Journal of Testing and Evaluation, Vol. 37, No. 1
Paper ID JTE102094
Available online at: www.astm.org

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Instrumented Impact Tests: Effects of Machine Variables and Specimen Position

ABSTRACT: An investigation has been conducted on the influence of impact machine variables and specimen positioning on characteristic forces and absorbed energies from instrumented Charpy tests. Brittle and ductile fracture behavior has been investigated by testing NIST reference samples of low-, high-, and super-high-energy levels. Test machine variables included tightness of foundation, anvil and striker bolts, and the position of the center of percussion with respect to the center of strike. For specimen positioning, we tested samples that had been moved away or sideways with respect to the anvils. In order to assess the influence of the various factors, we compared mean values in the reference ("unaltered") and "altered" conditions; for machine variables, *t*-test analyses were also performed in order to evaluate the statistical significance of the observed differences. Our results indicate that the only circumstance which resulted in variations larger than 5 % for both brittle and ductile specimens is when the sample is not in contact with the anvils. This should be taken into account in future revisions of instrumented Charpy test standards.

KEYWORDS: instrumented Charpy tests, impact machine variables, specimen position, *t*-test analysis

Introduction

Impact testing has a history extending back to the 1850s [1], when engineers realized that the loading rate can significantly affect material properties. For structural steels, the main result of increasing the loading rate is to raise the yield and tensile strength, which in turn causes a decrease in impact energy needed for cleavage fracture, an increase in energy needed for ductile fracture and a shift in the ductile-to-brittle transition temperature. The loading rate must therefore be considered when designing structures subjected to dynamic loading, such as buildings in earthquakes, ships and overland vehicles in collisions, aircraft landing gear, and, at the highest rates, structures subjected to ballistic projectiles and explosive shocks.

The conventional, noninstrumented Charpy test, which has recently celebrated its official centennial [2,3], can provide useful comparative information, but generally cannot offer any detailed insight into the failure mechanisms or yield quantifiable material properties. This is also true for some other impact test methods, such as the Pellini drop-weight or the Izod pendulum test.

Instrumenting the machine striker in order to measure and record the force applied to the notched sample during impact gives a much clearer picture of the events occurring, providing additional insight on the behavior of material under impact loading. Instrumented Charpy tests are currently regulated by test standard ISO 14556 [4], while standardization is also in progress within ASTM [5].

For fracture mechanics-based structural integrity evaluations, using fatigue precracked Charpy specimens is particularly useful. At the time of writing, ISO and ASTM standardization of fracture toughness tests at impact loading rates is ongoing [6,7].

In the nuclear field, the effects of neutron exposure on the fracture properties of the reactor pressure vessel can be assessed more reliably by using the results of instrumented Charpy tests than by applying the current regulatory practice, which relies on an empirical correlation between fracture toughness and the temperature corresponding to a fixed Charpy energy level (41 J). This is done in the framework of the so-called enhanced surveillance approach [8–11], which includes the determination of characteristic force values from instrumented Charpy tests and the derivation of alternative index temperatures [12,13].

Numerous studies have been conducted in the past [14–17] in order to investigate the experimental factors, related to both the machine and the specimen, which can affect the results of a Charpy test in terms of absorbed energy, as provided by the machine dial or the optical encoder (dial energy, KV). In this study, we have examined the influence of some of these machine/specimen variables on the results of instrumented Charpy tests, namely in terms of characteristic forces at general yield (F_{gy}), maximum forces (F_m), and absorbed energies calculated from the instrumented test record (W_t). KV values have been also included in the analyses.[3]

From the test machine point of view, we focused our attention on the bolts that connect the pendulum to its foundation and those that hold the anvils and the instrumented striker in place. Tests were run with the bolts partially loose (anvil, striker) or completely loose (foundation), and the results were compared to data obtained with all the bolts tightened to the manufacturer's specifications. Additionally, the center of percussion (COP) was moved away from the center of strike (COS) by adding weights to the pendulum hammer.

As far as specimen positioning is concerned, we investigated the effects of a lateral offset with respect to the centered position of the notch between the anvils and of a gap between the sample and the anvils. Again, results were compared to those obtained under ideal conditions (i.e., specimen centered and flush against the anvils).

The ultimate goal of this investigation was to find out whether, with respect to the "conventional" dial energy KV, instrumented Charpy forces and energies are less, more or equally sensitive to

Manuscript received August 25, 2008; accepted for publication October 10, 2008; published online November 2008.

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[3]Note that F_{gy} values were not considered in the case of low energy specimens, since the general yield does not occur or cannot be unambiguously defined in case of fully brittle behavior.

TABLE 1—*Overall test matrix.*

Variable considered	Low energy RT	Low energy −40°C	High energy	Super-high energy
Reference tests	5	5	5	5
Loose foundation bolts	5	5	5	5
Loose anvil bolts	5	⋯	6	⋯
Loose striker bolts	5	⋯	5	⋯
COP position changed	7	⋯	5	⋯
Lateral specimen offset	9	⋯	9	⋯
Specimen/anvils distance	8	⋯	8	⋯
TOTAL	44	10	43	10

experimental variations that could eventually occur during Charpy tests.

Material and Experimental

NIST certified impact verification specimens of different energy levels were used in this study. For all investigated variables, low (∼15 J) and high- (∼100 J) energy specimens were used; super-high-energy (∼240 J) samples were tested only when looking at the effect of foundation bolts.

