

# Impact Resistance of Materials for Guards on Cutting Machine Tools—Requirements in Future European Safety Standards

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Guards on machine tools are meant to protect operators from injuries caused by tools, workpieces, and fragments hurled out of the machine's working zone. This article presents the impact resistance requirements, which guards according to European safety standards for machine tools must satisfy. Based upon these standards the impact resistance of different guard materials was determined using cylindrical steel projectiles. Polycarbonate proves to be a suitable material for vision panels because of its high energy absorption capacity. The impact resistance of 8-mm thick polycarbonate is roughly equal to that of a 3-mm thick steel sheet Fe P01. The limited ageing stability, however, makes it necessary to protect polycarbonate against cooling lubricants by means of additional panes on both sides.

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cutting machine tools   guards   impact tests   sheet metals   vision panels

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## 1, INTRODUCTION

Occupational accidents at machine tools often imply injury of workers due to flying tools, machined parts, or fragments, because the protective guards on the machine do not stand the impact. Figure 1 shows an example of an enclosing guard on a turning machine; the transparent screen<sup>1</sup> was hit and destroyed by a machined part, which had worked loose from the three-jaw chuck as a result of a clamping fault.

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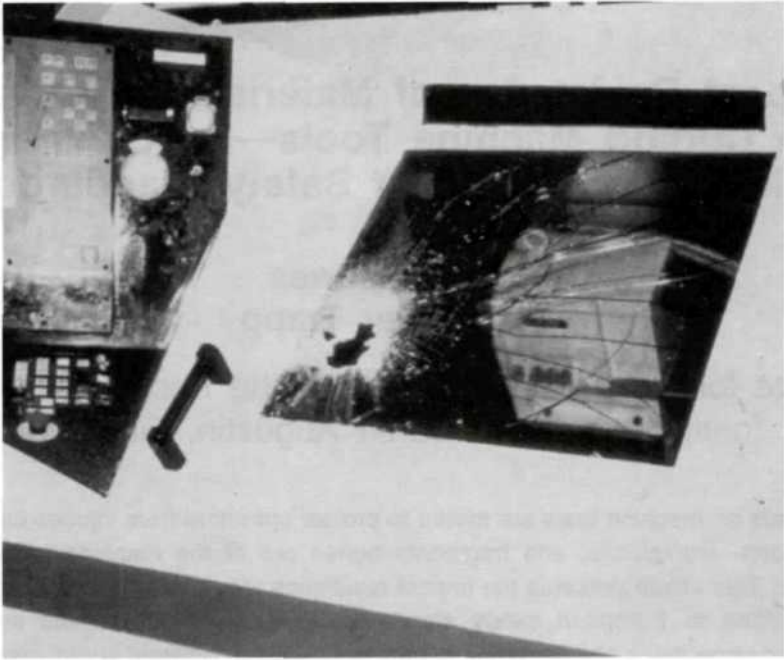


Figure 1. Transparent screen of an enclosing guard on a turning machine, which was destroyed by impact of a workpiece.

In the Federal Republic of Germany alone, about 1,900 reportable occupational accidents happen every year at turning machines because parts are flung out of the machine's working zone. This comes to approximately 20% of the overall number of occupational accidents occurring at such machinery (Mewes, Trapp, & Warlich, 1997). Accident figures in other countries are presumably the same. These figures underline the important role of guards in the context of accident prevention at machine tools. This is all the more important if one looks at the latest technical development towards high speed machining, which leads to even higher impact energies. Future European product standards will define clear requirements for guards in terms of impact resistance. In the field of cutting machine tools, draft standards are available for turning machines (prEN 12415; European Committee for Standardization [CEN], 1996b), milling machines (prEN 13128; CEN, 1998a), machining centres (prEN 12417; CEN, 1996a), and grinding machines (prEN 13218; CEN, 1998b). The paper presents a catalogue of machine-specific requirements with regard to impact resistance and provides the reader with information concerning the correct selection of material and dimensioning of guards on cutting machine tools.

## 2. TURNING MACHINES

Detailed requirements relating to the impact resistance of turning machine guards were first specified in the draft standard prEN 12415 (CEN, 1996b). These specifications say that the guard material and the complete guard must be designed so as to stand defined impact energies. The energy height depends on the diameter of the work holding device and on the peripheral speed (Table 1).

