DETERMINATION OF THE CHARACTERISTIC YIELD FORCE (F_{gy}) AND DISPLACEMENT (S_{gy}) FOR INSTRUMENTED MINI CHARPY-V SPECIMENS

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A method for the determination of the yield force (F_{gy}) is defined in Annex D of the TC5 Draft Standard for impact Testing of Sub-Sized Charpy Specimens. The procedure describes an iterative method for finding the elastic line (Hooke's line) from the oscillations in the initial part of the force-displacement curve. F_{gy} is then taken as the point of intersection of this line with a fitted line through the fully plastic range of the data. This allows the characteristic vales of force and displacement at general yield to be obtained in a consistent manner. This method is applied to data collected during Phase 1 of a Round Robin to validate the Proposed Standard. The resulting F_{gy} and S_{gy} values are compared directly with those values reported by the participating laboratories.

INTRODUCTION

The ESIS TC5 Technical Sub-Committee on Dynamic Testing at Intermediate Strain Rates has produced a document for instrumented impact testing of sub-size Charpy-V specimens (1). This has been prepared by the Working Party "European Standards on Instrumented Charpy Testing on Sub-Size Specimens", chaired by E. Lucon. This group has also carried out a Round-Robin exercise on specimens 3x4x27mm of ASTM A533B, Class1, JRQ monitoring material (2 and 3) with the aim of validating the Proposed Standard. Within the document (1) there are recommendations for the determination of characteristic values of force and displacement, including the force and displacement at the onset of general yield (F_{gy} and S_{gy}). A recommended procedure for the determination of the yield force is described in Annex D of the current version of the proposed Standard, but this was not included at the time the Round Robin was conducted. This meant that the various participants applied a range of methods to the data for evaluating the characteristic forces and displacement. The reported values of F_{gy} were obtained in various ways, some by "human eye" or fitting using commercial or home-written software routines. E. Lucon and other members of the Working Party supplied the raw data files for 16 of the 32 initial individual tests for which ASCII data files were available. These force-time data files which were obtained at various signal bandwidths and data sampling rates have been analysed using the recommended procedure laid down in the latest draft of the Proposed Standard (1). The force and displacement at general yield has been obtained using the recommended procedure and the results obtained then compared with the corresponding values reported by the participants of the Round Robin exercise.

The general difficulty with finding a yield force in bending is due to the variation in the amounts of yielded and elastic metal in the cross section. This results in a blurring of the

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yield point, as only a small volume of material at the surfaces of a specimen will be plastic initially whilst the central portion is still elastic. The plastic region grows towards the centre of the specimen as bending continues causing the yield force to be poorly defined. In dynamic loading this situation is complicated by the introduction of oscillations in the force record leading to increased difficulty in establishing a yield force. This is further complicated is the case of sub-size specimens by an increased amplitude of the oscillations in the force signal relative to the overall scale of the forces generated.

METHOD

The recommended method for finding F_{gy} in the Proposed Standard (1) attempts to numerically smooth the force-displacement data and then fit a straight line to this smoothed data to establish a Hooke's Line in the rising part of the force data. A value of general yield (F_{gy}) is taken as the point of intersection of the Hooke's Line with a line fitted through the oscillations of the force data in the fully plastic range. This method was proposed by Kalthoff (4) and is outlined in Annex D of the Proposed Standard (1) and is extended here to give the corresponding S_{gy} values..

The recommended method involved smoothing the force-displacement data by adjacent averaging, where the number of values averaged at each point was taken as the number of data points (N) in one period of oscillation (τ) of the force data. A linear regression line was then fitted through the smoothed data over an initial range from a point just beyond the inertia peak up to a force value of F_m /2. The correlation (R) of the initial linear regression line with the smoothed data was recorded and a second linear regression analysis carried out after increasing the upper limit of the analysis by one additional smoothed data point. Further linear regression analysis was performed iteratively in steps of one additional smoothed data point, with the data correlation value recorded at each iteration. This process was continued until the correlation coefficient reached a maximum value and the corresponding regression line taken as the 'Hooke's' line. The value of R increased as more smoothed data values within the rising part of the curve were included in progressive linear iterations up to R_{max}. At this point the linear regression line represents the best possible fit to the smoothed data and therefore the best representative Hooke's line. As further points in the flat, fully plastic range of the force data were included in the linear regression, the correlation coefficient dropped rapidly. The final Hooke's line should have its origin on the displacement axis within the inertia peak to be strictly valid. The Hooke's line was then taken as the slope of the linear regression line and the characteristic values of F_{gy} and S_{gy} taken at the point of intersection between the Hooke's line and a smoothed line fitted to the fully plastic range of the force data. There is no recommendation for the method of fitting this line, but in this analysis a 3rd order polynomial fit was used as this provided a good correlation to the plastic data and remained stable when extrapolated below the fully plastic range.

RESULTS AND DISCUSSION

Figure 1 shows results obtained from the application of the analysis procedure to the force-time data for one specimen to determine values of F_{gy} and S_{gy}. The Hooke's line and polynomial line are shown on the graph with the smoothed force data shown as a dotted line.

