effectively vary the *pK* of these groups. Similar conclusions can be drawn from published data for nylon[3], and it is obvious that the above result has wide applicability.

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Recrystallization and the Ductility of Chromium

UNUSUAL features observed during work on the ductility of chromium were the difficulty of detecting the completion of recrystallization of cold-worked material and the sensitivity of the ductile/brittle transition temperature of recrystallized material to small amounts of deformation, either residual or imposed.

The transition temperature of cold-rolled chromium (0·002 wt.-per cent nitrogen, 0·01 wt.-per cent oxygen) increased from − 60° C. to 130° C. or 380° C. on annealing at 1,050° C. or 1,100° C. respectively. Both treatments appeared to give completely recrystallized material of similar grain-size as judged by microscopic and normal X-ray back-reflexion examination. A distinction between the two materials could, however, be made using the more sensitive micro-focus X-ray technique, which revealed that the specimens annealed at 1,050° C. were not free from strain while those annealed at 1,100° C. were. This apparent marked dependence of transition temperature on residual cold work could explain the comparatively low and variable increases in transition temperature (70–200° C.) recorded by other workers on recrystallizing cold-worked chromium[1,2], although nitrogen content might also be important in this regard.

The following experiments indicate the sensitivity of the ductile/brittle transition temperature of recrystallized chromium to small amounts of deformation and emphasize the value of the micro-focus technique. As noted previously, wrought chromium strip recrystallized by annealing at 1,100° C. for two hours had a transition temperature of 380° C. However, similar strip sheath-rolled in mild steel and given an identical thermal treatment in the sheath had a consistently low transition temperature around − 55° C. Three possible explanations of this effect were suggested : (1) brittleness of the vacuum-treated specimens was due to impurity pick-up which did not occur in sheathed specimens ; (2) heating-rate as well as cooling-rate could have been a factor as has been found with molybdenum[3] ; (3) the low transition temperature of sheathed specimens was a result of deformation of the specimen by the sheath during cooling due to differential thermal contraction.

Neither of the first two possibilities was particularly attractive, and each was readily disproved by experiment. To test the third possibility, a type of 'sandwich' specimen was used comprising a strip of chromium between two much thicker strips of mild steel, the whole assembly being sealed under argon in a close-fitting mild-steel capsule. In one set of specimens the chromium and mild-steel 'sandwich' components were welded together at their ends before being sealed into the capsule, while in the other set the ends were left free. After heating the capsules at 1,100° C. in air for 2 hr. and slow cooling, it was found that the chromium strips which had been forced to expand and contract with the mild steel during heating and cooling were ductile at 0° C. whereas the remainder were brittle. No deformation could be detected in any of these specimens by the normal X-ray back-reflexion method. However, the micro-focus technique showed evidence of plastic deformation ($\sim 0{\cdot}1$ per cent strain) in strips which had been welded to their mild-steel supports while none could be detected in unwelded specimens.

Brandes and co-workers[4] have reported that compacted flake chromium, extruded at 1,200° C. in a sheath, can show ductility in bending at − 30° C. even though the nitrogen content was as high as 0·091 wt.-per cent. X-ray diffraction photographs of the material showed full recrystallization. The above work would indicate that Brandes's result possibly arose because (*a*) the material was not in fact fully recrystallized or (*b*) deformation occurred during cooling after extrusion due to a sheath effect and that the X-ray technique used was not sufficiently sensitive to detect residual cold work arising from either of these possibilities. Another possible explanation is that it is understood that the practice in Brandes's work was to determine the lowest temperature at which deformation occurred by bending a single specimen at an elevated temperature initially and then at successively lower temperatures until finally it broke in a brittle manner. Other work[2,5] indicates that this is not a valid procedure if an accurate measure of transition temperature is required.

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Strain–Age Hardening and Brittleness in Chromium

CURRENT theories of the cause of brittleness in 'pure' chromium ascribe the phenomenon to Cottrell locking[1], invoking the Mott–Stroh[2,3] theory of crack formation as the operative mechanism of brittle fracture, and nitrogen as the associated interstitial solute atom. There are several features of the tensile behaviour of annealed chromium (containing approximately 0·002 per cent nitrogen and 0·015 per cent oxygen), however, which this picture does not wholly explain, namely : (1) the very high temperature up to which embrittlement extends (about 350° C.)