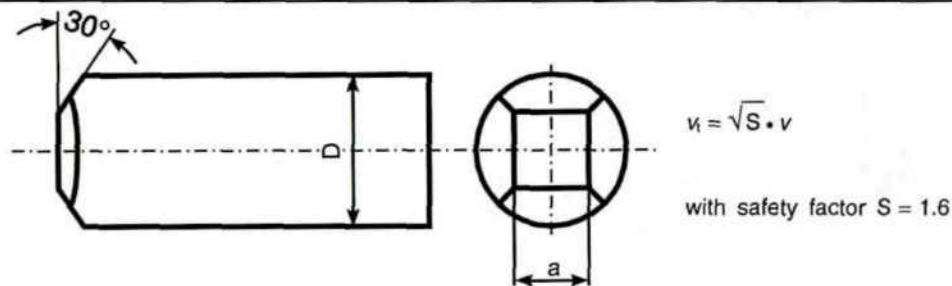
To assess the impact resistance, impact tests are conducted using cylindrical steel projectiles with a square front side. This test method was established on the basis of exhaustive theoretical and practical investigations, **which** revealed that (Mewes, Trapp, & Warlich, 1998)

- the false jaws in turning machines are particularly bound to work loose;
- the **translational** energy of the jaws is a determinant of the load; depending on the chuck size and the rotational speed this energy can reach 10,000 J. The rotational energy of jaws flung out of the machine comes to approximately 10% of the translational energy; it can therefore be ignored in a first approximate calculation;
- cylindrical steel projectiles with a square front side lead to better reproducibility and produce test results that are comparable to those obtained with commercial false jaws of the same dimensions and weight.

To get reference values for the construction and dimensioning of guards on turning machines, tests were conducted to determine the impact resistance of a number of usual materials. A schematic drawing of the pneumatic test facility used (Mewes et al., 1998) can be seen in Figure 2. Steel and aluminium sheets were investigated in impact tests along with transparent screens made from polycarbonate, polymethylmetacrylate, and laminated safety glass. Sample dimensions were 500 x 500 mm<sup>2</sup>. The overlap between the rigid frame and the samples was 25 mm on each side of the frame. Figure 3 shows the results achieved on a 3-mm thick steel sheet Fe P01. The indicated values are those of the critical energy  $E_c$  and the penetration energy  $E_p$ . According to the draft standard prEN 12415 (CEN, 1996b)  $E_c$ , describes the characteristic impact resistance. This is the energy limit beyond which a projectile is no longer safely retained by the guard. After the test, the samples showed only a bulge in the area where the projectile hit the guard (Figure 4). As soon as the energy increased, first cracks could be observed in the material until the projectile finally penetrated the guard at the energy  $E_p$  (Figure 5). The energy values  $E_c$  and  $E_p$  increase together

TABLE 1. Test Conditions for Guards Used on Turning Machines According to prEN 12415 (CEN, 1996b)

Work Holding Device Diameter (mm)		Peripheral Speed $v$ (m/s)	Projectile Dimensions $D \times a$ (mm $\times$ mm)	Projectile Mass $m$ (kg)	Impact Speed $v_i$ (m/s)	Impact Energy $E$ (J)	Resistance Class
from	up to						
	130	25	30 $\times$ 19	0.625	32	320	A <sub>1</sub>
		40			50	781	A <sub>2</sub>
		63			80	2,000	A <sub>3</sub>
130	250	40	40 $\times$ 25	1.250	50	1,562	B <sub>1</sub>
		50			63	2,480	B <sub>2</sub>
		63			80	4,000	B <sub>3</sub>
250		40	50 $\times$ 30	2.500	50	3,124	C <sub>1</sub>
		50			63	4,960	C <sub>2</sub>
		63			80	8,000	C <sub>3</sub>



with the projectile mass. This is due to the fact that the higher projectile mass leads to an increased projectile diameter (Miyamoto, Shida, Chiba, Othe. & Yoshizawa, 1979; Neilson, 1985).