Tests were performed on an instrumented Tinius–Olsen model 84 pendulum with 407.6 J capacity, located at NIST in Boulder, CO.[4] The instrumented striker conforms to the requirements of ASTM E23 (i.e., 8 mm radius of the striking edge).

Tests were conducted at room temperature (RT) (∼21°C), in order to avoid issues related to temperature control. However, when investigating the effect of loosening the foundation bolts, an additional set of low-energy specimens was tested at −40°C. This is the temperature prescribed by ASTM E23 for both low- and high-energy specimens, when tested for the verification of impact test machines.

The overall test matrix is given in Table 1. In the reference condition (i.e., with the machine fully compliant to ASTM E23), sets of five specimens were tested for each energy level, except for the low-energy samples where two sets were tested (one at RT and one at −40°C). Five to seven specimens per energy level and per condition were tested when investigating the influence of bolt loosening and center of percussion. Eight or nine tests per energy level were conducted to evaluate specimen positioning effects.

Loosening Machine Bolts

ASTM E23 requires the impact machine to be securely bolted to a concrete floor at least 150 mm thick or to a foundation having a mass at least 40 times that of the pendulum. The direct verification for parts requiring annual inspection includes ensuring that the foundation bolts and the bolts that attach the anvils and striker to the machine are tightened to the manufacturer's specifications.

Foundation Bolts

The machine used in this study is bolted to a concrete foundation having a mass of approximately 1500 kg, over 50 times that of the pendulum. The *T* bolts securing the machine to the foundation are tightened to a torque value of 515 J (380 ft·lb), which is higher than the manufacturer's specification.

Charpy tests on low, high, and super-high-energy specimens were performed with the foundation bolts completely loose. This is obviously an extreme situation which is unlikely to occur in real life.

The results (instrumented forces, instrumented absorbed energy, and dial energy) and the comparison with reference data are shown in Table 2.

Note that, in the case of the super-high-energy specimens, the acquisition time used was too short and the tails of the instrumented curves were truncated. As a consequence, W_t values cannot be considered reliable and are therefore reported in italics; however, the comparison with the reference condition remains meaningful.

It is interesting to note that, for the super-high-energy specimens, the test machine would fulfill the ASTM E23 indirect verification criteria even with the foundation completely unbolted. Coincidentally, the low-energy level at −40°C would fail the indirect verification in the reference condition but would pass with the foundation bolts completely loose. In this particular case, the absorbed energy is slightly decreased for the unbolted condition. This is contrary to what might be expected, but the scatter for the unbolted result is significantly higher than for the bolted condition.

Anvil Bolts

The torque applied to the anvil bolts for the baseline condition is 36.6 J (27 ft·lb), as specified by the manufacturer. The bolts were loosened down to 2.8 J (25 in.·lb), to a condition that might be described as "finger-tight."

Five tests on low-energy specimens and five tests on high-energy specimens were performed at RT with loosened anvils bolts and the results compared to the baseline data (Table 3).

It is noted that F_m increases for the low-energy specimens and decreases for the high-energy specimens.

Striker Bolts

The bolts holding the instrumented striker in place were loosened from the manufacture specification of 74.6 J (55 ft·lb) to 4.5 J (40 in.·lb) which again might be described as finger-tight.

Five tests on low-energy specimens and five tests on high-energy specimens were performed at RT with loosened striker bolts and the results compared to the baseline data (Table 4).

In comparison with foundation and anvil bolts, loosening the striker bolts seemed to have somewhat more detectable effects, particularly for the low-energy specimens.

Changing the Position of the COP

The COP of an object is defined as the point where a perpendicular impact will produce translational and rotational forces which perfectly cancel each other out at some given pivot point, so that the pivot will not be moving momentarily after the impulse. Centers of percussion are often discussed in the context of a bat, racquet, sword, or other long thin objects. For such objects, the COP may or may not be the "sweet spot" depending on the pivot point chosen.

ASTM E23 requires the COP of the pendulum hammer to be within 1 % of the distance between the axis of rotation and the COS on the specimen (corresponding to the length of the pendulum).

[4]The particular machine used for the testing is identified here because the results are expected to be strongly influenced by the machine design. This is not an endorsement of this, or any other machine.

