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Impact Resistance of Guards on Grinding Machines

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Guards on machine tools are meant to protect persons from injuries caused by parts ejected with high kinetic energy from the machine's working zone. With respect to stationary grinding machines, Standard No. EN 13218:2002, therefore, specifies minimum wall thicknesses for guards. These values are mainly based on estimations and experience instead of systematic experimental investigations. This paper shows to what extent simple impact tests with standardizable projectiles can be used as basis for the evaluation of the impact resistance of guards, provided that not only the kinetic energy of the projectiles used but also, among others, their geometry corresponds to the abrasive product fragments to be expected.

guards stationary grinding machines impact tests cylindrical projectiles grinding wheel ceramics

1. INTRODUCTION

Guards on cutting machine tools are of essential importance for occupational safety. They are intended to protect persons from injuries caused by parts ejected with high kinetic energy from the machine's working zone. Stationary grinding machines are a typical example. The grinding wheels used on them are exposed to high stresses during operation due to centrifugal, cutting and clamping forces. Although grinding wheels are subject to stringent safety requirements, which are mainly verified with bursting speed tests [1, 2], inappropriate storage or incorrect handling of the wheels, e.g., as well as faults in the machine control system may lead to bursting during operation. Such bursting may lead to severe, sometimes fatal occupational accidents, if the fragments cannot be retained by a guard with appropriate design and construction. Especially grinding wheels with resinoid or vitrified bond are liable to burst.

According to statistical data of the Deutsche Gesetzliche Unfallversicherung (German Social Accident Insurance) in the Federal Republic of Germany alone ~150 notifiable occupational accidents per year occur at stationary grinding machines due to ejected fragments. Accident figures in other countries are presumably the same. These figures emphasize the importance of guards for the protection of persons, especially at grinding machines. This fact is also taken into account in Standard No. EN 13218:2002 by specifying minimum wall thicknesses as an important basis for the design and construction of safe guards [3]. These values, however, are mainly based on experiences and estimations instead of systematic experimental investigations.

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As an alternative to the use of wall thickness tables, the standard contains a verification method by which breakage of an abrasive wheel running at its maximum operating speed is initiated by a gunshot. This time-consuming and cost-intensive method, however, leads to results, which are hardly reproducible. Therefore, it should be investigated if a simple impact test method with standardizable projectiles, as is already used in a similar form for other types of cutting machine tools [4, 5, 6, 7, 8], may be used instead as a basis for the evaluation of the impact resistance of guards. For this impact test method, however, rigid steel projectiles are used. Under these circumstances, the impact resistance of materials strongly depends on their mechanical properties like tensile strength and fracture elongation, but also on the shape and dimensions of the projectiles used (see, e.g., Backmann and Goldsmith [9], Corran, Shadbolt and Ruiz [10], Neilson [11], Jones [12] and Mewes, Trapp and Warlich [13]). It is, however, not known how materials react to impacts with projectiles made from grinding wheel ceramics.

2. EXPERIMENTAL METHODS

2.1. Materials

Test materials were sheets made from steel DC 01 and transparent screens made from polycarbonate (Table 1). Both materials are often used for guards. The impact resistance of these materials was determined in impact tests and, as a comparison, also in bursting tests.

TABLE 1. Thickness, Tensile Strength and Fracture Elongation of the Tested Materials

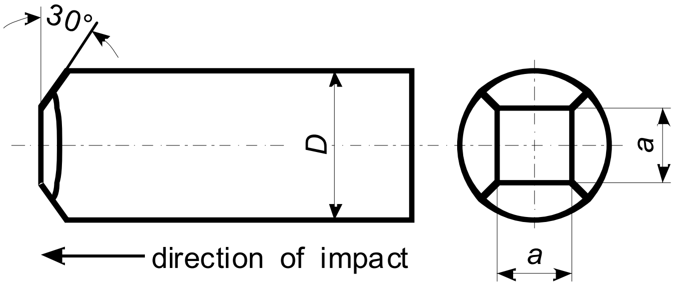
Material	Thickness (mm)	Tensile Strength (N/mm^2)	Fracture Elongation (%)
DC 01	3	405	28
PC	8	68	80

2.2. Impact Tests

The impact tests were carried out in a pneumatically operated test facility [8, 14] using cylindrical projectiles made from hardened steel (Figure 1) or commercial grinding wheel ceramics (Figure 2). The ceramic projectiles had compression strengths of 70–165 N/mm^2. Diameters and masses were equal to those of the steel projectiles.

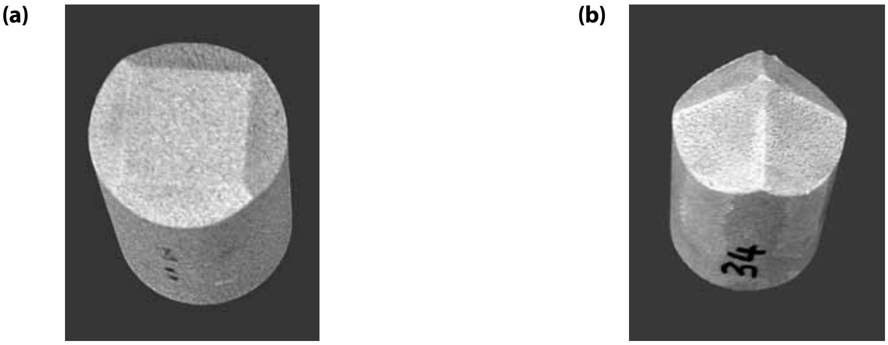
For the impact tests samples with dimensions 500 × 500 mm were mounted in a rigid steel frame. The overlap between the frame and the test samples was 25 mm on each side. The impact always acted on the centre of the samples.

