Scatter in Charpy Data Considered as a Transferrable Parameter

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Many users of steel have expressed a desire for guidance on characterizing the brittle fracture resistance of structural steels using Charpy V-notch (CVN) impact test data. CVN test specimens are smaller in size than most other fracture test specimens, have blunt notches rather than fatigue starter cracks, and are impact loaded rather than monotonically loaded as in most fracture mechanics-based test methods. These differences result in CVN tests being much less expensive with significantly less time required for specimen preparation and testing. This has led in part to CVN tests becoming the most widely used method for characterizing material toughness for many applications. However, these differences between CVN tests and other fracture mechanics-based test methods result in limitations of the usefulness of CVN data for performing fitness-for-service or remaining life calculations. To address this shortcoming, correlations between mean Charpy energy data and other fracture parameters at a given temperature have been widely used for at least 30 years. However, these correlations are known to have limitations, particularly for cases in which modern steels exhibit high upper shelf energy.

Scatter Assessment Method

EWI sought to find a method for taking several Charpy specimen results at different temperatures from a material and creating a transferrable parameter related to the scatter that can be common in toughness test data, particularly in the ductile-to-brittle transition regime. An example of two data sets with the kind of scatter of interest is shown in Figure 1. Orynyak et al.[1] had developed a method for use on nuclear pressure vessel steels that degrade in toughness due to radiation exposure.

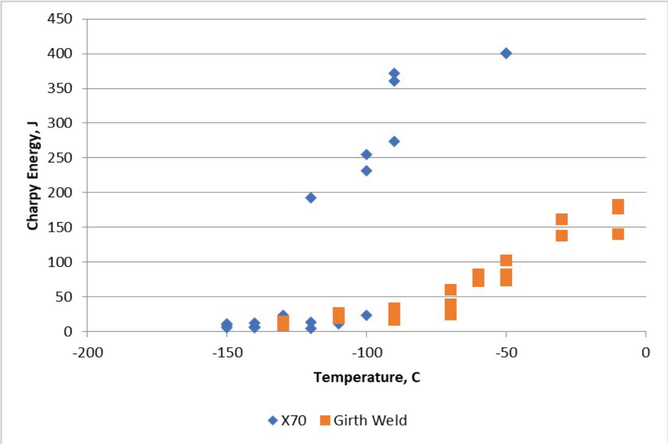

Figure 1: Example of two sets of CVN results showing different variability

This method calculates both an effective number of tests and a scatter parameter as a function of the Charpy energy at the transition temperature for a set of Charpy data. Several steps are involved. The first is fitting a hyperbolic tangent function to the experimental CVN energy versus temperature data set. This is the common way that a set of Charpy data is correlated to four variables of the fitting function. These four variables include the upper and lower shelf energy plateaus, the width of the transition regime in temperature, and the mid-transition temperature, typically based on the temperature that provides the mean absorbed energy between the upper and lower shelf energy levels. Next the same function is fitted to a modified data set where one of the data points is increased by a nominal amount, 1J. This is repeated iteratively for all the original data

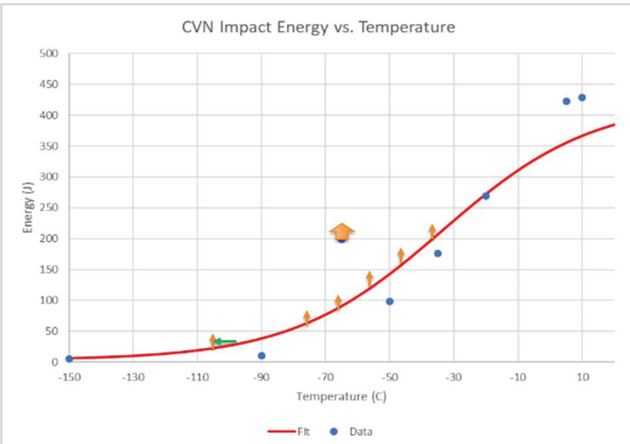

Figure 2: Schematic of the method where a single point at the large arrow is increased by 1J, causing the fitted red curve to move upward as shown by the smaller arrows including a shift in temperature at the transition shown by the green arrow

points. The amount that these new curves have shifted in temperature at the Charpy energy value chosen is shown in Figure 2. It is used to determine the scatter parameter. The effective number of tests shows how much of the shift is caused by individual shifted points.

EWI chose the common transition CVN absorbed energy for structural steels of 27J, which is specified as the minimum target absorbed energy in numerous industry standards. EWI examined four sets of its own experimental data that had at least ten individual CVN test records per data set along with data sets extracted from published literature to determine the amount of data needed to produce good statistical fits. The goal of this exercise was to get at least four or more datapoints, while also getting a good fit of the upper shelf energy using the hyperbolic tangent function. The results showed that eight to ten data points are needed, and these cannot be predominantly on the upper or lower shelves of the hyperbolic tangent curve fit. That is, at least three to four data points are needed in the transition region to produce a reasonable fit.

Application to Data Sets

EWI's data provided a range of scatter in temperature at the 27-J CVN criterion from 10.3°C to 23.3°C.[2] The lowest value was found on weld metal and an intermediate value was observed on the adjacent base metal of a weld typical in offshore pipelines. The higher values of scatter were found for weld and heat affected zone of a weld modeling large diameter on-shore pipe with 25 mm (1 inch) wall thickness. This variation in scatter between on-shore and off-shore pipe materials was not examined in this study but would be expected to be influenced by weld process variables and steel making practice and resulting chemical composition and microstructural texturing in parent pipe and weld regions.

The method was also applied to four pipeline steels tested by NIST[3] in three wall thicknesses, each with 11 or 12 data points. These results showed good correlation between the scatter parameters at different sizes for X52 and X100 pipe material, but no obvious correlation between the results for the X65 and X70 pipes with different size Charpy specimens (i.e. half-size versus full-size specimens).

Conclusion

EWI found that this data assessment method can be applied to a wider range of steels than had previously been shown, including structural pipeline and marine steels. Therefore, this approach offers a promising option for addressing scatter in CVN data and more reliably characterizing the ductile-to-brittle temperature transition behavior for structural steels.

To learn more about Charpy Data, please contact William Mohr at **bmohr@ewi.org**.

REFERENCES

[1] Orynyak, I. Zarazovskii, M. and Bogdan, A., 2013 “Determination of the Transition Temperature Scatter Using the Charpy Data Scatter,” ASME PVP Conference, PVP2013-97697.

[2] Mohr, W. and Birchfield, N., 2019, Scatter in Charpy Data Considered as A Transferrable Parameter, ASME OMAE2019, OMAE2019-96748

[3] Lucon, E. NIST Technical Note 1865, 2015, “Impact Characterization of Line Pipe Steels by Means of Standard, Sub-size and Miniaturized Charpy Specimens”.

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