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Design guidelines for bonding prisms to mounts

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ABSTRACT

Epoxy adhesives are widely used to bond prisms in cantilever fashion to mechanical mounting surfaces. Typically, the adhesive is applied in a prescribed thickness to a raised land on the mounting surface. This land then defines the area of contact with the prism. In order for the bond to survive, this area should equal or exceed some value related to the mass of the prism, the manufacturer's specified shear strength of the cured adhesive and the anticipated maximum acceleration due to shock and/or vibration during shipment, operation and mishandling by the user. In this paper, formulas relating prism clear aperture, material density and acceleration loading to minimum bond area for a representative commercially-available epoxy are derived for several common prism types. Since these computations are based on nominal conditions and some approximations, they should be regarded as guidelines for preliminary design purposes. Experimental verification of the choice of materials, application/cure methods and of the specific interface design is advisable in critical applications.

1. INTRODUCTION

A technique that is highly favored by optomechanical engineers for mounting small to medium-sized mirrors and prisms involves glass-to-metal bonds using adhesives. This design technique generally results in reduced interface complexity and compact packaging while providing mechanical strength adequate to withstand the severe shock and vibration conditions and extreme temperature changes characteristic of military and aerospace applications as well as of some industrial ones. The technique is also frequently used in less rigorous applications because of its inherent simplicity and reliability.[1]

The critical aspects of a glass-to-metal bond are the characteristics of the chosen adhesive, the thickness of the adhesive layer, the cleanliness of the surfaces to be bonded, the dissimilarity of the coefficients of thermal expansion for the materials bonded, the area of the bond interface, the environmment that the bonded assembly will experience and the care with which the bonding operation is performed. Several types of adhesives are available for use in such applications, but the most popular are the epoxies and the urethanes. The manufacturer's recommended procedures for applying and curing the selected adhesive should be followed unless special requirements of the application dictate otherwise. The manufacturer should be consulted if there is any question about process or material suitability for any particular application. Experimental verification of the choice of materials and methods and of the specific design is advisable in critical applications.

In this paper, we concentrate on the design of the adhesive interface between certain common types of optical prisms and mechanical mounts. For simplicity, we assume that the prism is cantilevered from a metal mounting surface and that the interfacing surfaces are flat. Figure 1 illustrates the general configuration for the case of mounting a roof penta prism on a circular land machined into an aluminum flange. Accelerations are assumed to place the bonded joint in shear although the adhesives typically have comparable tensile and shear strengths. Typically, these strengths are all of the order of $1.38X10^7$ N/m^2 (2000 lb/in^2) on properly prepared surfaces so we will base our present considerations on one representative adhesive type, namely 3M EC-2216 A/B epoxy, that has approximately this shear strength after proper cure.

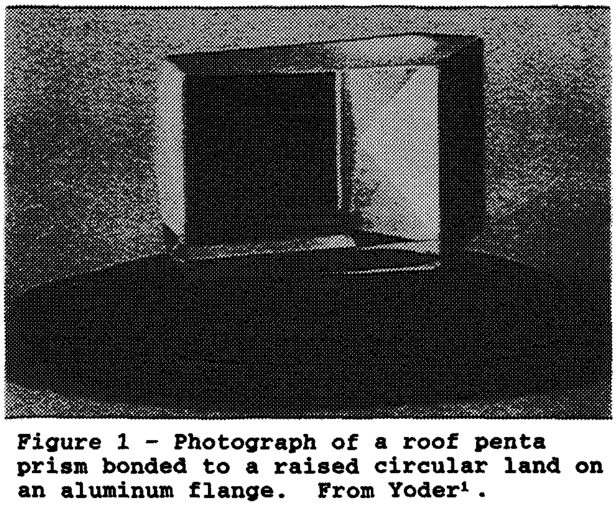

Figure 1 - Photograph of a roof penta prism bonded to a raised circular land on an aluminum flange. From Yoder[1].

To achieve the specified bond strength, the adhesive layer should have a specific thickness. In the case of EC-2216 A/B, this is 0.075 to 0.125 mm (0.003 to 0.005 in).

One common method for ensuring the right layer thickness is to place spacers (such as plastic shim stock) of the required nominal thickness at three symmetrically-located places on one of the surfaces to be bonded before applying the adhesive. Care must be exercised to register both parts firmly against the spacers during assembly and curing. The adhesive should not be allowed to creep between the spacers and either part to be bonded since this could affect the adhesive layer thickness.

One way of judging the adequacy of the mounting design is to compare a factor comprising the product of prism mass and anticipated maximum acceleration divided by the bond area to the shear strength of the cured adhesive. If the computed factor is smaller than the strength value, a safety factor will exist in the design. Typically, such a safety factor should not be smaller than two.