TABLE 2—*Effect of loosening the foundation bolts.*

	Baseline				Foundation unbolted			
Material	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
Low energy—RT	···	32.15	18.36	19.65	···	32.38	18.78	19.48
	···	32.38	18.64	19.68	···	31.90	18.54	19.48
	···	32.74	19.21	20.25	···	32.64	18.80	19.78
	···	31.00	18.62	19.08	···	31.90	19.35	20.21
	···	32.16	18.25	19.05	···	32.33	18.82	19.51
Average	···	**32.09**	**18.62**	**19.54**	···	**32.23**	**18.86**	**19.69**
standard dev.	···	**0.653**	**0.372**	**0.497**	···	**0.323**	**0.298**	**0.316**
Low energy −40°C	···	31.49	16.64	16.70	···	31.87	15.72	15.78
	···	31.55	16.84	16.89	···	30.70	16.33	16.37
	···	31.35	16.75	16.70	···	31.05	16.45	16.50
	···	31.60	16.98	17.03	···	31.98	17.01	17.29
	···	31.14	16.66	16.76	···	31.37	17.02	16.99
Average	···	**31.43**	**16.77**	**16.82**	···	**31.39**	**16.51**	**16.59**
standard dev.	···	**0.185**	**0.140**	**0.143**	···	**0.541**	**0.541**	**0.584**
High energy—RT	21.19	24.56	104.81	107.54	20.94	24.79	105.76	110.37
	20.81	24.59	107.86	113.01	20.96	24.78	105.69	110.49
	20.91	24.55	106.04	109.08	20.98	24.78	105.61	110.61
	20.97	24.55	105.78	111.53	20.99	24.77	105.54	110.73
	20.95	24.56	105.47	108.88	21.01	24.77	105.46	110.85
Average	**20.97**	**24.56**	**105.99**	**110.01**	**20.98**	**24.78**	**105.61**	**110.61**
standard dev.	**0.140**	**0.016**	**1.141**	**2.211**	**0.027**	**0.009**	**0.120**	**0.190**
Super-high energy—RT	20.20	25.63	*221.51*	237.97	20.52	25.65	*225.13*	243.21
	20.75	25.55	*231.83*	252.49	20.52	25.64	*228.33*	246.61
	20.43	25.55	*226.32*	244.32	20.64	25.60	*221.77*	239.44
	20.70	25.61	*222.74*	239.96	20.33	25.57	*221.21*	235.61
	20.76	25.66	*227.11*	244.83	20.76	26.12	*241.24*	260.65
Average	**20.57**	**25.60**	***225.90***	**243.91**	**20.55**	**25.72**	***227.54***	**245.10**
standard dev.	**0.246**	**0.049**	***4.064***	**5.602**	**0.160**	**0.228**	***8.177***	**9.614**

TABLE 3—*Effect of loosening the anvil bolts.*

	Baseline				Anvil bolts loosened			
Material	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
Low energy	···	32.15	18.36	19.65	···	33.55	18.80	19.94
	···	32.38	18.64	19.68	···	33.78	18.64	19.31
	···	32.74	19.21	20.25	···	32.58	18.57	19.61
	···	31.00	18.62	19.08	···	33.63	19.48	19.78
	···	32.16	18.25	19.05	···	32.79	18.67	19.61
Average	···	**32.09**	**18.62**	**19.54**	···	**33.27**	**18.83**	**19.65**
standard dev.	···	**0.653**	**0.372**	**0.497**	···	**0.542**	**0.372**	**0.234**
High energy	21.19	24.56	104.81	107.54	20.66	24.35	106.90	110.58
	20.81	24.59	107.86	113.01	20.66	24.36	100.57	104.19
	20.91	24.55	106.04	109.08	21.02	24.47	107.57	111.36
	20.97	24.55	105.78	111.53	20.92	24.36	104.69	108.34
	20.95	24.56	105.47	108.88	20.75	24.36	107.43	112.58
					20.81	24.47	104.69	107.85
Average	**20.97**	**24.56**	**105.99**	**110.01**	**20.80**	**24.40**	**105.31**	**109.15**
standard dev.	**0.140**	**0.016**	**1.141**	**2.211**	**0.145**	**0.058**	**2.660**	**3.021**

TABLE 4—*Effect of loosening the striker bolts.*

	Baseline				Striker bolts loosened			
Material	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
Low energy	···	32.15	18.36	19.65	···	32.95	19.12	19.51
	···	32.38	18.64	19.68	···	33.82	19.32	19.31
	···	32.74	19.21	20.25	···	33.51	19.69	19.71
	···	31.00	18.62	19.08	···	33.54	18.93	20.14
	···	32.16	18.25	19.05	···	33.82	19.59	19.78
Average	···	**32.09**	**18.62**	**19.54**	···	**33.53**	**19.33**	**19.69**
standard dev.	···	**0.653**	**0.372**	**0.497**	···	**0.355**	**0.317**	**0.311**
High energy	21.19	24.56	104.81	107.54	21.19	24.64	104.30	106.83
	20.81	24.59	107.86	113.01	21.42	24.58	104.29	108.50
	20.91	24.55	106.04	109.08	21.36	24.57	106.86	111.76
	20.97	24.55	105.78	111.53	21.33	24.80	107.29	111.32
	20.95	24.56	105.47	108.88	21.20	24.59	104.58	107.07
Average	**20.97**	**24.56**	**105.99**	**110.01**	**21.30**	**24.64**	**105.46**	**109.10**
standard dev.	**0.140**	**0.016**	**1.141**	**2.211**	**0.101**	**0.096**	**1.483**	**2.326**

This requirement ensures that minimum force is transmitted to the point of rotation. Moving COP and COS away from each other is expected to cause additional vibrations and therefore increase vibrational energy losses, particularly when testing brittle materials.

The location of the COP is determined from the equation

$$L = \frac{gp^2}{4\pi^2},$$

where:

g = the local gravitational acceleration in m/s^2
p = the period of a complete oscillation measured with a suitable time-measuring device in seconds, and
L = the distance between the axis of rotation and the COP in meters.

The length of the pendulum used in this study is 900.65 mm, and the original position of the COP is 898.79 mm from the axis of rotation. The COP-COS distance is therefore 1.86 mm, or 0.2 % of the pendulum length.

By adding 2 kg to the pendulum mass, we reduced the oscillation period and therefore shortened the distance between axis of rotation and COP to 893.73 mm and increased the COP-COS distance to 6.95 mm (0.77 % of the pendulum length). Subsequently, tests were run on low- and high-energy specimens and results were compared to data from reference tests (Table 5).

It is noted that instrumented energies for the low-energy specimens, contrary to expectations, decreases when the COP was moved away from the COS.

