Safety Glasses

Preventing Eye Injuries From Carbide Tips

By Steven A. Sanders, Clifford C. Bigelow and Frederick E. Schmidt Jr.

The use of safety glasses can prevent eye injuries in countless situations. Yet, all types of people—from skilled workers to do-it-yourselfers—continue to sustain eye injuries that could have been prevented with the use of appropriate protective eyewear. These include four specific incidents involving table saw users who sustained eye injuries when fragments of carbide tooth tips were ejected from the saw blades during operation.

In these particular cases, some of the injured users claimed that the carbide tip penetrated the safety glasses they were wearing, while others who were not wearing protective eyewear claimed that the glasses would not have prevented their injury. Testing was performed to compare the impact performance of safety glasses to impacts generated by carbide tooth tips ejected from spinning table saw blades during operation.

Results indicate that typical carbide tooth tips will not have sufficient energy to penetrate commercially available safety glasses and that the use of safety glasses could have prevented the eye injuries investigated.

IN BRIEF

- **Table saw users have sustained eye injuries due to fragments of carbide tips becoming ejected from the saw blades during operation. In some cases, the injured party claimed that the carbide tooth tip penetrated their safety glasses while others claimed that the glasses if worn would not have prevented their injury.**
- **For the incidents investigated, testing shows that carbide tooth tips ejected from table saw blades during operation could not penetrate commercially available safety glasses and that the use of safety glasses, or in most cases, proper use of the saw blade guard, could have prevented the eye injuries sustained.**
- **In some cases, proper eyewear was neither selected nor used in accordance with ANSI standards. This article describes a method for selecting suitable protective eyewear.**

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Carbide Tips

Circular saw blades vary greatly in size, utility and cost, but most modern wood-cutting circular saw blade teeth are constructed of a steel body or plate with cemented carbide tips brazed to the cutting end of the blade teeth. Carbide-tipped blades retain their sharpness much longer than standard steel or high-speed steel blades. Photo 1 shows the difference in appearance between steel and carbide-tipped teeth.

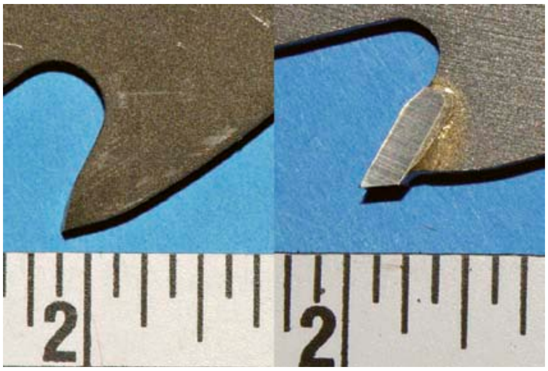


Photo 1: An alloy steel circular saw blade tooth (left) looks different from a carbide tooth tip (right).

Carbide is actually not a metal, but rather a hard, wear-resistant ceramic material. Most carbide tooth tips are cemented carbides, which are produced from small, hard and brittle carbide granules cemented together with a metal binder to create a hard, wear-resistant composite material with much better toughness than a tooth made from solid carbide. Cemented carbides are also referred to as ceramic-metal composites, or cermets. The metal binder for cemented carbides is usually a cobalt or nickel alloy, while the ceramic component typically falls into one of three major groups: tungsten carbide, chromium carbide or titanium carbide.

As with most materials, there is a compromise in material properties. Carbides are an economically viable alternative to the older, alloy steel blades where the high hardness of carbide and their resistance to softening by frictional heating affords them superior wear resistance to alloy steel teeth. The compromise is that their high hardness also results in a material that has lower toughness compared to alloy steel, and is more prone to brittle fracture under impact. Impact damage is a poten-