The measure for the evaluation of the impact resistance was the critical projectile energy, i.e., the energy, which just leads to plastic deformation (bulging) of the samples without already producing perforation or penetration (Figure 3). To be able to determine the impact resistance as exactly as possible, the projectile energy was increased gradually by increasing the projectile velocity. For each impact test, another test sample was used, i.e., all test samples were only subjected to one impact.



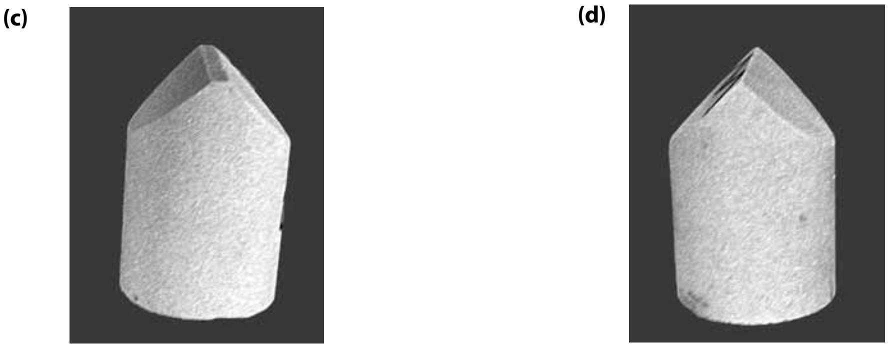
Mass m (g)	Diameter D (mm)	Front Face $a \times a$ (mm × mm)
625	30	19 × 19
1250	30	19 × 19
1250	40	25 × 25
1250	50	30 × 30
2500	30	19 × 19
2500	50	30 × 30

Figure 1. Steel projectiles (square-shaped front face).



front face: square (EN 12415:2003 [4])

front face: 90° pyramid with 4 × 4 mm plane surface



front face: 90° wedge with 4-mm wide plane surface

front face: 90° wedge

Figure 2. Ceramic projectiles.

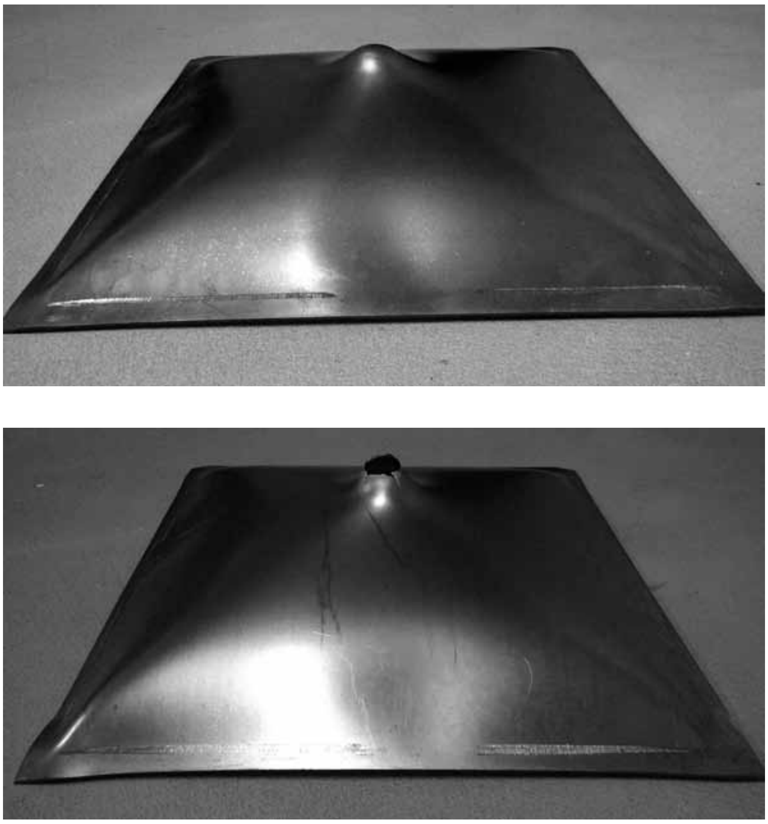


Figure 3. Bulging (top) and penetration (bottom) for steel sheet.