TABLE 5—*Effect of moving the COP away from the COS. (For one of the low energy tests, instrumented data were lost. For two additional low energy tests, an incorrect value of pendulum length was entered and therefore KV is not reliable.)*

	Baseline				COP moved			
Material	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
Low energy	···	32.15	18.36	19.65	···	···	···	18.94
	···	32.38	18.64	19.68	···	31.98	17.88	19.40
	···	32.74	19.21	20.25	···	31.43	17.89	19.47
	···	31.00	18.62	19.08	···	31.62	17.77	19.30
	···	32.16	18.25	19.05	···	31.56	17.67	18.98
					···	31.94	17.64	···
					···	31.08	17.90	···
Average	···	**32.09**	**18.62**	**19.54**	···	**31.65**	**17.80**	**19.22**
standard dev.	···	**0.653**	**0.372**	**0.497**	···	**0.235**	**0.104**	**0.244**
High energy	21.19	24.56	104.81	107.54	20.84	24.55	109.39	115.61
	20.81	24.59	107.86	113.01	20.98	24.45	108.40	113.87
	20.91	24.55	106.04	109.08	20.77	24.20	105.58	111.37
	20.97	24.55	105.78	111.53	21.00	24.39	107.95	113.83
	20.95	24.56	105.47	108.88	20.96	24.35	102.91	107.06
Average	**20.97**	**24.56**	**105.99**	**110.01**	**20.91**	**24.39**	**106.85**	**112.35**
standard dev.	**0.140**	**0.016**	**1.141**	**2.211**	**0.100**	**0.129**	**2.608**	**3.319**

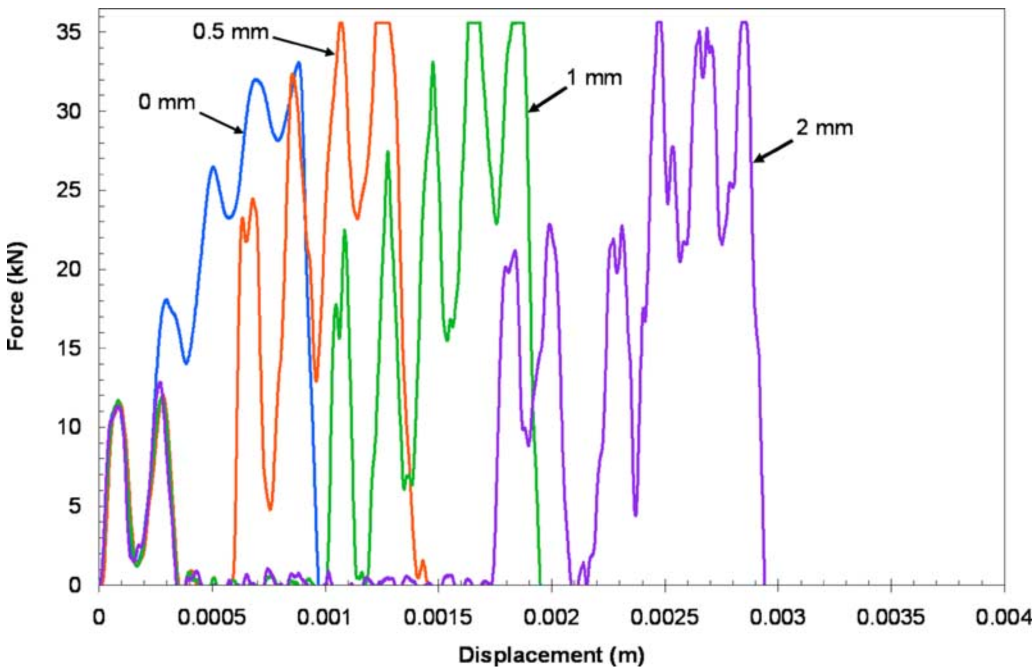

FIG. 1—*Effect of the distance between specimen and anvils on the instrumented test records of low-energy specimens. Note the force signal clipping above 35.6 kN.*

Specimen Position

The influence of specimen impact position was investigated by moving the samples away from the correct location (i.e., flush against the anvils and with the notch centered between the anvils). Conditions with specimens moved away from flush, and specimen notch positions moved off center were evaluated.

Specimen Not in Contact with the Anvils

In everyday laboratory practice, it is not uncommon that a Charpy specimen is not fully in contact with the anvils, particularly in the case of manual positioning and when the test is performed at low or high temperature, since the operator must fulfill the <5 s transfer time requirement specified in ASTM E23.

A sample that was not against the anvils can be easily detected from its instrumented test record, which shows significantly amplified dynamic oscillations up to general yield and a characteristic delay in the rise of the force signal with respect to the onset of data acquisition (see also Fig. 1).

For our study, we selected three values of the distance between specimen and anvils: 0.5, 1, and 2 mm. Up to five tests per condition were performed, although instrumented data were lost for several tests as will be discussed later. The results are summarized and compared with the reference data in Table 6.

Increasing the distance between specimen and anvils caused a generalized increase of the characteristic values of force and energy. The increment is particularly significant for maximum force values measured from low-energy specimens, where the enhanced dynamic oscillations lead to an overestimation of F_m. For the same reason, the uncertainty associated to F_{gy} values from high-energy specimens increased, whereas ringing effects were sufficiently dampened once maximum force was reached.

In general, brittle specimens were more significantly affected than ductile specimens.