Figure 1

Table Saw

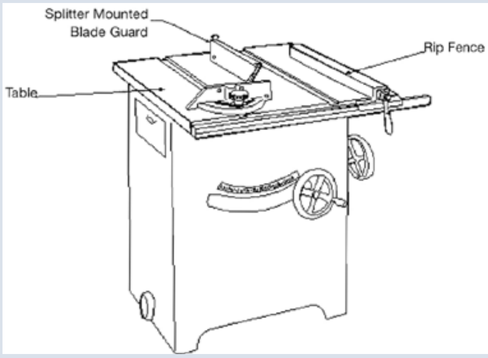
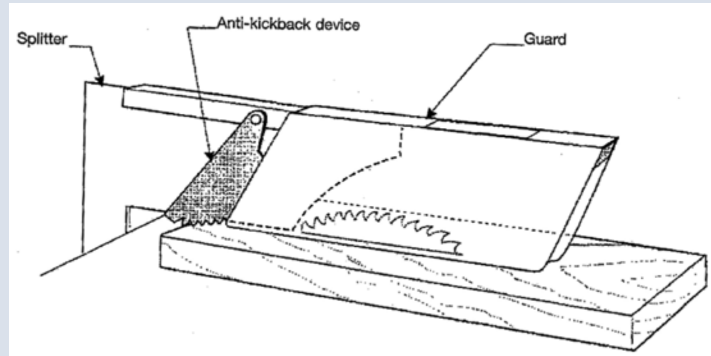


Figure 2

Splitter-Mounted Guard



Note. *Figure 1 is Illustration 7A from ANSI/WMMA O1.1-2004. Figure 2 is Illustration 7E from ANSI/WMMA O1.1-2004.*

tial mechanism for fragments of a carbide tooth tip being ejected from a spinning saw blade. However, the low material toughness is outweighed by the tremendous increase in durability and long-term cutting performance of carbide tipped blades.

Table Saws

Having clarified what a carbide tip is, let's also define what a table saw is. According to ANSI/WWMA (2004), a table saw is "a machine designed to use a circular saw blade mounted on an arbor below the work support means." In simpler terms, a table saw has a circular saw blade, of which the upper portion (typically driven by an electric motor) rises up through a slot in the table that provides support for the workpiece being cut (Figure 1).

Most table saws come equipped with some form of a blade guard, usually a splitter-mounted guard (Figure 2). A splitter or spreader is a flat metal piece placed behind and in-line with the saw blade. It is slightly narrower than the saw blade and is designed to prevent the workpiece from pinching the sides of the blade while cutting. While the guard helps prevent hand contact with the spinning blade, it also reduces the risk of the user being struck by any flying debris.

While ANSI/WWMA O1.1-2004 states that table saw manufacturers shall provide means to reduce the risk of projectiles being ejected from the saw (such as by a guard or other design feature), it recommends that operators use face or eye protection where ejected materials cannot be contained. The standard further states that the face or eye protection worn by the operator shall conform to ANSI/ISEA Z87.1.

Table saw manufacturers generally provide various design safety features (e.g., blade guards, antikickback devices), warnings and instructions to help protect against the reasonably foreseeable hazards associated with using table saws. However, table saw users could still be injured. Equipment manuals often contain multiple warnings and instructions advising users to always use the blade guard and to wear safety glasses, yet users may intentionally remove the blade guard or elect to not wear safety glasses while operating table saws (as in the cases investigated for this article).

Blade guards are designed to withstand anticipated impacts from debris ejected from the blade. However, because of the various sizes of workpieces and types of cuts that can be performed on a table saw, in some cases a blade guard may not be positioned to contain all ejected materials; this is why personal eye protection is always recommended. Table saw users can avoid many potential injuries by following warnings and instructions provided in the user's manual.

Impact Performance Requirements for Safety Glasses

ANSI/ISEA Z87.1-2003 categorizes eye and face protection devices into five different groups: spectacles, goggles, faceshields, welding helmets/handshields and respirators. In this context, the term *safety glasses* refers to eye protection spectacles with nonremovable plano (non-prescription) lenses. The 2003 version of Z87.1 outlines both basic-impact and high-impact testing requirements for safety glasses. Those that pass only the basic-impact requirements carry a Z87 stamp, while those that pass the high impact requirements are also stamped with a + (Photo 2).

