Hardening in Deep Drawing.

W.C. Emmens
Corus RD&T, Ijmuiden Technology Centre, Packaging
P.O. Box 10.000, 1970 CA IJmuiden, Netherlands
☎ +31-251-494469, fax ...470344, ❯ wilko.emmens@corusgroup.com

ABSTRACT The change of the mechanical properties of steel sheet during deep drawing and wall ironing has been studied. The micro hardness has been measured on cross sections, this obeyed a single hardening law. Cups were deep drawn in two different ways but the same hardness was found for both, correcting previous results. In the sheet material a variation of the hardness over the sheet thickness has been observed, this seems to disappear after wall ironing.

Introduction

In the production of drawn and wall ironed beer and beverage cans the material is subjected to different forming operations. Firstly the material is deep drawn and then wall ironed. These forming operations harden the material, thereby limiting the formability of the can wall in successive operations such as necking, flanging and shaping.

In a previous report [1] the change of mechanical properties during deep drawing and wall ironing has been studied by determining the change in hardness and tensile strength. These two properties however showed different results, and in the deep draw operation an inconsistency was found. From this results it was concluded that the actual process of deep drawing might influence the mechanical properties of the final can wall, and consequently also the formability of the can wall (regardless of how that is defined). As this might have consequences for the can making industry the deep draw operation is analysed here in more detail.

Experimental Procedures

The initial aim was the produce a certain deep drawn cup in different ways and study the difference in hardness. Understandingly the selection is limited by the availability of suitable tools, so only the two ways presented in figure 1 were used. The two modes of operation are:

I. starting with a blank of 134 mm diameter: in one draw to a cup of 67½ mm diameter; this cup is reduced to a diameter of 66 mm by a singe redraw ring in the wall ironer (single draw mode).

II. starting with a blank of 136 mm: in one draw to a diameter of 90 mm, in a second draw to a diameter of 66 mm (redraw mode).

These two modes are being used in the daily practice of canmaking. For both modes intermediate stages were
produced as well, some are presented in figure 1. Additionally some final cups were wall ironed with a wall thickness reduction of about 50%. A top grade low-carbon steel with a thickness of 0.24 mm. has been used in the experiments.

Thickness and strain.

From the products selected for these tests small strips of approx. 1 cm wide have been cut very carefully, these are shown in figure 2.

Product ID was obtained by redrawing part IC in a simple redraw ring without blankholder. This produces only little plastic deformation in the wall, so that the remaining elastic stresses are relatively high. These remnant elastic stresses generate the curving of the sections of the wall as can be seen in figure 2. The two sections labelled ID are from cups made using redraw rings with slightly different geometry.

The major and minor strains have been plotted in figure 3. In this figure the major strain \( e_1 \) is defined in a direction on the product which was radial in the original blank, the minor strain \( e_2 \) is always tangential. From figure 3 it can be concluded that in all products the strain is concentrated around the \( e_1 = e_2 \) line. Deviations are at the edge of the product caused by thickening.

The total effective strain in the walls of the deep drawn cups is presented in figure 4. Here the positions in the wall are converted to the original position in the blank (defined as the distance to the blank centre). In this way this figure also presents the strain history of the material. The difference between the two methods becomes clear in this way. The two unlabelled intermediate stages presented in the right hand part of figure 2 are presented here as well.

Hardness

For the sections presented in figure 2 the hardness has been measured. This has been done by measuring the micro-hardness (micro-Vickers, 200 grf. load) on a polished cross-section in the centre of the material at intervals of 3 mm (the load was applied tangentially). Not all
cross-sections were measured completely, only the ‘unique’ parts, and these were combined to obtain the hardness distribution for the complete cross-sections. The results are presented in figure 5 where the two unlabelled intermediate stages mentioned before are presented as well. Please note the relative large amount of scatter in the data, which is quite normal for hardness measurements.

Figure 5 shows a strong similarity to figure 4 indicating that there is in general a good correlation between plastic strain and hardening. However there are some deviations. For example there is a difference in hardness between sections IC and ID at high positions (figure 5 left), but the strains are almost equal (figure 4 left). Contrary, for sections IIB and IID there is a large difference in strain (figure 4 right), but the hardness values at high positions are almost equal (figure 5 right).

Figure 6 shows a strong similarity to figure 4 indicating that there is in general a good correlation between plastic strain and hardening. However there are some deviations. For example there is a difference in hardness between sections IC and ID at high positions (figure 5 left), but the strains are almost equal (figure 4 left). Contrary, for sections IIB and IID there is a large difference in strain (figure 4 right), but the hardness values at high positions are almost equal (figure 5 right).

