparison with the other measuring methods.

iii) Possibility of continuous measurement

Using pen writing recorders with those devices at the same time, the data of tension tests can be recorded continuously. Therefore,

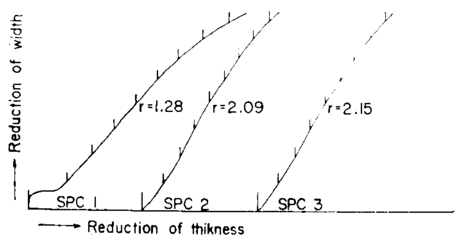

Fig. 6. Recorded patterns of the deformations of width and thickness on the X-Y recorder (90° to the direction of rolling).

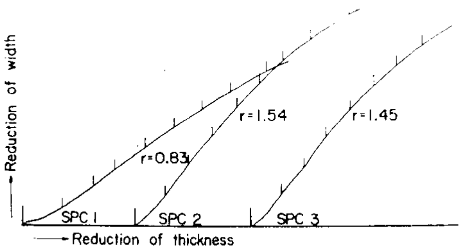

Fig. 7. Recorded patterns of the deformations of width and thickness on the X-Y recorder (45° to the direction of rolling).

it will be able to record the variation of the relative rate of the reductions of width and thickness accompanied with the increase of elongation. This behavior has been studied by the authors, and will be detailed later. Some of these graghs recorded by the X-Y recorder are shown in Fig. 6 and 7.

iv) Possibility of very preci e measu ement

Those devices are combined with the strain meter. Therefore, when amplification of strain meter is increased, those devices have very high sensitivity. For example, 0.01% strain can be detected by our devices. Applying the static strain meter, we can easily read within 0.1% of the value of those plastic deformation, *i. e*, if the plastic deformation is 0.1 mm, the variation of 0.0001 mm can be read out.

v) Posibility of multi point measuremetns at the same time

Those transducers are very small, and their structures are very simple. Therefore, several kinds of transducers can be mounted on a test piece. Consequently, some behaviors of deformations will be able to be observed by each kind of the transducer. For instance, the deformations of several points can be measured, and each kind of deformation can be measured at the same time, so on.

§ 4. Some Experimental Results and Consideration

The test pieces of those experiments were sheet metals of rimmed steel (SPC 1, 0.08% C steel) and killed steel (SPC 2 and 3, 0.03% C steel). The shape of the test piece is shown in Fig. 3. The tension test machine is shown in Fig. 8, it is a multi-testing machine which can load on test piece up to 5 tons with constant speed strain. It is named Autograph and has been made by Shimadzu Seisakusho Ltd. The test pieces have been elongated with constant speeds of 5 or 10 mm/min..

The authors have carried out the experiments of continuous measurements of r values of sheet steel with our devices made by the authors, accompanied with the X-Y recorder and the pen writing oscillograph. Fig. 6 and 7 show graphs of the relation between the reduction of thickness (x axis) and the reduction of width (y axis) on the X-Y recorder. The markers represent the time of 5, 10, 15, 20, 25, 30, 35 and 40 percent elongation of gauge length of 20 mm. The gradient of the curve shows the tendency of r

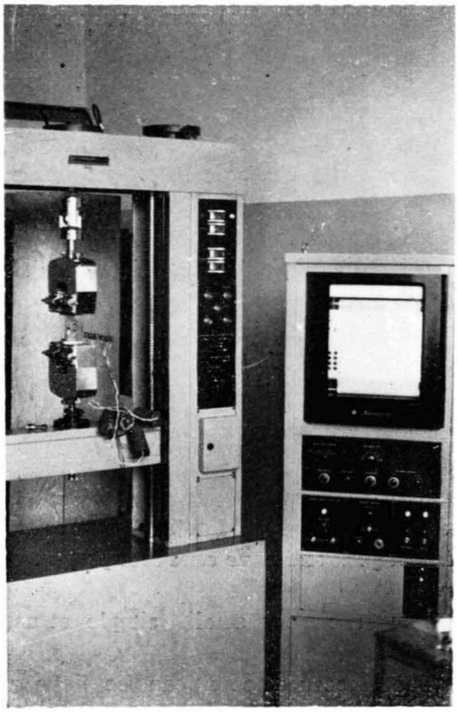

Fig. 8. Tension test machine.

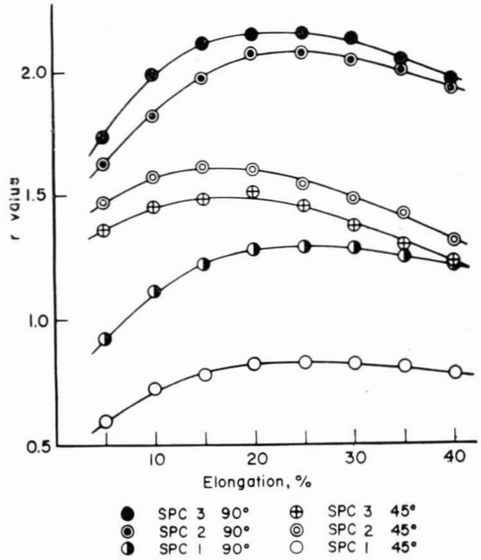

Fig. 9. Variation of r values with the process of elongation.

value of the test piece, *i.e.*, if the gradient is small, then the r value of the material is small. Namely, such material has the character that the reduction of width is small and the reduction of thickness is large.