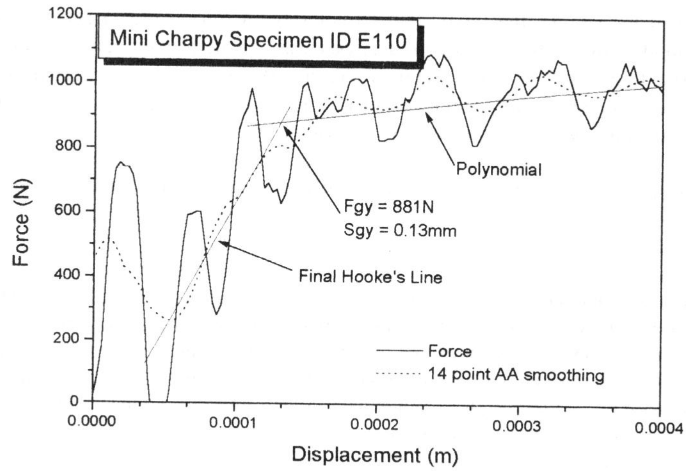

Figure 1. Typical Force-displacement graph showing the final Hooke's line.

Figure 2 shows the variation in the correlation coefficient, plotted against displacement for each linear regression iteration from the data. The correlation coefficient increases steadily with each regression iteration, reaching a maximum value just prior to a drop in slope of the linear regression line. This drop occurs when data from the fully plastic range is included in the regression analysis. In all the valid cases the correlation coefficient was found to increases progressively as more of the smoothed data points in the rising part of force are included in the regression analysis and decreases only when data from the fully plastic range is included.

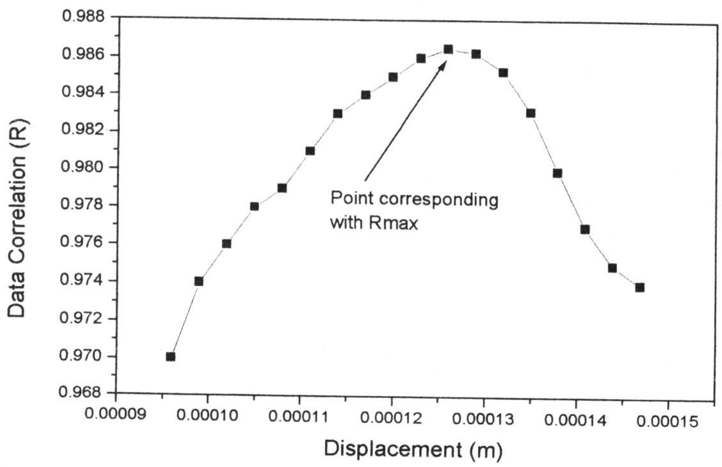

Figure 2. Regression iteration data from the force-displacement data in figure 1.

In some of the results, the force data did not show a typical inertia peak followed by rising oscillations. In these cases the analysis was not performed, as the data was not considered to be valid. It is important to note that the point on the displacement axis of figure 2 corresponding with the position of R_{max} represents the upper limit for the iterative analysis and does not correspond to the value of S_{gy}.

Table 1 shows all the values of F_{gy} obtained both from a) the values reported by the participating laboratories in the results of the Round Robin and b) the application of the analysis procedure in the Proposed Standard. The reported values of yield forces resulted in an overall average value for F_{gy} of 984N with a standard deviation of 40N. When the procedure was applied the overall average value for F_{gy} changed slightly to 967N with a standard deviation of 59N. The columns labelled Ave. and St.Dev. in Table 1 show the average values and standard deviations for the individual laboratories. It is interesting to compare the values obtained in this analysis with those reported by the laboratories. The recommended procedure resulted in an increase in standard deviations in three cases and a reduction in two cases (as only one set of data was available for lab.10 therefore the standard deviation will not change). The shaded values of Fgy indicate those cases where the origin of the final regression line failed to lie within the inertia peak. If these values of Fgy are excluded from the analysis there is a slight decrease in the standard deviations for each of these laboratories.

		Reported Value			**Analysis**			**N**	**Fm/2**
Lab	**ID**	**Fgy**	**Ave**	**St Dev**	**Fgy**	**Ave**	**St Dev**		
2	**3411**	1010			1017			6	650
2	**3421**	1010			998			3	650
2	**3431**	970	**997**	**23**	1016	**1010**	**11**	3	650
3	**E305**	960			1013			4	670
3	**E318**	990			1094			4	670
3	**E337**	940	**963**	**25**	931	**1013**	**82**	6	670
6	**FSO0001**	1000			953			6	675
6	**FSO0002**	1000			910			6	680
6	**FSO0003**	1000	**1000**	**0**	962	**942**	**28**	8	680
9	**E146**	1100			960			15	690
9	**E148**	1000	**1050**	**71**	1049	**1005**	**63**	17	660
10	**E209T**	968	**968**		928	**928**		120	625
11	**E096**	950			896			13	635
11	**E109**	950			924			13	650
11	**E110**	940			881			14	630
11	**E124**	960	**950**	**8**	933	**909**	**24**	22	635
Average		**984**			**967**			**16**	**658**
St Dev		**40**			**59**				

Table 1. F_{gy} and S_{gy} values obtained from the analysis and reported in the Round Robin.