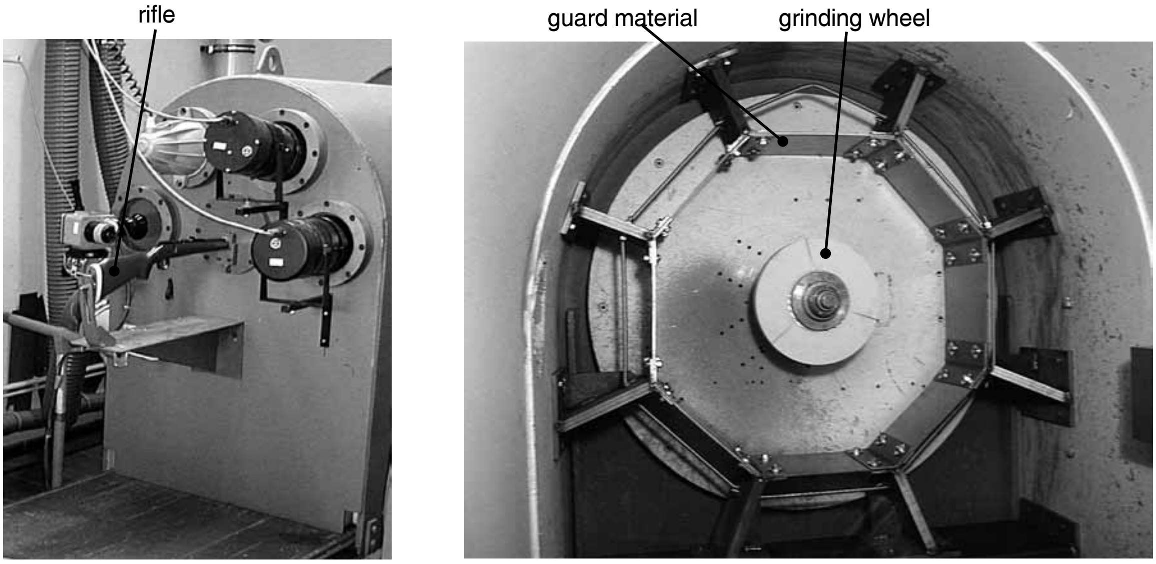


Figure 4. Set-up for bursting tests.

2.3. Bursting Test

To validate the impact results, bursting tests with real grinding wheels were carried out. For these tests, a guard made from the materials used in the impact tests, polycarbonate (8 mm) and DC 01 (3 mm), was simulated on a bursting speed test machine (Figure 4). The dimensions of the test samples were 210 × 255 mm each.

The guard was arranged as an octagon with a vertical distance of 195 mm from the periphery of the mounted wheel. The grinding wheels consisted of the hardest material also used for the grinding wheel projectiles and had the dimensions ($D \times T \times H$) 250 × 40 × 76.2 mm. The wheels were designed for a maximum operating speed of 50 m/s by the manufacturer. The bursting tests were carried out with straight wheels (mass m = 4 kg) and with wheels chamfered on both sides (2 × 45°) (mass m = 3.4 kg). The fragments of the straight wheels roughly simulated the projectile shape in accordance with Standard No. EN 12415:2003 [4] and the fragments of the chamfered wheels simulated the sharper projectiles.

If possible, the grinding wheels were accelerated to a peripheral speed that resulted in a translational fragment energy corresponding to the critical projectile energy of the 1250-g projectiles from the impact tests. Subsequently, the grinding wheels were destroyed by a shot from a small calibre rifle. The grinding wheels burst into four or more fragments emanating from the point of impact. The tests were filmed with a high speed camera and then evaluated.

Following the test, the grinding wheel fragments were laid together and photos were taken. From the known point of impact it was then possible to find which fragment had hit which plate at which point. The angles of the fragments were measured. Subsequently, the translational energy of a fragment E_{trans} was calculated from the equation (see Standard No. EN 13218:2002 [3])

$$E_{\text{trans}} = \frac{2}{9 \cdot \pi} \cdot m \frac{\left(1 - Q^3\right)^2}{\left(1 - Q^2\right)^2} \cdot \frac{\sin^2 \alpha}{\hat{\alpha}} \cdot v^2, \qquad (1)$$

where m—mass of the grinding wheel, α—the half angle of fragments (°), $\hat{\alpha}$—half fragment angle (rad), v—peripheral speed, Q—ratio of bore diameter H to outside diameter D of the grinding wheel.

Then, the damage found in the polycarbonate or steel sheets was compared to that from the impact tests.

3. RESULTS

3.1. Impact Tests

Figures 5–6 show the influence of the strength of the projectiles on the impact resistance of steel sheet and polycarbonate in the impact test.