As previously mentioned, the occurrence of instrumented data loss was problematic for the low-energy samples at 1 and 2 mm distance: data were not acquired in five out of nine tests, whereas in one instance only (out of six tests performed) high-energy data were lost. No acquisition failure was recorded for specimens placed 0.5 mm away from the anvils. It is therefore clear that distances of 1 mm or more increase the likelihood of acquisition failure, probably due to false triggering.

Some interesting features emerge from the comparison of instrumented test records (low-energy specimens in Fig. 1):

- traces of the offset low-energy specimens are clipped at a force level in excess of 35.6 kN, which corresponds to the threshold of the acquisition system, whereas curves for the reference condition do not reach this force level;
- on the displacement axis, the rise of the force signal roughly corresponds to the initial distance between specimen and anvils.

In all cases, large inertia peaks are observed at the beginning of the instrumented traces, caused by the specimen rebounding between the anvils and the striker before full contact is achieved.

Lateral Specimen Offset

Annex A1 of ASTM E23 prescribes that the specimen be positioned against the anvils such that the center of the notch is located within 0.25 mm of the midpoint between the anvils. The use of self-centering tongs is recommended to achieve this.

In our study, we selected three values for the specimen lateral offset: 0.5, 1, and 2 mm. All distances were outside the ASTM E23 tolerance.

For each condition, three tests on low-energy and three tests on high-energy specimens were conducted. No failed data acquisition was experienced. Results and comparison with reference values are provided in Table 7.

Moving the specimen off center appears to have a systematic,

TABLE 6—*Effect of the distance between specimen and anvils.*

	Low energy			High energy			
Distance from anvils	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
0 mm (reference)	32.15	18.36	19.65	21.19	24.56	104.81	107.54
	32.38	18.64	19.68	20.81	24.59	107.86	113.01
	32.74	19.21	20.25	20.91	24.55	106.04	109.08
	31.00	18.62	19.08	20.97	24.55	105.78	111.53
	32.16	18.25	19.05	20.95	24.56	105.47	108.88
Average	**32.09**	**18.62**	**19.54**	**20.97**	**24.56**	**105.99**	**110.01**
standard dev.	**0.653**	**0.372**	**0.497**	**0.140**	**0.016**	**1.141**	**2.211**
Distance from anvils	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
0.5 mm	33.98	19.73	20.61	19.54	24.92	108.95	114.19
	34.78	21.22	22.70	19.22	24.52	107.48	112.30
	34.83	20.22	21.38	19.49	24.79	107.84	110.50
	34.86	20.45	21.52				
Average	**34.61**	**20.41**	**21.55**	**19.42**	**24.74**	**108.09**	**112.33**
standard dev.	**0.423**	**0.621**	**0.863**	**0.172**	**0.204**	**0.766**	**1.845**
Distance from anvils	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
1 mm	33.70	22.10	22.76	19.94	24.82	114.48	118.62
	35.62	21.04	22.53	19.66	24.84	110.03	113.53
Average	**34.66**	**21.57**	**22.65**	**19.80**	**24.83**	**112.26**	**116.08**
standard dev.	**1.358**	**0.750**	**0.163**	**0.198**	**0.014**	**3.147**	**3.599**
Distance from anvils	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
2 mm	35.62	24.54	25.48	20.45	24.84	114.76	117.02
	35.02	25.10	26.23	22.00	24.87	112.22	113.29
				20.66	25.14	111.75	112.88
Average	**35.32**	**24.82**	**25.86**	**21.04**	**24.95**	**112.91**	**114.40**
standard dev.	**0.424**	**0.396**	**0.530**	**0.841**	**0.165**	**1.619**	**2.281**

though moderate effect on instrumented forces. The force values steadily increase with the offset. The effect is less pronounced and not systematic for energy values and W_t/KV ratio, with both W_t and KV being slightly lower for 2 mm than for 1 mm.

Discussion

In order to assess the statistical significance of loosening the machine bolts, we used a simple statistical test (unpaired *t* test) to determine whether the differences between mean values of each instrumented variable are statistically significant at the 95 % confidence level. The degree of statistical significance depends on the value of the two-tailed probability,[5] P, using a threshold value 0.05, as follows:

- $P > 0.05 \Rightarrow$ not significant,
- $0.01 < P < 0.05 \Rightarrow$ significant,
- $0.001 < P < 0.01 \Rightarrow$ very significant, and
- $P < 0.001 \Rightarrow$ extremely significant

In the case of variables related to the specimen position, we decided not to perform any statistical analysis, due to the limited number of data available for each condition (from 2 to 4).

Table 8 summarizes the results of the statistical *t*-test applied to the results of the tests conducted on low-, high-, and super-high-energy specimens in order to investigate the effect of test machine variables. In Table 8, the following convention is used to indicate the statistical significance (at the 95 % confidence level) of the observed differences between mean values

Symbol	Meaning
NS	Not significant
*	Significant
**	Very significant
***	Extremely significant

From the examination of Table 8, it is generally clear that the investigated effects are neither particularly evident nor systematic, nor are they consistent between the different parameters and energy levels. Therefore, it is unlikely that a user could detect them from a simple examination of an individual test record, without resorting to a more detailed statistical analysis. Force values (namely maximum forces) seem to be slightly more sensitive than energy values.

As far as specimen position is concerned, our results showed that moving the samples away from the anvils is more influential than displacing it sideways. The effects were clearly visible on the instrumented test record and were particularly significant when the distance between specimen and anvils exceeded 0.5 mm. Brittle specimens were more affected than ductile specimens, and, for our test system, clipping of the force signal due to saturation of the

[5]In statistical hypothesis testing, P is the probability of obtaining a value of the test statistic at least as extreme as the one that was actually observed, given that the null hypothesis (i.e., no difference between the means) is true.

