Addendum to "Study on Fracture Initiation in Normalized and Cold-Worked Mild Steels"*

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In the preceding study a certain extra-ordinary behaviours such as unstable ductile fracture were observed in the notched tensile test of mild steel cold rolled as heavily as 85%. In the present note the fracture behaviours were studied when the mild steel was cold rolled to intermediate degrees, in order to answer the question whether the extra-ordinary behaviour is brought about only through the change in plastic properties of the matrix due to cold working or by some other effects. The chemical composition and the geometry of test piece† are the same as those given in detail in the preceding paper*.

The test results are shown in Fig. 1 together with those of the normalized and 85% cold rolled mild steels reported earlier.

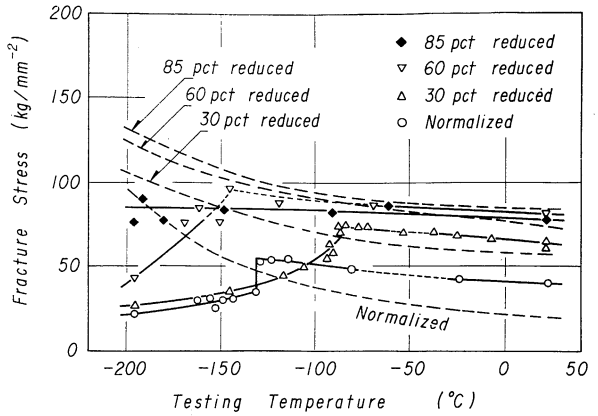

Fig. 1 Influence of the amount of cold work on the notched tensile properties of mild steel.
Broken lines indicate the corresponding lower yield stresses.
Transition in the fracture surface appearance took place in the temperature region indicated as dotted lines.

The results are summarized as follows.

(1) Fracture stress in the "low stress" fracture region is changed little by 30% cold reduction from that for the normalized mild steel, and noticeably increased by 60% reduction.

(2) Fracture stress transition temperature is raised considerably by 30% reduction††, but lowered by 60% reduction.

(3) At the transition temperature a discrete change is observed in the fracture stress and crack opening displacement†††.

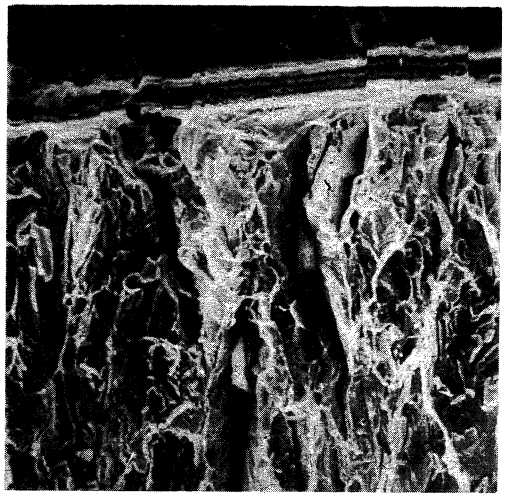

Photo. 1 Scanning electron microphotograph of the fracture surface of 60% cold-worked mild steel, tested in tension at temperature of −196°C and strain rate of $0.8\times10^{-4}\,sec^{-1}$, showing frequent delamination crackings due to triaxial tension at the notch root. (×300×⅔)

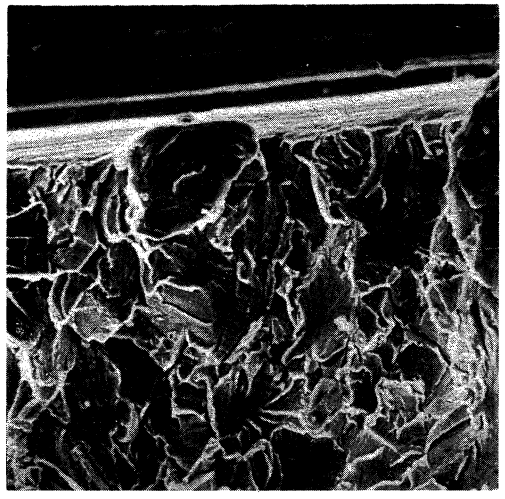

Photo. 2 Scanning electron microphotograph of the fracture surface at notch root of 30% cold-worked mild steel, tested in tension at temperature of −196°C and strain rate of $0.8\times10^{-4}\,sec^{-1}$, cited for comparison in frequency of delamination crackings with Photo. 1. (×300×⅔)

* M. Iino and H. Mimura : Trans. JIM, 11(1970), 3.

† C 0.19%, Si<0.5%, Mn 0.63%, S 0.023% and P 0.019%, specimen width 50 mm, thickness 3 mm, notch depth 10 mm and notch tip radius 0.1 mm.

†† This "embrittlement" brought about by the intermediate prestraining is, indeed, one of the main experimental results to be noted, which will be explained roughly by supposing that the transition in fracture stress takes place when the flow stress at and around the notch root is permitted to reach that for a large scale yielding, and also remembering the 30% cold work raised the latter considerably keeping substantially constant the stress for low stress fracture.

††† COD was measured using the clip gauge in the present work for the sake of easy performance. The phenomenon of this discrete change will be examined in the following paper.

In order to make clear how heavy cold work increases fracture stress, the fracture surface was examined under a scanning electron microscope. Considerably frequent delamination crackings were found at the notch tip of specimens cold rolled heavily i.e., 60% and 85%, in plain contrast with the 30% cold rolled specimen, which produced for less frequent ones (see Photo. 1 and Photo.2 for comparison).

It is to be inferred that these delamination crackings took place on tensile test loading and not in the cold rolling process, in view of the absence of delamination in the normalized specimen which was cold rolled by 85% prior to normalizing. It follows that the effect of cold rolling should be considered to come from two origins: intrinsic change in aggregate or matrix properties and delamination. The former is discussed in a previous paper*. Some characteristics of the experimental results can be explained in terms of the latter as follows.

It is generally accepted that brittle fracture stress increases as the plate thickness is decreased. A further decrease in plate thickness will introduce a change in fracture mode, i.e., from brittle to ductile. In ductile fracture, the K_c value is generally observed to decrease with decrease in plate thickness[1], and thinner plate is more apt to fracture in an unstable manner. It will be understood that the experimental results are well explained by replacing the expression "more heavily cold worked" by "thinner" in the above statement, and that the fracture behaviours of a specimen with delamination crackings can be considered to be similar to that of thinner plates.

In conclusion, the fracture behaviour of heavily cold rolled mild steel is controlled by delamination as well as by the intrinsic nature of cold rolled structure of the matrix or aggregate.

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(1) V. Weiss and S. Yukawa: ASTM Special Technical Publication No. 381, p. 8.