DISCUSSION

Ketil Videm[1] (*written discussion*)—Our experiments have shown an additional area of interest regarding the uniformity of the texture in pilgered Zircaloy cladding tubes. When the Q factor of the rolling step is above one, the "local Q factor" at the inner parts of the tube is higher than at the outer parts, leading to a somewhat higher tendency to radial basal pole orientation in the inner part of the tube. Since the metal has a tendency to flow out between the dies during pilgering, this might give rise to a nonuniform texture, if not taken correctly care of in the tool design. As a result of this edge effect each set of pilgering tools will have an optimum feeding rate, but the P factor is not altered by reasonable changes in feed rate.

F. C. Eddens[2] (*written discussion*)—Mr. Schemel has made it clear that investigators of texture in Zircaloy tubes must take into account the Q factor of the total tool profile used to produce the tube in order to properly describe the history of the specimen reported on.

The parameter which quantitates the relative states of strain in tube reduction known as Q has become well known and is used often in relation to texture discussions. There are various definitions of the value. Mr. Schemel has chosen the use of the midpoint diameter rather than the outside diameter or the inside diameter in his Q or P calculations.

Standardization is lacking and, what may be more important, there is a fundamental problem with the Q values as presently defined. This problem arises from the use of *percent reductions* in the calculations. What is intended is a measure of the biaxial state of *strain* in the deformed work piece. A ratio of the percent reduction of wall to percent reduction in diameter does not faithfully represent this value of the biaxial strain ratio. An example chosen to show the ambiguity of the existing Q definitions is as follows.

Compare Q of two reductions: (1) a 1.000 in. outside diameter tube with a 0.100 in. wall reduced to a 0.890 in. outside diameter tube with a 0.080 in. wall, and (2) a 1.000 in. outside diameter tube with a 0.100 in. wall reduced to a 0.670 in. outside diameter tube with a 0.040 in. wall.

[1]Institutt for Atomenergi, p.b. 175, 2007 Kjeller, Norway.
[2]General Electric Co., Wilmington, N.C. 28401.

Reduction No. 1 has a wall reduction of 20 percent and an average diameter reduction of 10 percent and hence a Q of 2. Reduction No. 2 has a wall reduction of 60 percent and an average diameter reduction of 30 percent and hence also a Q of 2.

It is apparent, however, by examining the two ratios of strain (either engineering strain or natural strain) that the two reductions are not alike and, for example, would not both belong in a single constant-Q tool design.

The apparent difficulty illustrated can be avoided by the use of ratios of natural strain in calculations of Q values. When this is done, the Q values resulting are independent of the total area percent reduction involved. Therefore, the Q value calculated between *any* two points in a pass reduction can be made equal.

The following definition of the Q of tube reductions is suggested for standardization and for reasons just illustrated.

$$Q\epsilon = \frac{\text{wall natural strain}}{\text{mean diameter natural strain}}$$

$$Q\epsilon = \frac{\ln \dfrac{\text{wall in}}{\text{wall out}}}{\ln \dfrac{\text{avg. diameter in}}{\text{avg. diameter out}}}$$

Using this definition and symbol, the $Q\epsilon$ for the illustrated pass No. 1 is 2.1 and for pass No. 2 is 2.6, showing the significant difference that does exist.

This method has been used with good analytical results both in comparing Q values of total tube reducer passes, and in plotting incremental values along tooling paths, similar to the author's work.