TABLE 7—*Effect of lateral specimen offset.*

	Low energy			High energy			
Lateral offset	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
0 mm (reference)	32.15	18.36	19.65	21.19	24.56	104.81	107.54
	32.38	18.64	19.68	20.81	24.59	107.86	113.01
	32.74	19.21	20.25	20.91	24.55	106.04	109.08
	31.00	18.62	19.08	20.97	24.55	105.78	111.53
	32.16	18.25	19.05	20.95	24.56	105.47	108.88
Average	**32.09**	**18.62**	**19.54**	**20.97**	**24.56**	**105.99**	**110.01**
standard dev.	**0.653**	**0.372**	**0.497**	**0.140**	**0.016**	**1.141**	**2.211**
Lateral offset	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
0.5 mm	32.32	18.46	18.94	21.06	24.56	108.62	113.61
	33.14	18.93	19.21	20.98	24.57	108.30	113.08
	32.60	18.95	19.91	21.05	24.37	106.40	111.28
Average	**32.69**	**18.78**	**19.35**	**21.03**	**24.50**	**107.77**	**112.66**
standard dev.	**0.417**	**0.277**	**0.501**	**0.044**	**0.113**	**1.200**	**1.221**
Lateral offset	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
1 mm	33.50	19.36	20.11	21.17	24.60	105.67	111.73
	32.51	18.53	18.98	21.10	24.59	108.45	112.87
	33.30	18.80	19.04	20.97	24.62	110.12	114.68
Average	**33.10**	**18.90**	**19.38**	**21.08**	**24.60**	**108.08**	**113.09**
standard dev.	**0.523**	**0.423**	**0.636**	**0.101**	**0.015**	**2.248**	**1.488**
Lateral offset	F_m (kN)	W_t (J)	KV (J)	F_{gy} (kN)	F_m (kN)	W_t (J)	KV (J)
2 mm	33.64	19.50	20.68	21.24	24.72	103.45	113.77
	34.49	20.67	21.01	21.24	24.93	103.39	109.52
	32.79	18.88	19.44	21.54	24.92	107.92	114.10
Average	**33.64**	**19.68**	**20.38**	**21.34**	**24.86**	**104.92**	**112.46**
standard dev.	**0.850**	**0.909**	**0.828**	**0.173**	**0.118**	**2.598**	**2.554**

strain-guage signal was observed. Moreover, the likelihood of losing the instrumented data due to mistriggering was greatly increased. A lateral offset of the sample affected forces more than energies, but the consequences were not very significant.

Figures 2–4 summarize the outcome of our investigation for brittle and ductile Charpy tests respectively. Data are presented in terms of average forces and energies measured after "altering" one of the experimental parameters, as a function of the average values for the reference ("unaltered") condition.

In the case of brittle behavior (Fig. 2), most of the investigated variables tended to increase maximum forces and absorbed energies as a result of additional vibrational energy losses, except when

TABLE 8—*Statistical significance of the various machine parameters based on the t-test results.*

Test machine variable	Test parameter	Low-energy specimens (RT)	Low-energy specimens (−40°C)	High-energy specimens	Super-high-energy specimens
Foundation bolts	F_{gy}	⋯	⋯	NS	NS
	F_m	NS	NS	***	NS
	W_t	NS	NS	NS	NS
	KV	NS	NS	NS	NS
Anvil bolts	F_{gy}	⋯	⋯	NS	⋯
	F_m	*	⋯	***	⋯
	W_t	NS	⋯	NS	⋯
	KV	NS	⋯	NS	⋯
Striker bolts	F_{gy}	⋯	⋯	**	⋯
	F_m	**	⋯	NS	⋯
	W_t	*	⋯	NS	⋯
	KV	NS	⋯	NS	⋯
COP position	F_{gy}	⋯	⋯	NS	⋯
	F_m	NS	⋯	*	⋯
	W_t	***	⋯	NS	⋯
	KV	NS	⋯	NS	⋯