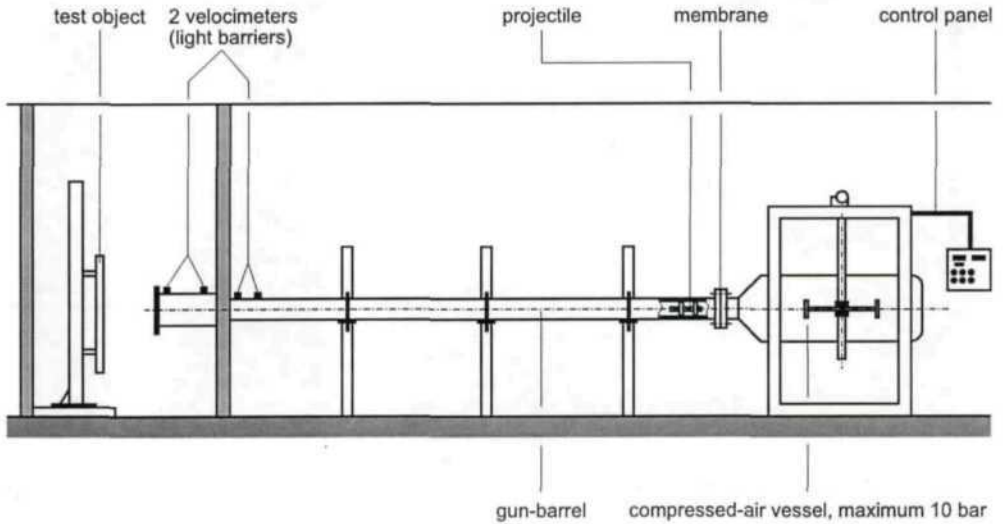


Figure 2. Equipment for an impact test.

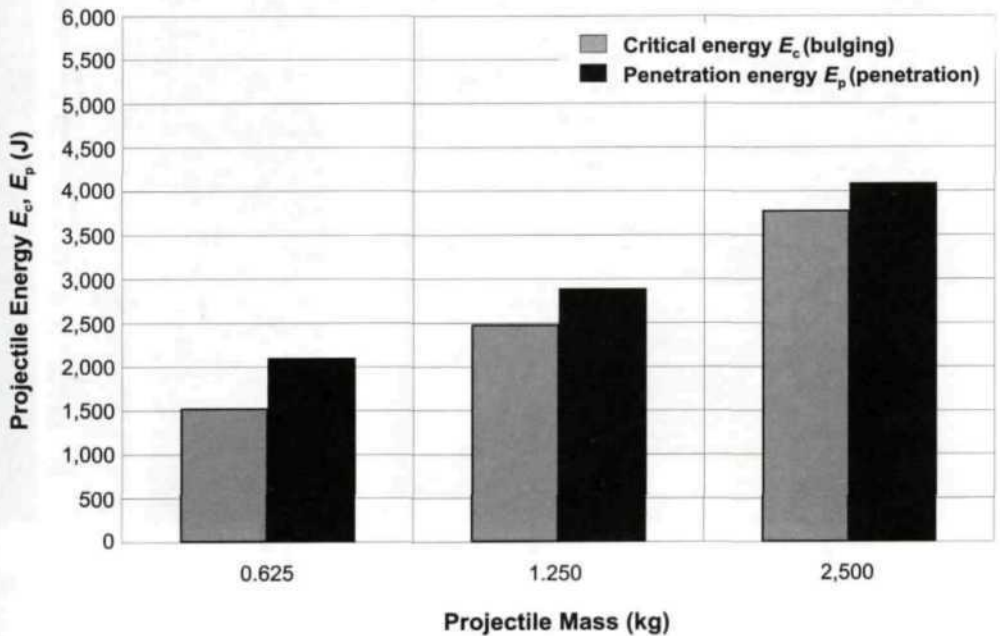


Figure 3. Results of impact tests according to prEN 12415 (CEN, 1996b) on a 3-mm steel sheet Fe P01.