Since the volumes of all prisms can be geometrically related to their aperture sizes (typically called "A") for passage of a collimated light beam of circular cross-section propagating parallel to the optical axis, we can derive formulas for the masses of such prisms in terms of their A's and the densities of the materials from which the prisms are made. Minor chamfers and bevels are generally neglected and all prisms are assumed to have square or rectangular entrance and exit faces. This gives a conservative estimate of bond capability.

Given the area of the bond interface, the maximum accelerations that the assemblies should withstand can be computed. Conversely, given the acceleration specifications, the minimum bond areas can be computed. It should be noted that, for each prism type, there is some maximum bond area that can be accomodated. For simplicity, we here assume that the bond area is circular unless the bonded surfaces are elongated, in which case, a racetrack-shaped area is assumed. The adhesive is assumed to be spread uniformly over this area. While we speak here of prisms as made of glass and the mating mechanical parts as made of metal, it should be realized that the technique also may apply to other types of rigid materials.

We here consider 16 different types of individual prisms and prism assemblies commonly used in optical instruments. These prism types are listed in Table 1. Designs for these prisms are in many cases derived from MIL-HBK-141, Optical Design[2] with the balance coming from miscellaneous publications[3-5] and from the author's designs for specific applications.

Table 1 - Prism types considered

Monolithic cube	Penta	Porro
Beamsplitter cube assy.	Roof penta	Porro erecting assy.
Right angle	Harting-Dove	Abbe
Rhomboid	"Reversion" assy.	Abbe erecting assy.
Amici	Pechan assembly	
Schmidt	Delta	

2. DESIGN OF THE PRISM INTERFACE

To illustrate the technique advanced here, we consider a cube prism (see Figure 2) made of a single piece of glass with square aperture A cm. It has a volume of A^3 cm^3 and a mass in grams of A^3d where d is the glass density in g/cm^3. Assuming the minimum bond area to be Q cm^2 and the impressed acceleration to be G times gravity, we express the shear stress in N/m^2 in the joint as $98.1A^3dG/Q$. Allowing for a safety factor of two and an epoxy shear strength of $1.38X10^7$ N/m^2, we compute the area Q as $1.42X10^{-5}A^3dG$ cm^2. The largest circle that can be inscribed within a square prism face of dimension A has an area of $0.785A^2$. A bond with this maximum area should withstand an acceleration factor G of $5.53X10^4/Ad$ times gravity with a safety factor of two. If the prism is made of glass with a density of 2.51 g/cm^3 and has an aperture A of 2.54 cm (1 in), the acceleration at which the maximum-area bond should theoretically fail is 8665 times gravity. For most applications, an area considerably smaller than this maximum would suffice. For example, a 1 cm (0.4 in) diameter bond should support accelerations up to 1350 times gravity.

Basic prism dimensions are summarized in Figures 3 through 17 for each of the 15 additional prism configurations under consideration. For the convenience of the reader, the key design parameters (geometrical volume, required minimum bond area for one times gravity and safety factor of two and maximum possible circular or racetrack bond area) for each prism type are summarized in Table 2.

Table 2 - Key design parameters for the sixteen prism types

Prism Type	Volume (cm^3)	Required Bond Area (cm^2)	Maximum Bond Area (cm^2) Circular	Racetrack	Remarks
Monolithic cube	A^3	$1.42X10^{-5}A^3dG$	$0.78A^2$		
Beamsplitter cube assembly	A^3	$1.42X10^{-5}A^3dG$	$0.27A^2$		Bond one prism
Right angle	$0.5A^3$	$7.10X10^{-6}A^3dG$	$0.27A^2$		
Rhomboid	$A^2(A+B)$	$1.4X10^{-5}A^2(A+B)dG$	$0.39A^2$	$0.68A^2$	For $B=0$
			$0.78A^2$	$0.58A^2+0.50AB$	For $B>0.414A$
Amici	$0.78A^3$	$1.10X10^{-5}A^3dG$	$0.16A^2$	$0.31A^2$	
Schmidt	$0.86A^3$	$1.23X10^{-5}A^3dG$	$0.32A^2$		$a=0.1A$
Penta	$1.50A^3$	$2.13X10^{-5}A^3dG$	$1.13A^2$		
Roof penta	$1.79A^3$	$2.55X10^{-5}A^3dG$	$0.82A^2$		
Harting-Dove	$3.90A^3$	$5.54X10^{-5}A^3dG$	$0.95A^2$	$2.05A^2$	$a=0.05A$ For $N=1.5170$
"Reversion" assy.	$4.20A^3$	$5.97X10^{-5}A^3dG$	$1.09A^2$	$1.99A^2$	
Pechan assembly	$1.80A^3$	$2.56X10^{-5}A^3dG$	$0.60A^2$		Bond on larger prism
Delta	$1.05A^3$	$1.49X10^{-5}A^3dG$	$0.63A^2$		For $N=1.7174$
Porro	$1.29A^3$	$1.83X10^{-5}A^3dG$	$0.51A^2$		$a=0.1A$
Porro erecting assembly	$2.57A^3$	$3.67X10^{-5}A^3dG$	$0.51A^2$		
Abbe	$1.84A^3$	$2.62X10^{-5}A^3dG$	$0.46A^2$		$a=0.1A$
Abbe erecting assembly	$3.69A^3$	$5.24X10^{-5}A^3dG$	$0.50A^2$	$0.96A^2$	Bond on Porro prism