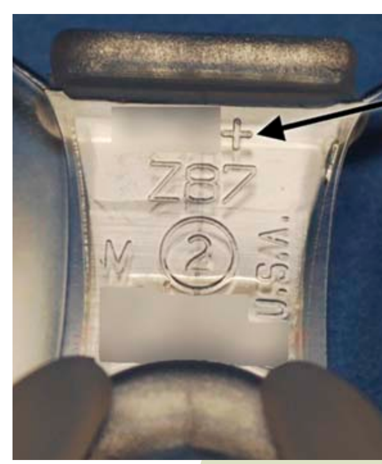


Photo 2: The + stamp (see arrow) is added to high impact safety glasses per ANSI/ISEA Z87.1.

In the 2010 version of ANSI/ISEA Z87.1, safety glasses are categorized as either nonimpact or impact protectors. Impact-rated protectors must pass all high-impact testing requirements and are marked with Z87+ while nonimpact-rated protectors are those that do not pass all high-impact testing requirements and are only marked with Z87 (ANSI, 2010).

Both the 2003 and 2010 versions of the standard delineate four impact tests for safety glasses: 1) drop ball impact; 2) high mass impact; 3) high velocity impact; and 4) lens penetration. The drop ball and high mass impact tests use a 1-in. diameter steel ball and a 500 gram pointed projectile, respectively, dropped from a height of 50 in. onto the lens of the safety glasses. The high velocity impact test requires that a ¼-in.-diameter steel ball impact the lens of the safety glasses at a speed of 150 ft per second (fps). The lens penetration test consists of a

Table 1

Kinetic Energies: ANSI Z87.1 Impact Test Projectiles

Test description	Drop ball impact	High mass impact	High velocity impact	Lens penetration
Test projectile description	1-in.-diameter steel ball	Pointed projectile	¼-in.-diameter steel ball	Weighted needle
Projectile mass (g)	68	500	1.1	44.2
Projectile drop height (in.)	50	50	n/a	50
Calculated impact velocity (ft/s)	16.4	16.4	150	16.4
Calculated impact kinetic energy (ft-lb)	0.6	4.6	0.8	0.4

44.2-g weighted needle dropped from a height of 50 in. onto the lens.

Although the shape, mass and speed of objects used to impact the safety glass lenses vary between these four tests, it is useful to compare the kinetic energy of each impacting object. Equation 1 describes the kinetic energy of any object.

$$K.E. = \frac{1}{2} mv^2 \quad \text{Equation 1}$$

where m is the mass of the object and v is its velocity.

Table 1 presents the calculated kinetic energies of the projectiles used in the ANSI/ISEA Z87.1 impact tests. It is important to note that for nonremovable plano lenses, the ANSI tests are performed with the safety glasses placed on an anthropomorphic headform. For eye protection spectacles with removable or nonplano (prescription), the lenses are removed and installed in a fixture for testing.

When safety glasses are impacted while being worn, the ability of the eyewear to flex and move helps dissipate some of the projectile's kinetic energy. When a lens is removed from the frame and mounted in a rigid test fixture, the source of energy dissipation is greatly reduced. Thus, when being struck by the same projectile in the same manner, the impact performance of a lens that has been removed and mounted in a rigid fixture could be diminished compared to when it is installed in safety glasses placed on a headform.

Testing involved placing safety glasses on an anthropomorphic headform and firing projectiles at the eyewear with an air rifle (Photo 3, left). An enclosure (Photo 4, right) was constructed to contain the projectiles.

Impact Testing of Safety Glasses

Although different projectiles may have similar kinetic energies, many other factors contribute to a material's impact performance, such as projectile/material geometry, orientation at impact and material properties. To this point, the investigators conducted laboratory testing to evaluate the impact performance of safety glass lenses with carbide tips. Eight different models of protective eyewear from various manufacturers were purchased for use in the impact testing. Each pair bore markings that indicated that it met either the basic or high-impact requirements of ANSI/ISEA Z87.1. The lenses were typically 3- to 4-mm-thick and were made from polycarbonate.