A better impression of the strain-hardness relation can be obtained by combining all results as in figure 6. This figure also contains results from previous tests; these will be discussed below. The results show that in view of the scatter in the data no significant difference is found between method I and method II. In fact all results form a single hardness-strain relation. For both methods wall ironed cans have been produced with a wall thickness reduction of approx. 50%. The hardness profile of one example of each has been measured, the results are presented in figure 7. Again no difference between the two methods is found.

Discussion of hardness results

We can now analyse the results obtained. The calculation of the deformation modes (figure 3) shows that for all products (including all intermediate stages!) the mode is deep draw, which means that $e_1 = -e_2$, or: there is no significant change in thickness. The only exception is the material near the edge which shows thickening.

If material is deformed in a single deformation mode ($=e_2/e_1$ ratio) then the hardening must follow the simple law expressed by the true-stress/true-strain curve. This we see in figure 6 were all results form a single curve, although with a considerable scatter. This scatter now may easily lead to false conclusions, because the scatter of results obtained within a single product seems much less. For example, if we had only the hardness profiles from sections ID and IID (see figure 6) one could easily conclude that there is a significant difference between the two production modes. But with all data available we now conclude that the results for sections ID and IID fall within the overall band of scatter, so that no difference is found.

Something similar occurred with the results from the previous tests, plotted as well in figure 6. These results are form the first draw and the second draw, very much comparable to sections IIB and IID in the recent tests. Unfortunately in the previous tests the scatter was higher in area of overlap (strain 0.2-0.4), and as the overall scatter in these results was quite low, it was suggested that there was a principle difference between the first and second draw. This false impression could easily be obtained because only smoothed curves were used in the analysis. With the data now available we know that that conclusion was wrong. Although the general level of hardness is approx. 10% higher than in the previous tests,
the results correlate satisfactorily with the recent results. The same holds for the hardness of the ironed walls: comparable products from the previous tests also showed 10% higher hardness level but otherwise a similar hardness distribution.

These results do not look very spectacular and confirm the general expectations. They are however important for the can manufacturer because they show that the properties of the final can wall are not influenced by the way the cups are made. Unfortunately at the same time they eliminate a possible way of influencing the formability of the can wall.

**Hardness variation over the thickness**

During deep drawing the material is bent and unbent over the die radius, for the redrawn parts of method II three times in total. During these bending operations the material near the sheet surface is deformed more than the material in the centre. This might cause a difference in hardness between the centre of the material and the surface. To check this the hardness has been measured on three positions over the sheet thickness at products ID and IID (see figure 2). In this case the hardness has been measured using a low load of 10 or 25 grf.

The results are shown in figure 8, where each data point is an average of five measurements. Please note that due to the lower load the hardness in the centre may differ somewhat from the values obtained with higher loads as presented in figures 5 and 6. Despite the scatter normally present in hardness measurements it is shown here that the hardness in the centre is lower than near the sheet surface. The values for product IID are somewhat higher that those for product ID due to differences in measuring procedure. The differences in hardness between centre and edge do not seem very high, but correlation with figure 7 shows that these differences correspond to a difference of 0.2 in equivalent strain.

![Figure 8](image8.png)

**Figure 8.** Hardness variation over the thickness, for products ID and IID. See figure 2 for the exact locations of measurement on the cup wall.

Surprisingly however, the results for undeformed sheet (which were actually taken from the bottom of some cups) show that this effect is already present before deep drawing and therefore must be caused by the rolling operation. A possible cause may be shear of the outer layers in rolling, and consequently, this effect of harder edges may be restricted to a narrow region.

The variation of the hardness over the thickness after wall ironing is presented in figure 9 in a similar way. At the bottom, where the amount of wall ironing was only very low, a difference between edge and centre can still be seen. But on other locations in the wall, where the reduction of wall thickness is about 50%, the hardness seems to be uniform over the thickness of the wall. Note however that due to the reduced thickness, the measuring locations ‘edge’ are relatively closer to the centre than in the deep drawn parts, so the harder area may just have been missed.

![Figure 9](image9.png)

**Figure 9.** Hardness variation over the thickness after wall ironing on three positions on the can wall.

Variations of (mechanical) material properties over the sheet thickness are generally neglected in sheet metal forming. In many forming operations only the mean properties are concerned and it is very difficult to measure variations over the thickness anyway. The results obtained here show that variations over the thickness exist and may be significant in situations where the deformation also varies over the thickness as in bending operations. It is not known if this phenomenon should concern us or not. Further research in this field is recommended because it may also be important for future sophisticated forming modelling, for example in the prediction of springback after bending.

**Conclusions**

- Hardness measurements may easily give a false impression of accuracy.
- The properties of can walls are not affected by the way the deep drawn cups are produced.
- In sheet steel the mechanical properties vary over the sheet thickness.

**Literature**