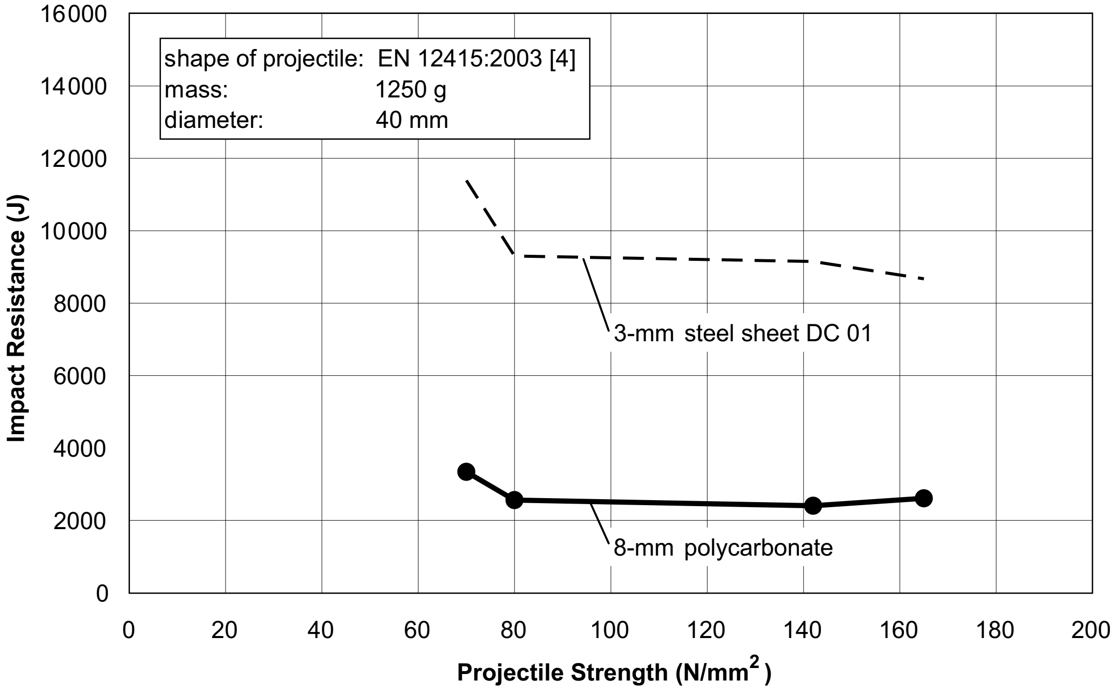


Figure 5. Impact resistance of polycarbonate and steel sheet using blunt ceramic projectiles of different strengths.

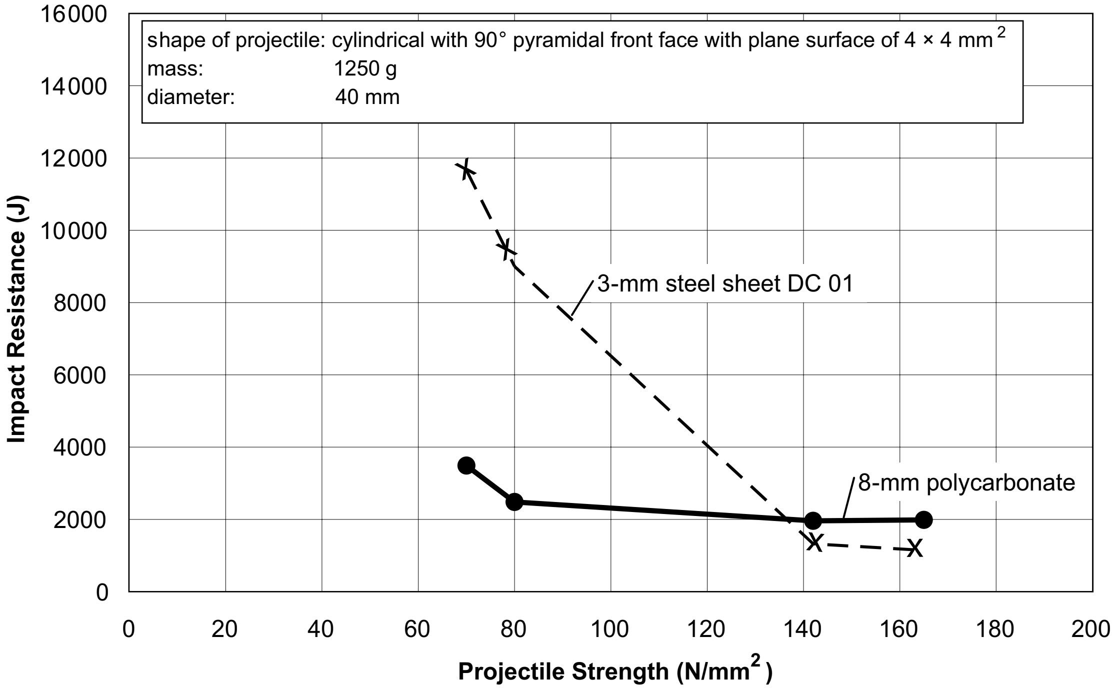


Figure 6. Impact resistance of polycarbonate and steel sheet using sharp ceramic projectiles of different strengths.

Especially for the investigated steel sheet, a significant effect of the projectile strength on the impact resistance could be observed. In the impact tests with the blunt projectiles, the front faces of which corresponded to the specifications in Standard No. EN 12415:2003 [4], an increase of the projectile strength from 70 to 165 N/mm^2 already caused a reduction in the impact resistance from ~11 400 to ~8700 J (Figure 5). With a steel projectile of same geometry, the

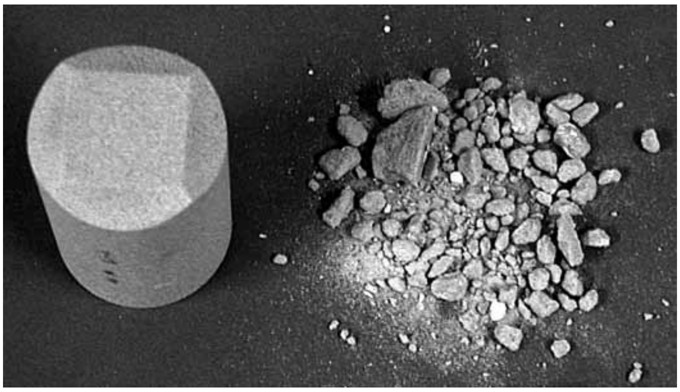


Figure 7. Ceramic projectile (strength: 80 N/mm^2) with front face in accordance with Standard No. EN 12415:2003 [4] before impact (left) and after impact (right), projectile energy: 9303 J.

strength of which was ~600 N/mm^2, an impact resistance of only 2500 J was found. Contrary to the ceramic projectiles, which were damaged until complete destruction with increasing impact energy (Figure 7), the steel projectile kept the original shape of its tip, which thus remained fully efficient.