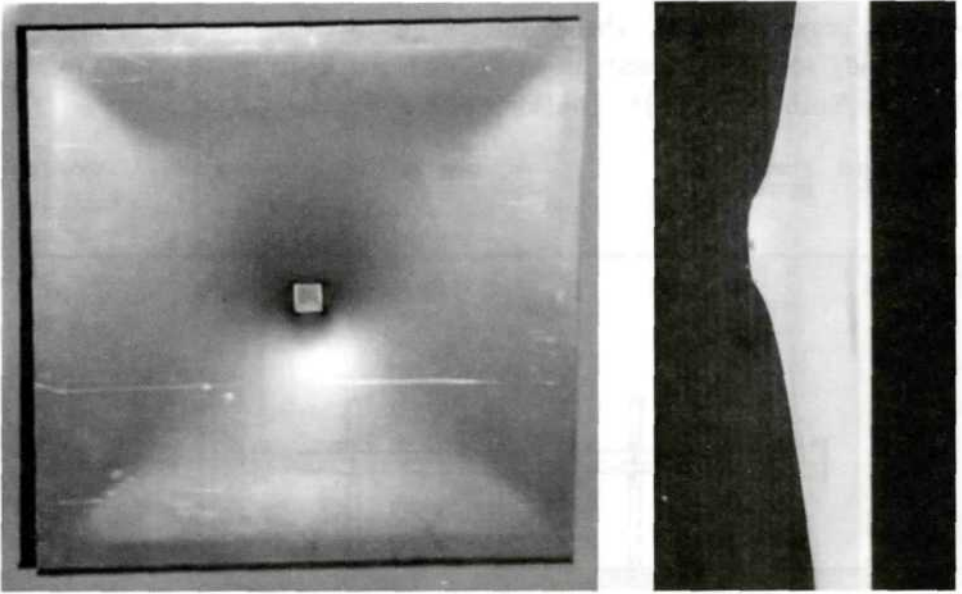


Figure 4. Plastic deformation (bulging) of a steel sheet Fe P01 at the critical energy  $E_c$ , left: top view, right: side view.

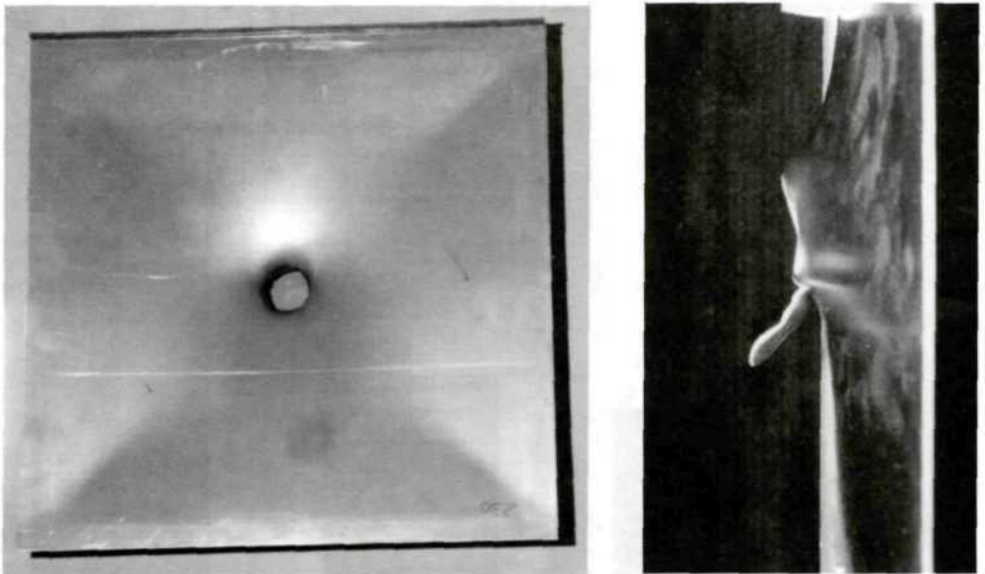


Figure 5. Penetration of a steel sheet Fe P01, left: top view, right: side view.

On the basis of the test results, it is possible to attribute the guard materials to different resistance classes listed in Table 1. Table 2 shows this classification. It should be emphasized that compliance with the requirements

**TABLE 2. Impact Resistance of Different Guard Materials (Resistance Classes) According to prEN 12415 (CEN, 1996b)**

Material	Thickness <i>d</i> (mm)	Tensile Strength <i>R<sub>m</sub></i> (N/mm <sup>2</sup> )	Fracture Elongation $\epsilon_B$ (%)	Resistance Class								
				A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>
Steel sheet Fe P01	3.0	405	28	+	+	-	+	+	-	+	-	-
Steel sheet S235JR	3.0	413	31	+	+	-	+	+	-	+	-	-
Steel sheet S185	5.0	305	43	+	+	+	+	+	+	+	+	-
Aluminium alloy AlMg3	5.0	242	18	+	+	-	+	-	-	+	-	-
Polycarbonate	6.0	68	80	+	+	-	+	-	-	-	-	-
	8.0			+	+	-	+	+	-	+	-	-
	10.0			+	+	+	+	+	-	+	+	-
	12.0			+	+	+	+	+	-	+	+	-
Polymethylmetacrylate	12.0	70	4	-	-	-	-	-	-	-	-	-

Notes. + —requirements fulfilled, - —requirements not fulfilled.