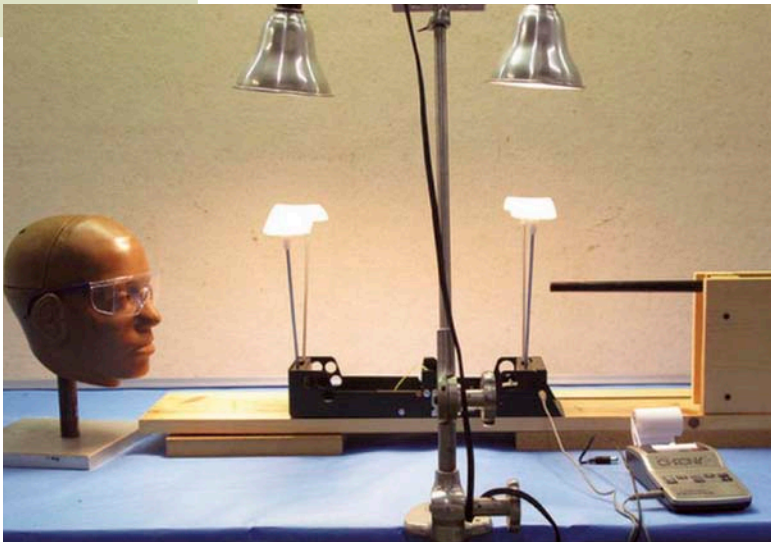
Testing involved placing safety glasses on an anthropomorphic headform and firing projectiles at the eyewear with an air rifle (Photo 3). The speed of each projectile was measured and recorded using a Chrony F-1 Shooting Chronograph. An enclosure (Photo 4) was constructed to contain the projectiles after impacting the eyewear.

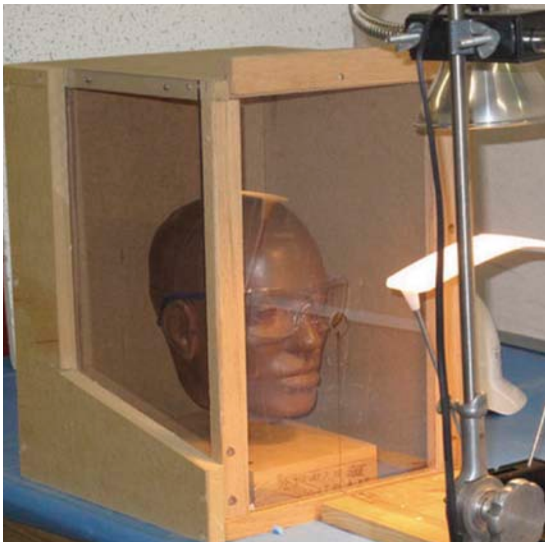
To test whether a carbide tip ejected from a table saw blade during operation could penetrate the safety glasses, the investigators had to first determine the maximum speed of a carbide tip on a spinning blade. Release of a carbide tip or a fragment of the tip as the blade is spinning will result in a tangential path from the blade. The velocity of a blade tooth tip during operation of a saw is a function of the blade diameter and rotational speed, as seen in Equation 2, where r_{blade} is the blade radius and ω_{blade} is the angular velocity of the blade.

$$v_{tip} = r_{blade} \times \omega_{blade} \quad \text{Equation 2}$$

For the cases investigated, it was found that table saws had 10-in. blades with maximum rotational speeds of 5,000 rpm or less. Referencing Equation 2, a 10-in. saw blade spinning at 5,000 rpm would have a tip speed of approximately 218 fps.

A projectile's shape is another characteristic that would likely affect its ability to penetrate the lens. Pointed or sharp-edged projectiles will result in a higher surface stress concentration and an in-





creased likelihood of penetration. While the size and shape of carbide tooth tips on table saw blades can depend on the blade's design and purpose, carbide tip fragments will likely have such sharp edges.

To evaluate the effect of projectile geometry and mass on impact resistance, various projectiles including carbide tips removed from circular saw blades and sharp-tipped steel projectiles (Photo 5) were used in the testing. The mass of the projectiles used in the testing varied from roughly 0.33 g (carbide tips, BBs and small screw tips) to about 1 g (larger screw tips).

Photo 5: Projectiles used in impact testing include (bottom row, left to right): carbide tip, BB, jacketed BB, screw tip; and (top row): various screw tips.