The influence of the projectile strength was even more significant than in the tests with the relatively blunt projectiles when using sharp projectiles with pyramidal front faces (Figure 6). With increasing strength of the ceramic projectiles from 70 to 165 N/mm^2 the impact resistance of steel sheet was reduced by a factor of ~10. The projectiles from the two harder grinding wheel materials mainly kept their shape during impact and thus effected more strain on the steel sheet. The projectiles from softer grinding wheel ceramics, in contrast, already showed a significant truncation of the projectile tip at relatively low energies (Figure 8). Thus, these projectiles approximately behaved like blunt projectiles in the impact test. Consequently, the impact resistance was also comparable to that determined for impacts with blunt projectiles of equal strength.

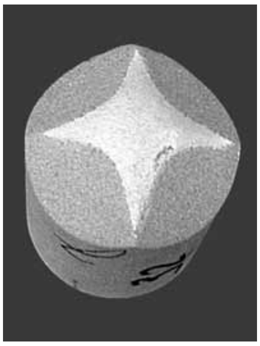


Figure 8. Ceramic projectile (strength: 80 N/mm^2) with 90° pyramidal front face and 4 × 4 mm plane surface after impact on steel sheet, projectile energy: 1381 J.

The impact resistance of the investigated polycarbonate screens with a thickness of 8 mm, however, only marginally depended on the strength of the projectiles used. This was true both for the impact with blunt (Figure 5) and with sharp projectiles (Figure 6).

The influence of the shape of the projectile front face on the impact resistance was investigated further by integrating into the programme two wedge-shaped projectile geometries with and without plane surface (Figure 2). These projectiles had strengths of 80 and 142 N/mm^2, respectively. The diameter of the cylindrical projectiles was 40 mm, the mass was 1250 g.

According to these tests, the impact resistance of steel sheet was nearly independent of the shape of the front face, if the tests were conducted with the relatively soft ceramic projectiles (strength: 80 N/mm^2) (Figure 9). Under these conditions, the impact resistance of 8410–9766 J resulted. This behaviour can be explained by the rounding-off or destruction of the soft projectiles during impact.

When using harder ceramic projectiles (strength: 142 N/mm^2), however, the shape of the tip had a strong influence on the impact resistance. The impact resistance was 9150–13 000 J. The blunter the projectile tip, the higher the impact resistance was.

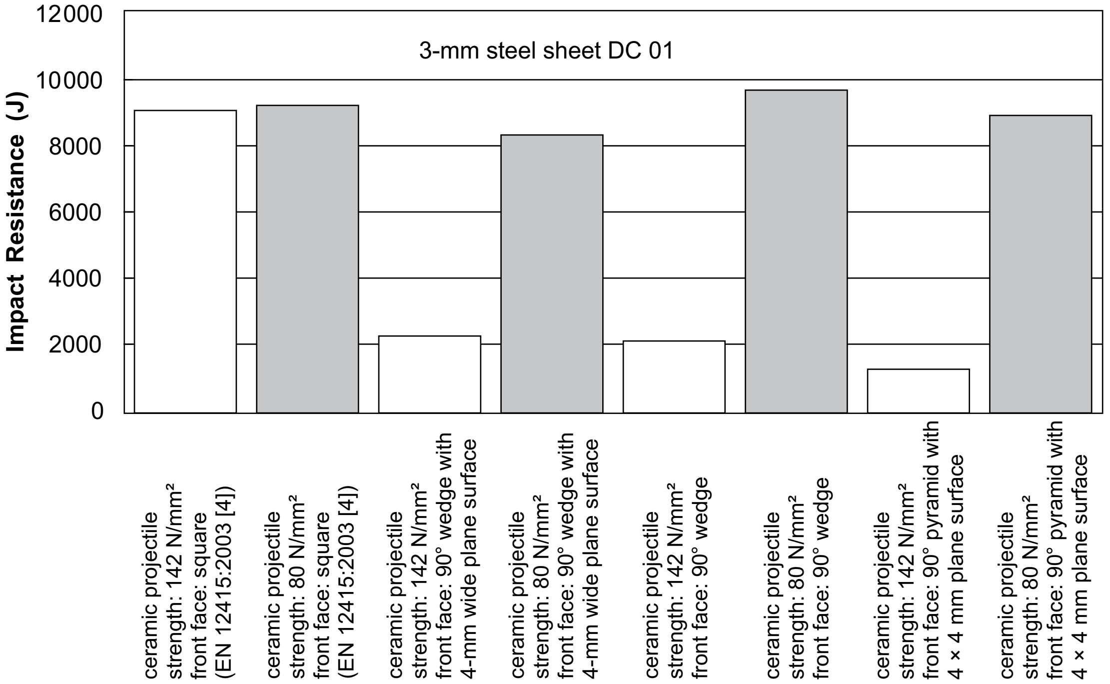


Figure 9. Impact resistance of 3-mm steel sheet using ceramic projectiles (diameter: 40 mm, mass: 1250 g) with different front faces.