We will remark on those recorded results. The curves of the materials of SPC 2 and 3 are smooth. However, the curves of SPC 1 materials (rimmed steel) are not smooth at the initial deformation, and show the step at the yield point elongation which appears generally in rimmed steel. As generally known, the yield point elongation does not occur on the whole area of the test piece at the same time. Moreover, the slip-bands are oblique to the tensile direction. Therefor, for that reason it can be explained that the recorded curves of SPC 1 materials have a step at the initial stage of tension tests.

r values of these materials have been obtained from the curves in Fig. 6 and 7 at each point of elongation, and they are shown in Fig. 9. It has been shown that all recorded curves have considerable curvature and these r values are not constant during the process of elongation. However, the rate of the variation of r values is minimum, and r values are maximum at the range from 20 to 25% elongation.

One must consider what is the most adequate r value corresponding to deep drawing limit, and many experiments must be carried out. Now the authors consider that the most desirable r values might be obtained at about 25% elongation, because the variations and the errors of r values are small in this range.

§ 5. Discussion

i) Those measurements are very quick and easy by using our devices. However, if the time is too long to prepare the test piece, the quickness of measurement is not so effective. The method of producing the test piece must be considered, for instance, the shape of test piece is recommended to be a rectangular in form made by a shear cutting machine. Then the time to prepare the test piece will be shortened. However, one must care that the cut work will effect to material quality of test piece.

ii) In order to do easily and quickly the calculation of r value from the data obtained by use of our devices, we translate Eq. 1 to approximated and simplified formula as follows,

$$r = \ln\left\{1 - \frac{\Delta W}{W_o}\right\} \Big/ \ln\left\{1 - \frac{\Delta T}{T_o}\right\}$$

where $\Delta W = W_o - W$ and $\Delta T = T_o - T$, and let us expand the terms of logarithm and adopt the first approximation, because in general case $\Delta W/W_0$ and $\Delta T/T_0$ are about 0.1, and the second order terms are very small.

$$r \doteq \frac{\Delta W}{W_0} \Big/ \frac{\Delta T}{T_0} = \frac{T_0}{W_0} \frac{\Delta W}{\Delta T} \tag{3}$$

where T_0/W_0 is constant if the test pieces are produced of the same size. Then the measurements may be only of the ratio $\Delta W/\Delta T$, which can be easily measured using our devices. By assuming that the width is 25 mm and the thickness is 0.80 mm, the ratio between ΔW and ΔT may be calculated corresponding to various r values. These calculated curves are shown in Fig. 10. When the recorded curves on the X-Y recorder are obtained, and if those calculated curves are superimposed on the recorded curves, r values can be obtained very easily without the calculation for each test. Consequently, the

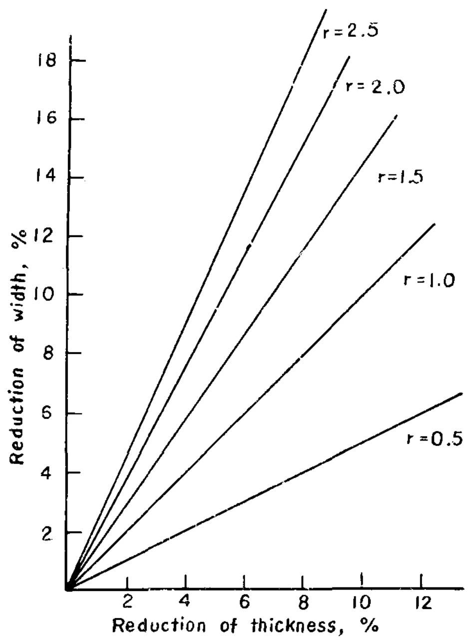

Fig. 10. Relation between the reduction of width and the reduction of thickness corresponding to r values.

tests of sheet metals become very easy and quick.

iii) The authors have carried out the continuous measurements with our devices and the X-Y recorder. Thus, they have clarified that r values vary with the process of elongation and also that the variations of r values, however, are small at the range from 20 to 25% elongations. Considering also the errors which have been discussed in section 2 of this report, it seems that it should be recommended to use r values at about 25% elongation.

§ 6. Summary

(I) The authors have made the devices to measure r value of sheet metal directly. Those devices adopted electrical resistance strain gauges, and have excellent properties as follows.

i) They are very small, simple structure and robust.

ii) The measurements can be done very quickly and easily.

iii) Continuous measurements can be done by using those devices and pen writing recorder or X-Y recorder.

iv) Mmulti-points measurements can be done with some kind of those transducers.

(II) From this investigation of measurements of r values, it has been clarified that r values are not constant relating to the elongation, and it is recommended that r value to be used is the value at about 25% elongation, because variation of r value is the smallest at this elongation.

Referance

1) S. Yoshida, & his co-workers: Scientific Papers of the Institute of Physical and Chemical Research, Vol. 58, No. 1, (1964) 1