Table 2

Range of Kinetic Energies for Impact Test Projectiles

Projectile	Carbide tip	BB	Small screw tip	Jacketed BB	Large screw tip
Mass (g)	0.32	0.32	0.32	0.60	1.0
Impact velocity (ft/s)	105-332	259-768	257-304	201-215	216-356
Kinetic energy)ft-lb)	0.12-1.2	0.74-6.5	0.72-1.0	0.83-0.95	1.6-4.3

Impact Testing Results

Although the maximum carbide tip speed of the saw blades involved in the cases investigated was calculated at 218 fps, projectile velocities in testing were varied and increased to upward of 768 fps (the maximum speed attainable with the air rifle used in the testing). Table 2 summarizes the projectile impact test conditions. All of the impact tests were thoroughly documented, including photographs and high-speed video.

Tests showed that although the lenses sustained various degrees of surface indentations, none of the projectiles penetrated any of the spectacle lenses. Even when using projectiles with masses greater than carbide tips and at velocities significantly higher than those achievable by a carbide tip during normal table saw operation, all of the lenses prevented the projectiles from penetrating or contacting the headform. None of the impacts cracked, separated or penetrated the lenses. The polycarbonate lenses exhibited high toughness, and in each case, it was able to absorb impacts much more severe than those required by the ANSI standard. Photos 6 through 11 show examples of the various impacts.

Impact Testing Conclusions

The testing performed showed that carbide tips ejected from spinning table saw blades were not capable of penetrating the safety glasses examined, even at velocities significantly greater than the table saw blades could possibly achieve during normal operation. Furthermore, none of the projectiles with masses greater than carbide tips were able to penetrate the safety glasses examined, even at velocities greater than those the table saws could achieve during normal operation. All of the protective eyewear tested resisted impacts far greater than the requirements for impact-rated eyewear per ANSI/ISEA Z87.1.

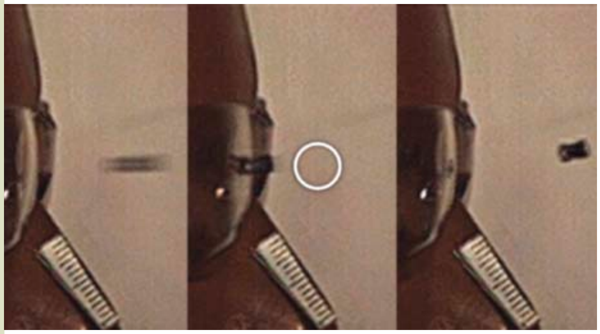
Selecting Eye Protection

While testing has shown that safety glasses could have prevented the injuries in the cases investigated, readers should not assume that safety glasses can protect against every type of eye hazard. For example, what if a projectile's kinetic energy exceeds the eyewear's ability to resist such an impact? What if hazards besides impact exist?

To select PPE suitable for a given setting, one must first identify the reasonably probable hazards in that setting. Annex J of Z87.1-2010 provides guidance on hazard assessment and selection of appropriate eye/face protection:

> The safety officer or other knowledgeable, responsible party should conduct an eye and face hazard assessment of the occupational or educational work setting. The hazard assessment should determine the risk of exposure to eye and face hazards, including those which may be encountered in an emergency. Employers should be aware of the possibility of multiple and simultaneous hazard exposures and be prepared to

Photo 6 (left) depicts lens deformation due to BB impact at 718 fps, while Photo 7 (right) shows lens deformation due to BB (#4, #7) and small screw tip impacts (#5, #6). Projectile speeds were 481 fps (#4), 304 fps (#5), 257 fps (#6), and 621 fps (#7).



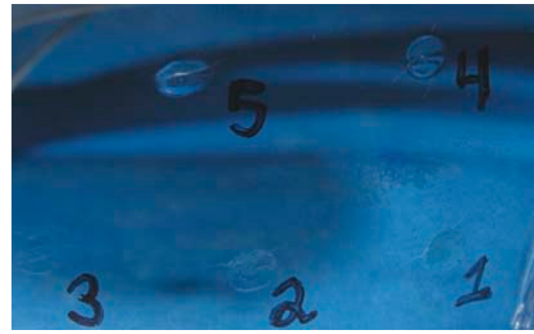


Photo 8 (left) shows a high-speed video still progression of lens deformation due to impact by a jacketed BB. Note the incoming projectile (left), the BB striking the lens (center) and the BB rebounding after impact (right). Note the permanent deformation of the lens due to impact (circle). Photo 9 (right) shows lens deformation due to BB (#1, #3) and jacketed BB impacts (#4, #5). Projectile speeds were 273 fps (#1), 277 fps (#2), 278 fps (#3) and 211 fps (#4, #5). Indentation #4 resulted from the impact seen in Photo 8.