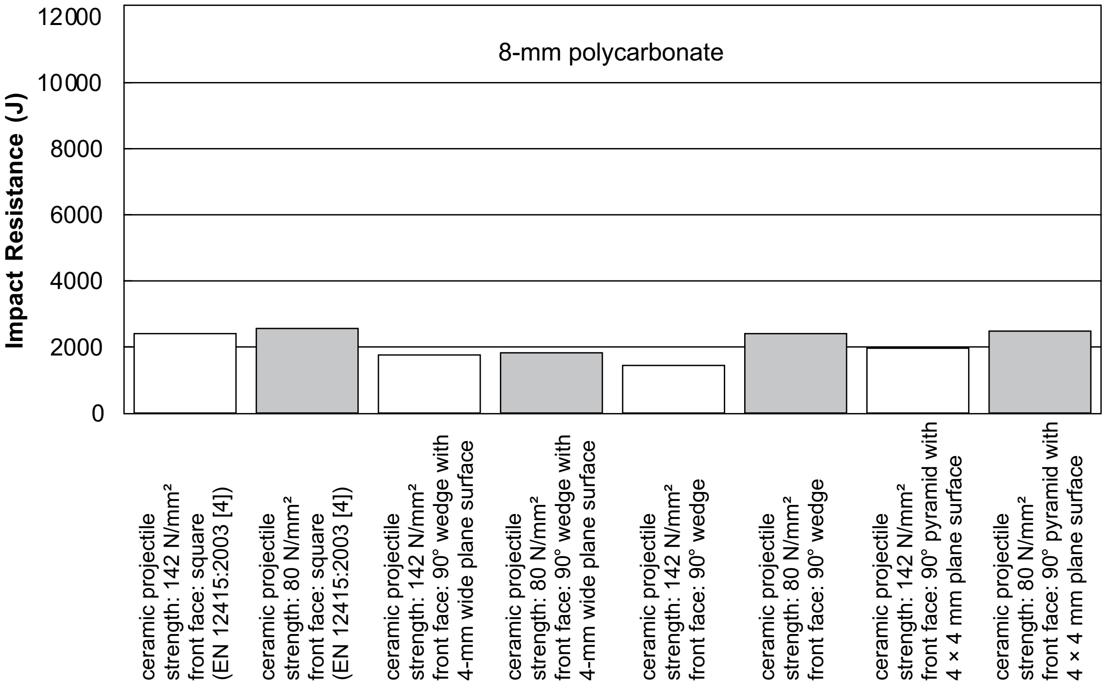


Figure 10. Impact resistance of 8-mm polycarbonate using ceramic projectiles (diameter: 40 mm, mass: 1250 g) with different front faces.

In contrast to steel sheet, the polycarbonate screens did not reveal such a significant influence of the face shape on the impact resistance in these tests, either. This was valid both for the softer and for the harder ceramic projectiles. The impact resistance was 1440–2560 J (Figure 10).

Further tests showed that also the projectile diameter influenced the impact resistance. Figure 11 is an example for steel sheet DC 01 for the impact with blunt and sharp-edged projectiles made from steel or grinding wheel ceramics. Except for one single case, an increase in the diameter of the projectile caused a significant increase in the impact resistance. A larger projectile diameter caused the energy to be transferred via a larger surface, which finally led to an increase in the impact resistance. In the present case, an increase in the projectile diameter from 30 to 50 mm roughly doubled the impact resistance, whereas the absolute magnitude of the impact resistance depended strongly on the shape of the front face and the strength of the projectiles.