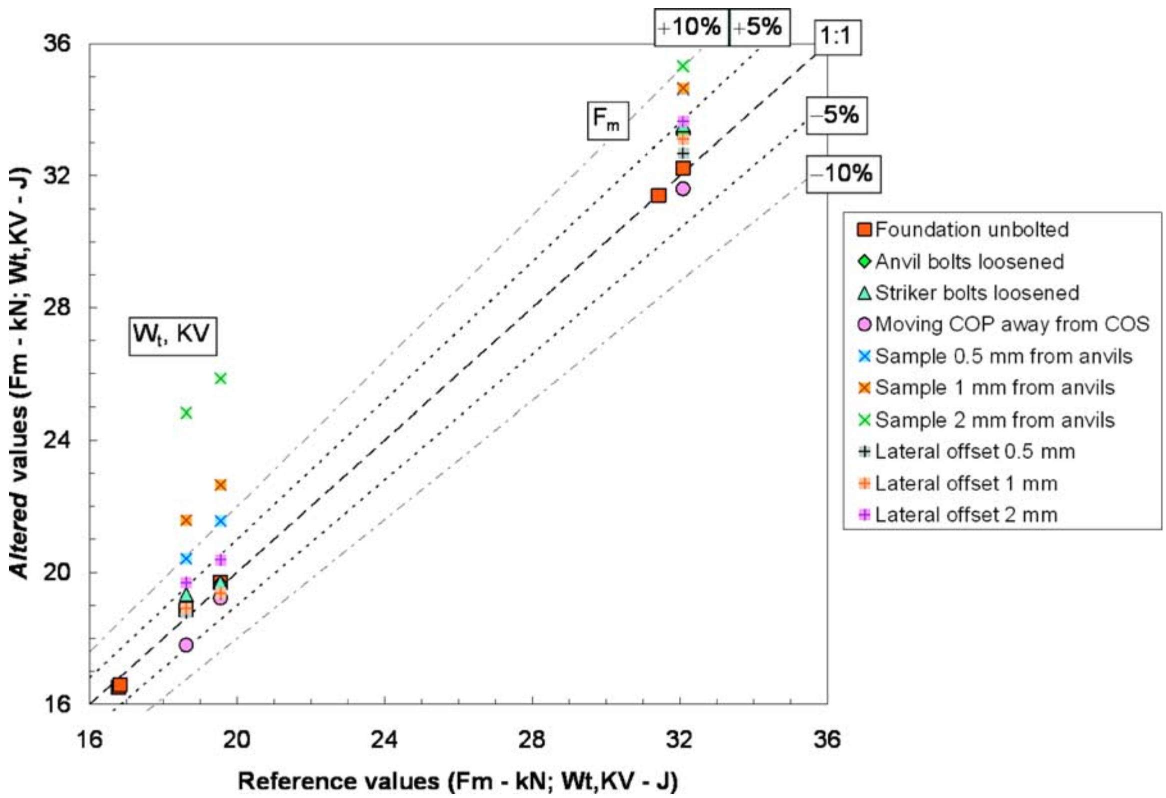

FIG. 2—*Effect of test machine variables and specimen positioning for brittle specimens (low-energy level at RT and −40°C).*

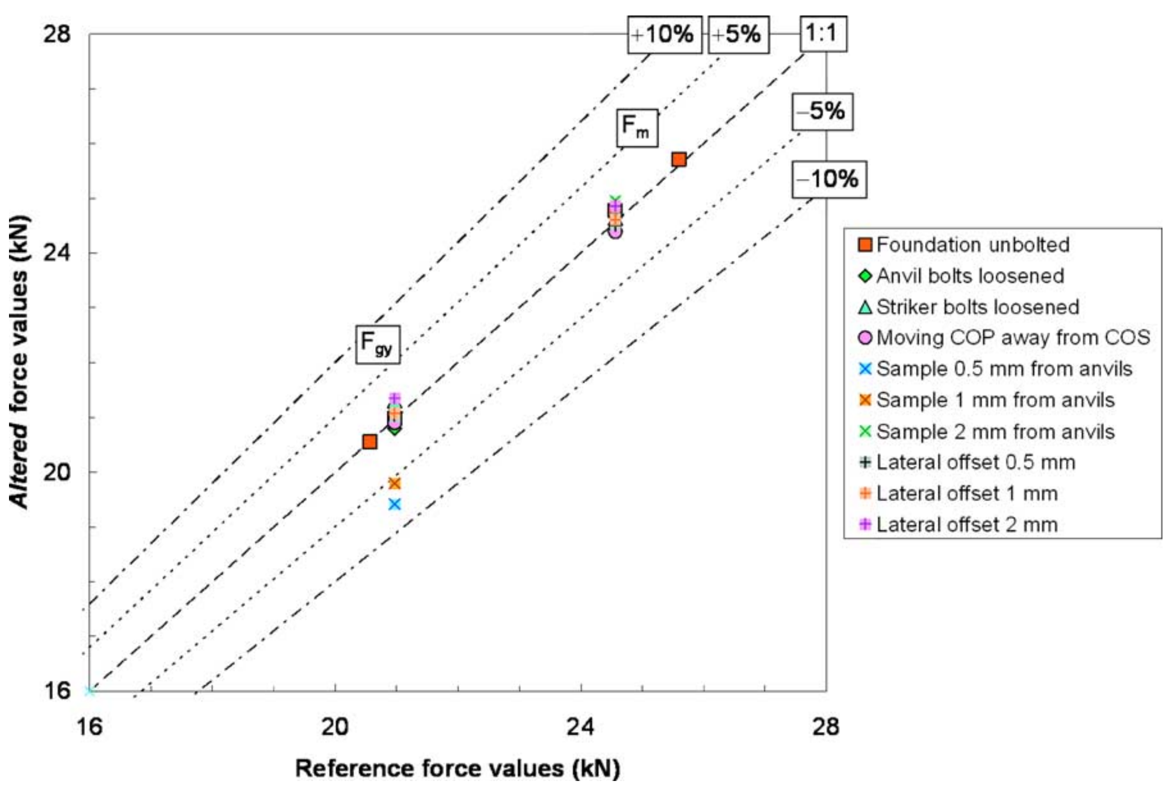

FIG. 3—*Effect of test machine variables and specimen positioning on characteristic forces for ductile specimens (high- and super-high energy).*