Photo 10 (top) shows deformation due to carbide tip impacts. Projectile speeds were 105 fps (#1), 107 fps (#2), 332 fps (#3), 271 fps (#4) and 307 fps (#5). Photo 11 (bottom) shows lens deformation due to large screw tip impacts. Projectile speeds were 324 fps (#3) and 356 fps (#4).

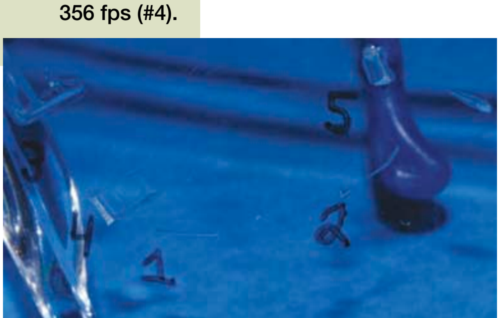
protect against the highest level of each hazard. Eye and face protectors alone should not be relied on to provide protection against any identified hazards, but should be used in conjunction with guards, engineering controls, and sound occupational and educational safety practices.

The first step of a hazard assessment is a survey of the work area to identify potential eye/face hazards, such as impact, heat, chemical or liquid splash, dust, glare and optical radiation. The second step is to identify hazard types and sources such as:

- motion that could result in impact with people, equipment or projectiles;
- high temperatures that could result in burns, fires or explosions;
- hazardous chemicals;
- particulate matter (e.g., sparks, dust);
- optical radiation (e.g., ultraviolet lamps, welding);
- electrical hazards.

The third and fourth steps are to organize, then analyze the data gathered in steps one and two. The fifth step is to select the protector(s) that are deemed suitable for the identified hazards. Annex I of Z87.1-2010 provides a chart to aid the selection process. The sixth and final step of the hazard assessment is to regularly reassess the work area to identify any changes in the associated hazards.

When selecting PPE for protection against impact, one must make a judgment to ensure that the PPE ultimately selected is "consistent with the reasonably probable hazard" (ANSI/ISEA, 2010). The standard also states:



> Protectors not specifically rated for impact or protectors complying only with the applicable requirements of Section 5 may be used only in an environment where the known or presumed impact, radiation and dust, mist and splash hazards do not exist or are of minimal intensity or probability of occurrence. Impact-rated protectors should be used in an environment when the known or presumed hazards are of a high velocity, high mass or high impact nature.

For a high-velocity impact hazard (such as that present during table saw operation), Annex I of Z87.1-2010 recommends that the following impact-rated protectors be considered for use: spectacles with side protection; goggles with direct or indirect ventilation; and faceshield worn over spectacles or goggles.

To select appropriate protector(s), one must first determine what must be protected: just the eyes or the entire face? If only the wearer's eyes are to be protected, then either spectacles or goggles alone could be considered. If the user's entire face is to be protected, then a faceshield worn over spectacles or goggles should be considered.

The characteristics of the impact hazard identified (e.g., projectile material, geometry, mass, velocity) are another consideration. While goggles afford greater impact protection than spectacles and faceshields afford even greater impact protection than goggles, the gear selected should be suitable for the most severe of the reasonably probable impact hazards. Furthermore, the presence of other hazards may dictate the type of impact eye/face protection that is necessary. Ultimately, it is up to the user (or the responsible party) to determine what hazards are to be protected against, then to select the PPE appropriate for the task.

Conclusion

In the four cases investigated, testing showed that commercially available safety glasses meeting the ANSI/ISEA Z87.1 standard can protect a user's eyes from the impact hazard presented by carbide tips ejected from table saws. The impact performance of the safety glasses tested typically far exceeded the minimum impact requirements of ANSI/ISEA Z87.1.

As OSH professionals know, PPE is just one of several ways to protect a user from this type of hazard. Proper table saw design and guarding, following warnings and instructions (in operator manuals, and on table saws and blades themselves) and on-the-job/employee training all contribute to reducing the risk of injury from projectile hazards. **PS**

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