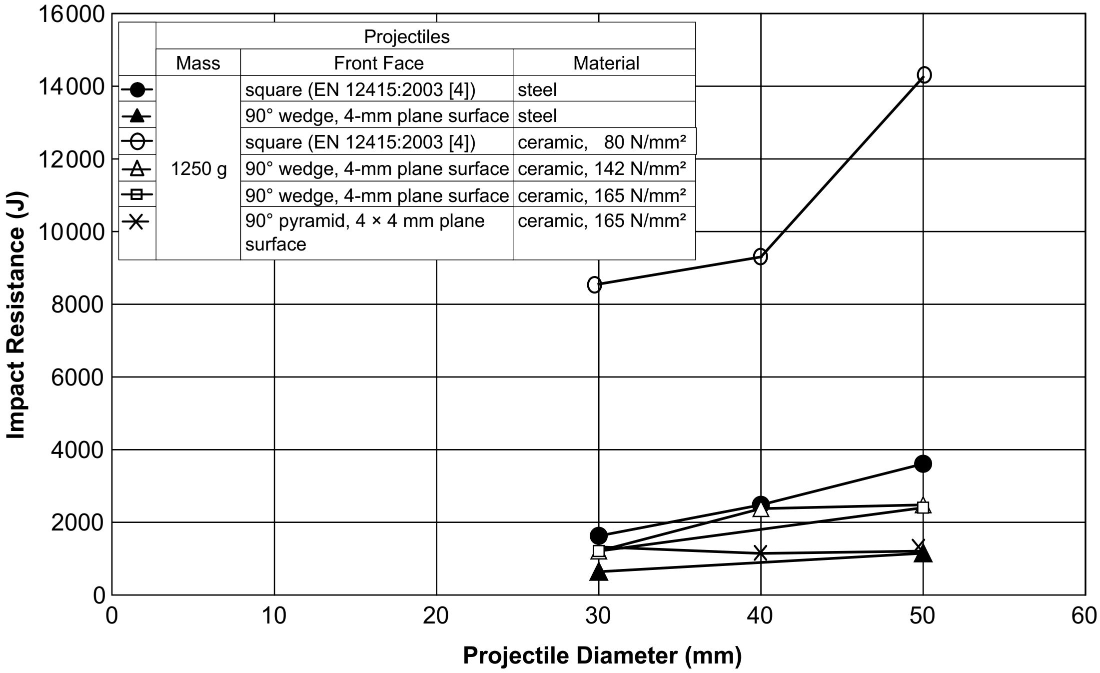


Figure 11. Influence of the projectile diameter on the impact resistance of steel sheet DC 01 (thickness: 3 mm).

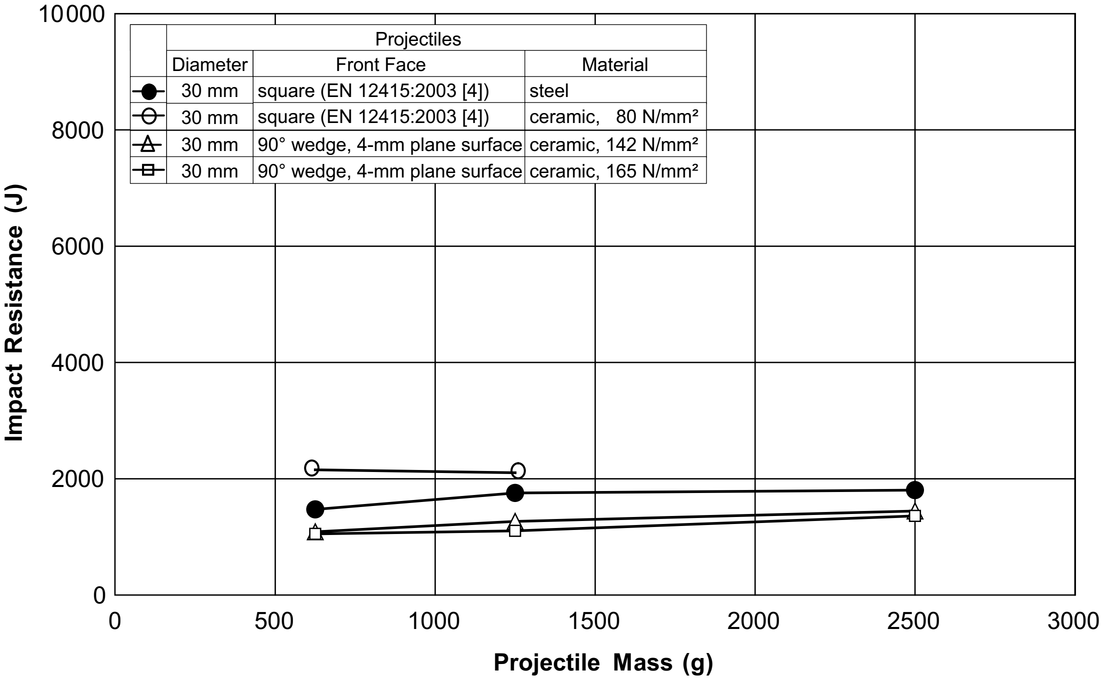


Figure 12. Influence of the projectile mass on the impact resistance of polycarbonate (thickness: 8 mm).

The use of very sharp projectiles with pyramidal front face (strength: 165 N/mm^2) resulted in a very different behaviour. The impact resistance was nearly independent of the projectile diameter, apart from experimental scatter. Obviously, the magnitude of the impact resistance only depended on the geometry of the projectile tip in this case. Due to the comparatively high strength of 165 N/mm^2, the shape of the projectiles nearly remained intact even for high impact energies.

The behaviour of the polycarbonate screens was similar to that of the steel sheets. Depending on the shape and strength of the projectiles the impact resistance grew by a factor of ~1.5–2, if the projectile diameter increased from 30 to 50 mm. Here, as well, the very sharp projectiles with pyramidal front faces were the exception.

The mass of the projectiles, however, had nearly no influence on the impact resistance. Figure 12 is an example for polycarbonate.

3.2. Bursting Tests

In the bursting tests with straight and profiled grinding wheels, the impact resistance of 2000–2400 Nm was found for polycarbonate screens with a thickness of 8 mm. The mass of the impacting fragments was 0.8–1.4 kg. High speed photographs proved that the fragments hit the samples with their peripheral surface corresponding to the width of the grinding wheel of 40 mm (Figure 13). Thus, the fragments observed in the bursting test were roughly comparable to the projectiles with a mass of 1250 g and a diameter of 40 mm.

The impact tests showed impact resistance between ~2600 Nm when using blunt projectiles and 1440–2000 J when using sharp projectiles. These results correspond fairly well to those in the bursting tests, especially when taking into account the different dimensions of the samples in the impact and in the bursting tests.