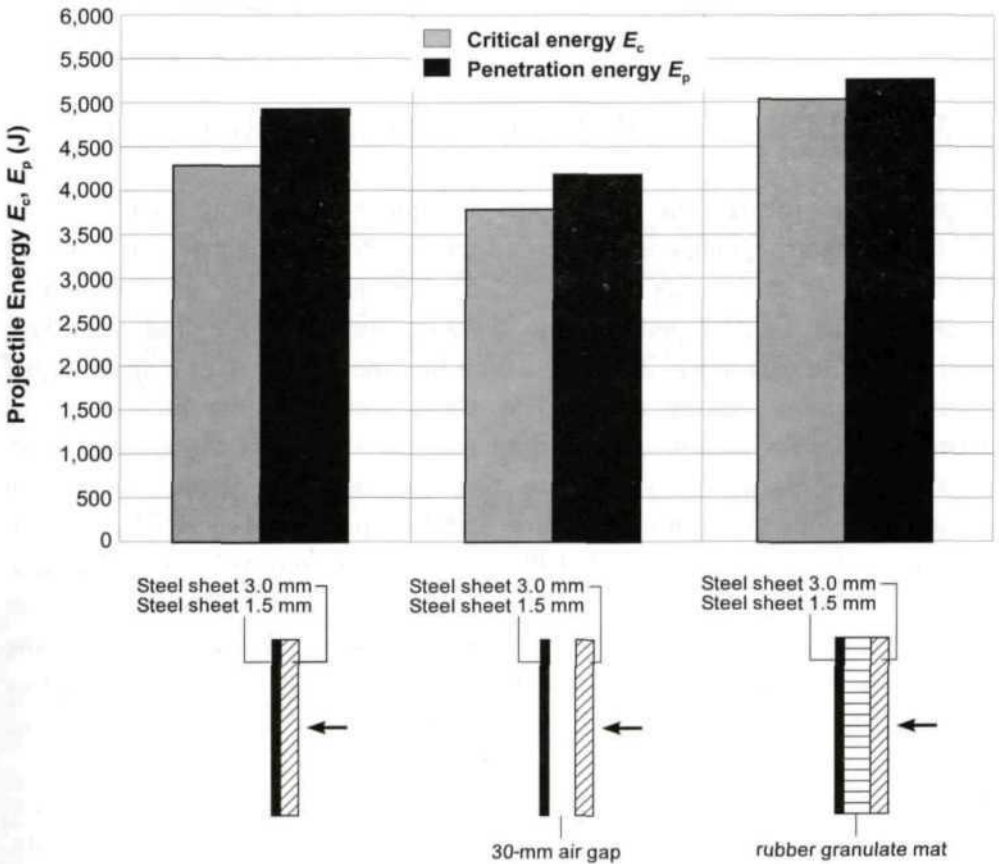


Figure 6. Results of an impact test with a 1.25-kg projectile according to prEN 12415 (CEN, 1996b) on double layered steel sheets.

of an upper resistance class, as for instance  $C_1$ , does not automatically imply compliance with all lower resistance classes, that is, A and B. None of the tested materials could be attributed to the highest resistance class  $C_3$ , where protection against an impact energy of at least 8,000 J must be ensured. To achieve this resistance level multilayer combinations must be used, as for instance two 5-mm thick steel sheets S185. It is also possible to enhance the impact resistance by using composite steel sheets with energy-absorbing layers in between (Figure 6). Whenever composite structures of thicker and thinner sheet metals are used, the thicker sheet should be turned towards the working zone (impact side). Test results show that the impact resistance obtained with this arrangement is about 10% higher than that of the inverse arrangement with the thinner sheet facing the impact side. Table 2 also reveals that polycarbonate proves to be a particularly suited material for vision panels.

### 3. MILLING MACHINES AND MACHINING CENTRES

Requirements relating to the impact resistance of milling machine and machining centre guards are specified in the draft standards prEN 13128 (CEN, 1998a) and prEN 12417 (CEN, 1996a). Guards used on these machines must be designed so as to stand the impact of a cylindrical 100-g steel projectile (diameter: 20 mm), which hits the guards with a speed equal to the maximum cutting speed. The 100-g weight of the projectile was defined in approximation of a milling cassette flying off the cutting head. Assessment criteria are similar to those defined for impact testing in accordance with the turning machine standard prEN 12415 (CEN, 1996b).