The data in table highlights the difficulty in determining the value of N to be used in the analysis as the period of oscillation of the force measured experimentally does not remain completely constant. Having chosen a value for N, the smoothing effect varies in different parts of the data as the period of oscillation varies. This effect results in smoothing that is alternately poor and then betters throughout the data being smoothed. The number of data points (N) in one period of oscillation (τ) is used as the number of samples for averaging of the raw force data as proposed by Kalthoff (4). The number of points found in each case is given in Table 1 and is seen to vary significantly, ranging from 3 to 120. This was due to the variations in the data sampling rate used to record the force values, and will ensure that the degree of smoothing is the optimum for the data sampling rate employed. Increasing or decreasing the value of N from that in one period will impair the degree of smoothing. It is noticeable that in all the data analysed, the initial period of oscillation varies slightly from that subsequently, therefore the period must be measured within the elastic data to be smoothed if the smoothing is to be most effective. Even when this is done, the smoothing is usually slightly less effective just after the inertia peak due to the variation in period observed in the force data.

Table 2 shows all the values of S_{gy} obtained both from a) the values reported by the participating laboratories in the results of the Round Robin and b) the application of the analysis procedure in the Proposed Standard. The reported values of displacement at yield resulted in an overall average value for S_{gy} of 0.179mm with a standard deviation of 0.04mm. When the procedure was applied the overall average value for S_{gy} changed slightly to 0.156mm with a standard deviation of 0.026mm.

		Reported Value			Analysis		
Lab	**ID**	**Sgy**	**Ave**	**St Dev**	**Sgy**	**Ave**	**St Dev**
2	**3411**	0.14			0.2		
2	**3421**	0.16			0.12		
2	**3431**	0.14	**0.147**	**0.012**	0.16	**0.16**	**0.04**
3	**E305**	0.2			0.16		
3	**E318**	0.18			0.2		
3	**E337**	0.19	**0.19**	**0.01**	0.17	**0.177**	**0.021**
6	**FSO0001**	0.23			0.13		
6	**FSO0002**	0.24			0.14		
6	**FSO0003**	0.23	**0.233**	**0.006**	0.15	**0.14**	**0.01**
9	**E146**	0.14			0.14		
9	**E148**	0.14	**0.14**	**0**	0.18	**0.16**	**0.028**
10	**E209T**	0.23	**0.23**		0.12	**0.12**	
11	**E096**	0.21			0.16		
11	**E109**	0.16			0.16		
11	**E110**	0.14			0.13		
11	**E124**	0.13	**0.16**	**0.036**	0.18	**0.158**	**0.021**
Average		**0.179**			**0.156**		
St Dev		**0.04**			**0.026**		

Table 2. S_{gy} values obtained from the analysis and reported in the Round Robin.

The columns labelled Ave. and St.Dev. in Table 2 again show the average values and standard deviations for the individual laboratories. Again we can compare the values obtained in this analysis with those reported by the laboratories. The recommended procedure resulted in an increase in standard deviations in four cases and a reduction in only one case. The shaded values of Fgy indicate those cases where the origin of the final regression line failed to lie within the inertia peak. If these values of Fgy are excluded from the analysis there is a slight decrease in the standard deviations for two of these laboratories and a slight increase in one.

The procedure for finding F_{gy} was not found to be either consistently higher or lower than those values reported by the participating laboratories, probably due to the differences in the methods used to determine F_{gy} in each case. The procedure applied to finding S_{gy} was also not found to be either consistently higher or lower than those values reported by the participating laboratories. The values of F_{gy} will be most strongly influenced by the method used to fit a line through the fully plastic part of the data. This is because of the relatively shallow slope of the polynomial line fitted through the fully plastic range of the data. Clearly the values of S_{gy} will be most strongly affected by the slope of the Hooke's line.

CONCLUSIONS

- The method recommended in the Proposed Standard Method for Instrumented Impact Testing of Sub-Size Charpy-V Specimens of Metallic Materials, Draft 5 has been successfully applied to the force-time data to produce an elastic line in the rising part of the smoothed force data from which values of the general yield force (F_{gy}) and displacement (S_{gy}) have been obtained.
- Application of the procedure was successful in most of the cases examined including those where oscillations in the force-time data was excessive and cases where the signal bandwidth was below that normally required. But not in cases where no inertia peak was present.
- The period of oscillation of the force-time curve (τ) must be measured within the rising elastic part of the force-time data if the adjacent average smoothing is to be effective.

REFERENCES

1. ESIS-TC5, "Proposed Standard Method for Instrumented Impact Testing of Sub-Size Charpy-V Specimens of Metallic Materials", Draft 5, Aug. 1996.
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