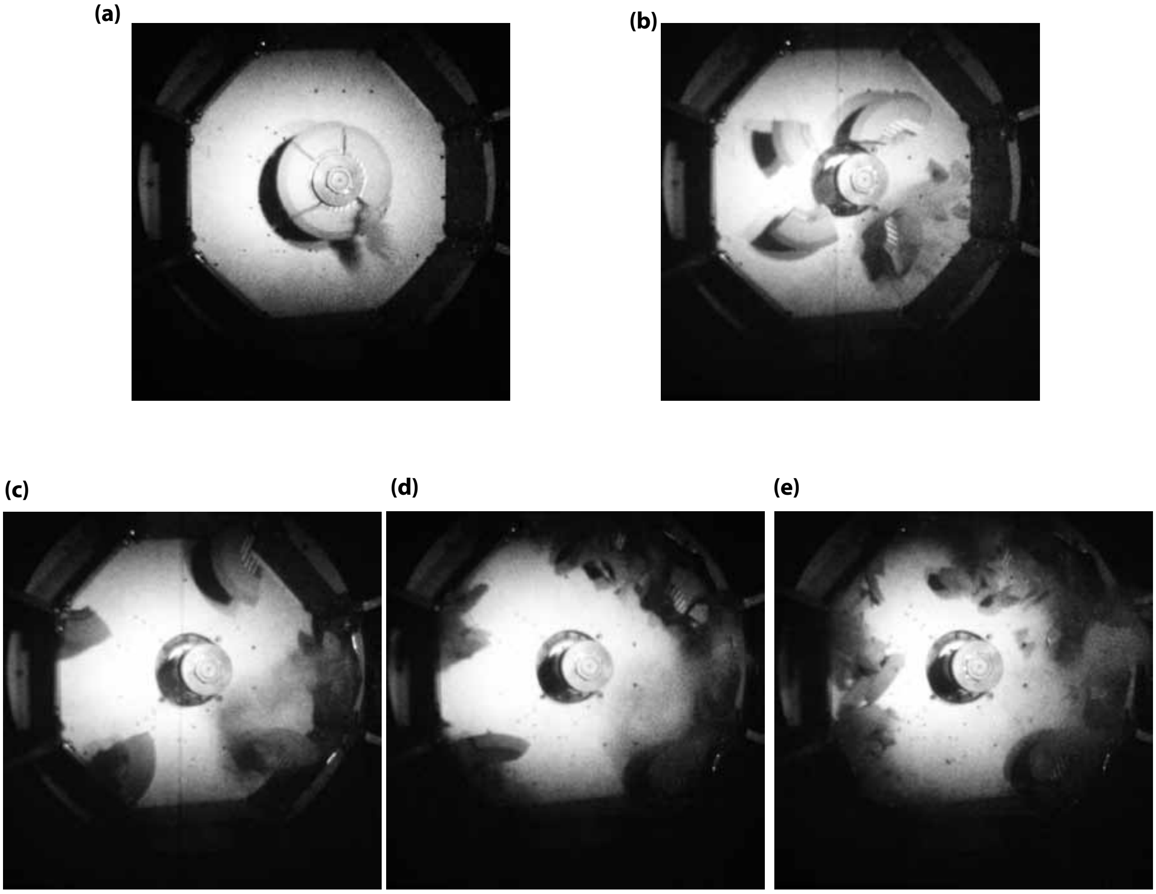


Figure 13. Grinding wheel fragments during impact on test samples.

As opposed to the polycarbonate screens, the steel sheets could not be loaded to the limit. The bursting of both the straight and the profiled grinding wheels produced translatory fragment energies of ~2700 Nm, which only led to a plastic deformation of the sheets.

4. SUMMARY AND CONCLUSIONS

The ability of components to withstand impact loads without damage affecting functional capability and safety does not depend only on the mechanical properties of the materials used and the energy of the impacting parts. The geometry and the strength of the impacting parts are also of vital importance for the impact resistance. To realistically investigate and evaluate the strength of materials for impact loads, the different factors arising from material properties and conditions of impact and the partly complex interactions between these factors have to be taken into account.

The tests carried out with projectiles made from conventional grinding wheel ceramics show that the impact resistance of materials decreases to a greater or lesser extent with increasing sharp-edgedness, decreasing diameter and increasing strength of the impacting parts. The actual extent of the influence of those parameters on the impact resistance depends on the type of material subjected to impact. Increased sharp-edgedness of the projectiles, e.g., had considerably less effect on polycarbonate than on steel sheet. The influence of the projectile strength on the impact resistance was also lower for polycarbonate than for steel sheet.

According to the results of impact and bursting tests, in principle it is possible to evaluate the impact resistance of guards on stationary grinding machines only on the basis of impact tests with standardizable projectiles and thus do without the time-consuming and cost-intensive verification method in Standard No. EN 13218:2002, where real abrasive products running at maximum operating speed are destroyed inside the guard [3].

When performing impact tests, the shape, mass and dimensions of the projectiles should correspond to the fragments of bursting grinding wheels. Furthermore, the kinetic energy of the projectiles should equal the translatory fragment energy [3] considered as decisive for the stress on the guards. As the strength of the abrasive products used on a grinding machine is not necessarily known beforehand or abrasive products of different strengths may be used, the most unfavourable conditions should be assumed and a correspondingly high projectile strength should be chosen. Therefore, the use of steel projectiles is recommended, which, as opposed to projectiles made from grinding wheel ceramics, also have the advantage of being reusable. In principle, guard dimensions chosen on the basis of impact tests with steel projectiles instead of ceramic projectiles are on the safe side.

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