The draft standards prEN 13128 (CEN, 1998a) and prEN 12417 (CEN, 1996a) contain no information as to which materials possess sufficient impact resistance qualities for which cutting speeds. Table 3 presents the test results obtained with the draft standard method. It could be shown that it is possible to use the tested materials for cutting speeds that, in some cases, reach far into the speed range found in high-speed machining. A 3-mm steel sheet Fe POI for instance satisfied the test requirements of the aforementioned draft standards up to a cutting speed of 6,900 m/min. Higher speeds are still achievable with composite metal sheets. Whenever thicker and thinner sheets are used together, the thicker sheet should always face the working zone side of the machine, as described in section 2.

TABLE 3. Application (Maximum Cutting Speed) of Different Guard Materials According to prEN 13128 (CEN, 1998a) and prEN 12417 (CEN, 1996a)

Material	Thickness $d$ (mm)	Tensile Strength $R_m$ (N/mm <sup>2</sup> )	Fracture Elongation $\epsilon_B$ (%)	Maximum Cutting Speed $v_c$ (m/min)
Steel sheet Fe P01	1.5	369	28	4,800
	3.0	405	28	6,900
Steel sheet Fe P01	1.5 + 3.0 <sup>1)</sup>	369 + 405, respectively	28	9,000
	3.0 + 1.5 <sup>1)</sup>	405 + 369, respectively	28	8,400
Aluminium alloy AlMg3	5.0	242	18	7,200
Polycarbonate	4.0	68	80	5,100
	6.0			6,000
	8.0			7,200
	12.0			9,000
Polycarbonate	2 × 6.0			10,200
	2 × 12.0			13,800
Polymethylmetacrylate	12.0	70	4	1,500

Notes. 1—working zone side.

It is interesting to see that in the case of transparent screens, the use of several thin screens instead of one thick screen increases the overall impact resistance. According to the results documented in Table 3 a combination of two 6-mm polycarbonate screens, placed closely side by side, stands a maximum cutting speed of 10,200 m/min, whereas a single 12-mm polycarbonate screen turns out to have a maximum impact resistance of only 9,000 m/min.

#### 4. STATIONARY GRINDING MACHINES

Grinding wheels used on stationary grinding machines are subjected to centrifugal, clamping, and cutting forces occurring in the grinding process. Fabrication defects, unbalances, incorrect storage, and human errors in selection can lead to grinding wheel fracture (Figure 7). The kinetic energy of the wheel fragments can reach  $10^8$  J. To protect persons working in the immediate vicinity of grinding machines, grinding wheels must be equipped with abrasive product guards. The latter must be designed and installed so as to retain the biggest fragments. The European safety standard prEN 13218 (CEN, 1998b) presently in preparation indicates minimum values of guard wall thickness for different types of grinding machines, depending on the grinding wheel dimensions and the maximum peripheral operating

speed. Wall thickness is also influenced by the guard material. Steel and cast steel are particularly suited for this purpose. In addition, the mentioned draft standard contains empirical equations to calculate the required wall thickness. This calculation is based on the maximum translational energy of the fragments. The equation to calculate the fragment energy can also be found in the draft standard prEN 13218 (CEN, 1998b).

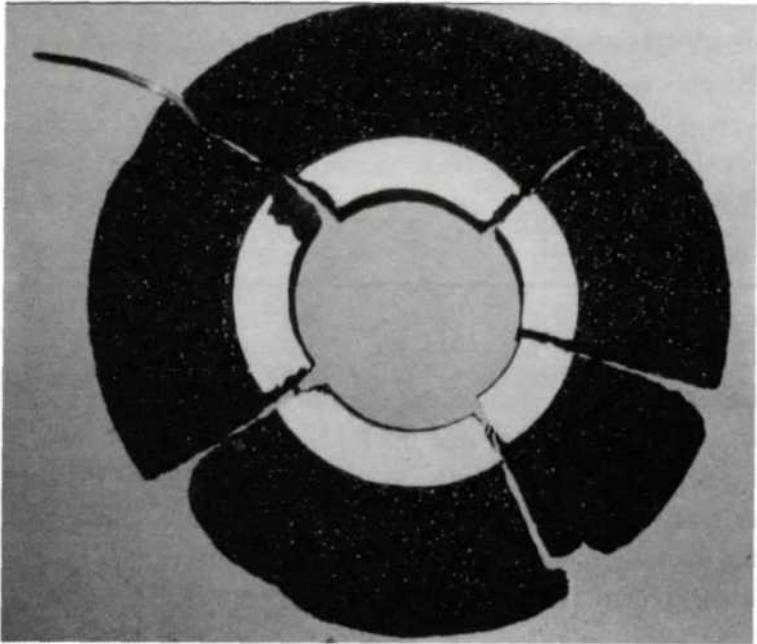


Figure 7. Failure of a grinding wheel during use.