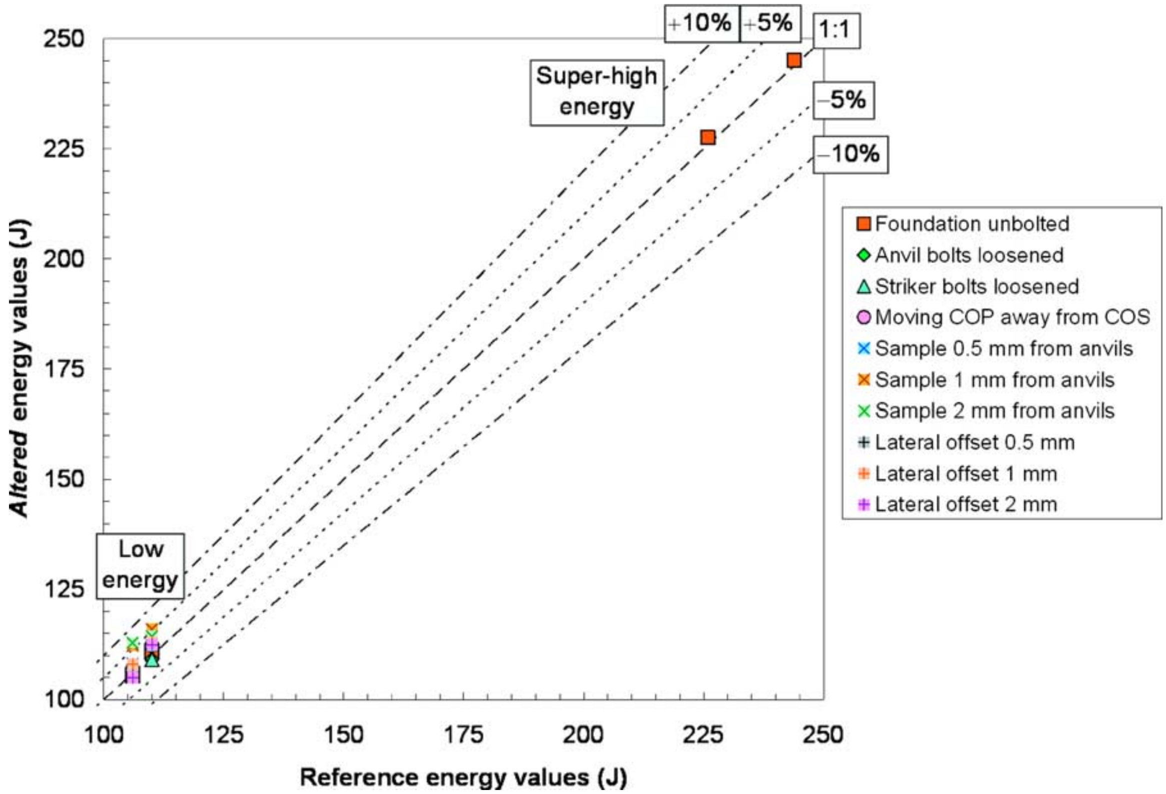

FIG. 4—*Effect of test machine variables and specimen positioning on absorbed energies for ductile specimens (high- and super-high energy).*

the COP was moved away from the COS. In general, altering the specimen position before impact was more influential than loosening the test machine bolts. Surprisingly, fully unbolting the pendulum from its foundation had the least significant influence.

The variations observed with respect to the reference condition were relatively moderate, i.e. less than 5 %, except when the specimen was moved away from the anvil by more than 0.5 mm. For specimen/anvil distances of 1 and 2 mm, absorbed energies increased by much more than 10 %.

Fully ductile specimens (Figs. 3 and 4) are generally less sensitive than brittle specimens to the investigated variables. In particular (Fig. 3), maximum forces are substantially unaffected (variations well below 5 %), whereas for general yield forces only the distance between specimen and anvil caused variations between 5 and 10 %. In terms of absorbed energies (Fig. 4), both from the instrumented test record or from the machine encoder, an increase was generally observed, but no larger than 5–6 % of the reference value.

Conclusions

Our investigation on the effect of test machine variables (bolting of foundation, anvils and striker; position of the center of percussion) on instrumented Charpy test results leads to the general conclusion that most of the observed variations are not very significant (<10 %), and neither consistent nor systematic, particularly in the case of fully ductile behavior. As a consequence, they are unlikely to be detected from the instrumented test record or from the value of absorbed energy yielded by the machine encoder.

The most notable effect is when the specimen is not in contact with the anvils; particularly for brittle tests (such as the low-energy NIST reference samples) and when the sample is more than 0.5 mm from the anvils, absorbed energies can be overestimated by way more than 10 %. It would be advisable that instrumented Charpy test standards require data from Charpy tests in which the gap between specimen and anvils was more than 0.5 mm to be discarded. This requirement would be relatively easy to implement, since (a) the test record of such a test has a typical appearance (delay between test initiation and force signal rise; very pronounced dynamic oscillations prior to general yield); and (b) the displacement corresponding to the rise of the force signal provides a rough estimate of the initial distance between specimen and anvils.

In our investigation, we have only considered the effect of one variable at a time. It is possible that the synergetic effects between two or more variables could be more easily detected from either the instrumented test record, the absorbed energy value or both.

One the most significant outcomes of our study is that a "good" (i.e., ASTM E23—compliant) machine has a high probability of still delivering high-quality results, including passing the indirect verification of ASTM E23, even when it is unbolted from its foundation, the striker and anvils are just finger tightened and the specimens are offset from the midpoint between the anvils. However, we expect that these results are strongly influenced by machine design. Therefore, the magnitude of the effects reported here may differ significantly from results obtained on a machine having a different design.

Finally, we can say that instrumented forces are more sensitive than absorbed energies to the variables considered, whereas calculated (W_t) and dial (KV) energies are equally (in)sensitive. This implies that, if Charpy tests are performed using an instrumented striker, effects can be detected which would not be noticed if one looked only at energy values returned by the machine encoder.

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