It is possible to analyse the impact resistance of abrasive product guards against grinding wheel fragments in experimental tests. For this purpose the grinding wheel is intentionally destroyed while it is turning at maximum peripheral operating speed.

### 5. VISION PANELS

Vision panels help the operator observe the manufacturing process. Besides, transparent screens must make proof of a sufficient impact resistance, if they are likely to be hit by flying parts.

Nowadays vision panels are generally made of safety glass, polycarbonate (PC), combinations of glass and polycarbonate, or polymethylmetacrylate (PMMA). Transparent screens made of glass or PMMA proved to have a poor impact resistance and do not offer adequate protection against flying parts. Impact tests in accordance with prEN 12415 (CEN, 1996b) using a 0.625-kg projectile on 24-mm thick composite panes made only from safety glass showed that even a low impact speed of 35 m/s, equivalent to a kinetic energy of 382 J, leads to destruction (Figure 8).



Figure 8. Penetration of 24-mm laminated safety glass by a 0.625-kg projectile according to prEN 12415 (CEN, 1996b), projectile velocity: 35 m/s.

At present, polycarbonate is the material with the best impact resistance qualities. As documented in Tables 2 and 3 the energy absorption of an 8-mm thick polycarbonate pane is almost equal to that of a 3-mm thick steel sheet Fe P01.

When exposed to cooling lubricants, however, polycarbonate can show ageing effects (Mewes et al., 1998). As a result the impact resistance may suffer considerably in the course of the service life. Figure 9 presents the results of impact tests with a 1.25-kg projectile carried out on up to 15-year-old polycarbonate screens (**thickness:** 12 mm) used in machine

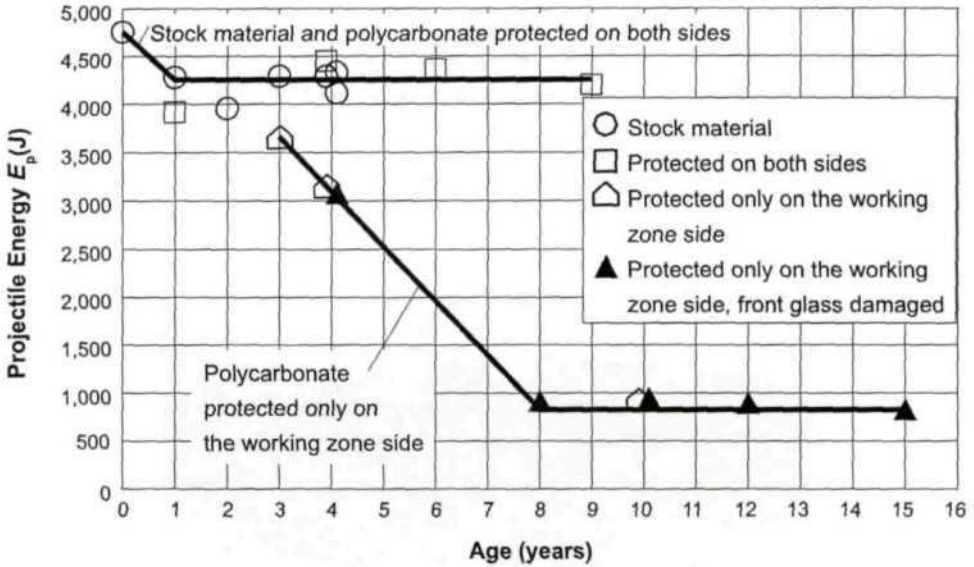


Figure 9. Influence of age and exposition to cooling lubricants on the penetration energy of 12-mm polycarbonate plates.

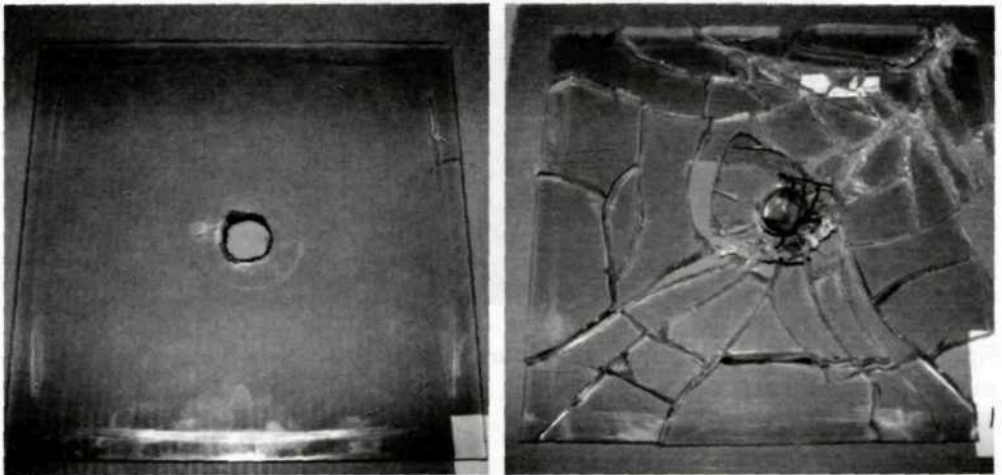


Figure 10. Penetration of new, unaged polycarbonate (left) and polycarbonate exposed to cooling lubricants (right).

tools. Apparently, even the finely dispersed oil and cooling lubricant particles in the workplace atmosphere, which form a thin surface film on the screens, can cause ageing processes and thus losses in the impact resistance. Figure 10 gives evidence of these ageing effects. In the impact tests, polycarbonate screens exposed to cooling lubricants fractured brittle

into many pieces. In the case of new or exposure-protected screens, the damage occurred only on the area where the projectile hits the screen.

At the moment inexpensive alternatives to polycarbonate that satisfy all requirements in terms of impact resistance, resistance against cooling lubricants, and transparency are not available. Therefore, the only possible solution is to protect polycarbonate against cooling lubricants, for example, by using protective panes (Figure 11). On the working zone side, safety glass is a suitable material for this purpose, as it offers also protection against thermal and mechanical damage caused by chips. The operator's side should be equipped with an additional pane made of polycarbonate or another transparent plastic material. Glass or similarly brittle materials are not allowed because, in case of an accident, splinters are likely to represent a health risk to the operator.

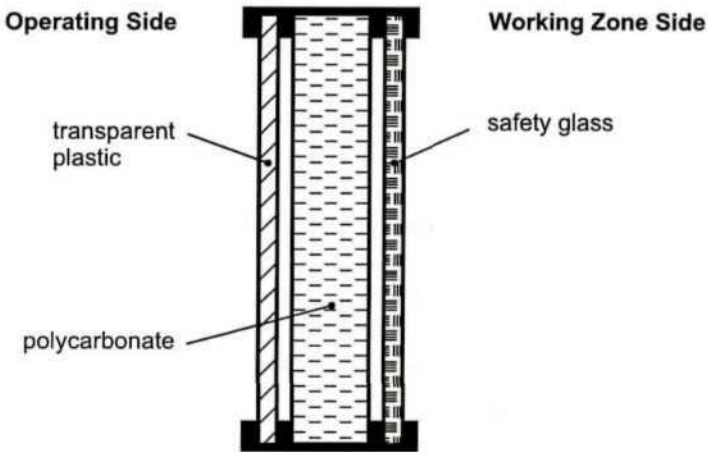


Figure 11. Design principle for a transparent screen with optimum protective effect.

## 6. SUMMARY AND CONCLUSIONS

Guards used on cutting machine tools are intended to protect workers against injuries due to flying parts. To achieve this protective aim, guards and their transparent screens must make proof of satisfactory impact resistance qualities. The paper provides information about the selection of suitable materials and guard dimensioning in accordance with European safety standards for turning machines, milling machines, machining centres, and grinding machines. In addition, it describes the test methods to check the required impact resistance properties. According to these standards the

impact resistance of steel sheets, **aluminium** sheets, and vision panels was investigated using blunt, cylindrical steel projectiles.

The following conclusions in terms of material selection and guard dimensioning can be drawn from this investigation to improve operational safety on cutting machine tools:

- **The** impact resistance increases with increasing thickness, tensile strength, and breaking elongation of the guard material.
- In the case of composite structures with thicker and thinner sheet metals, the thicker one should always face the working zone.
- Energy-absorbing intermediate layers improve the impact resistance.
- Polycarbonate is an especially suitable material for transparent guard screens, because it possesses a high energy absorption capacity.
- Several thin polycarbonate panes achieve better impact resistance results than one single polycarbonate pane with the same thickness.
- Additional protective panes facing the working zone and the operator's **side should** be used together with polycarbonate screens, as the latter show little ageing stability when exposed to cooling lubricants.

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