3. CONCLUSION

We have here discussed a technique that should facilitate the preliminary design of the bonding interface for many types of commonly used prisms. It is important to reiterate that experimental verification of designs created by this technique would be appropriate for critical applications.

4. REFERENCES

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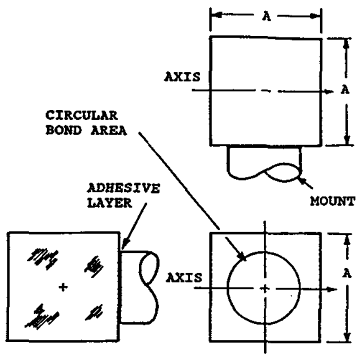


Fig. 2 - Monolithic cube prism

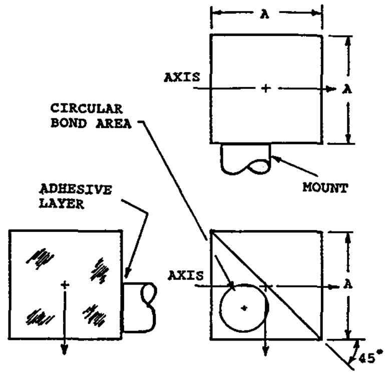


Fig. 3 - Beamsplitter cube prism assembly

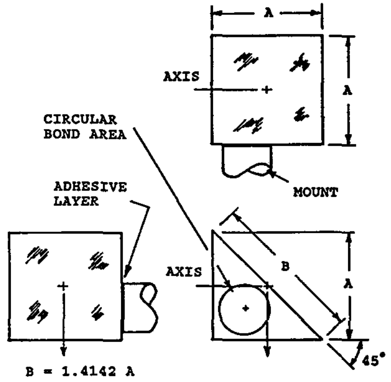


Fig. 4 - Right angle prism

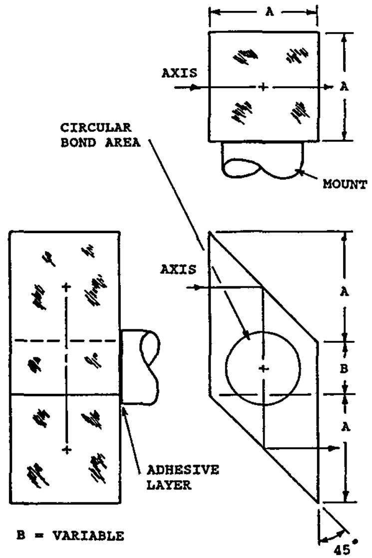


Fig. 5 - Rhomboid prism

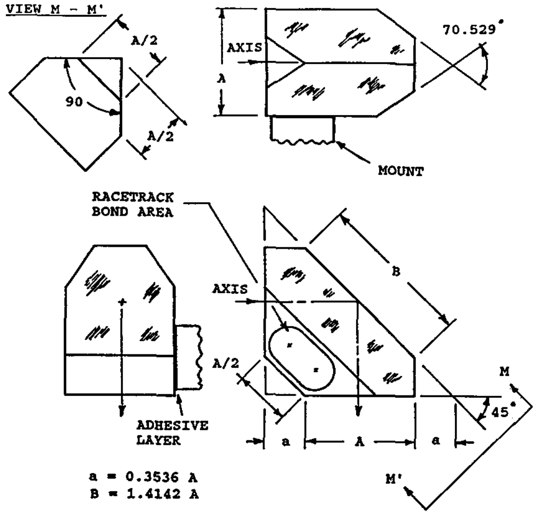


Fig. 6 - Amici prism

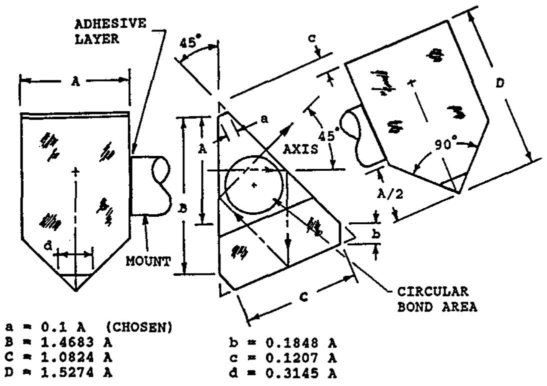
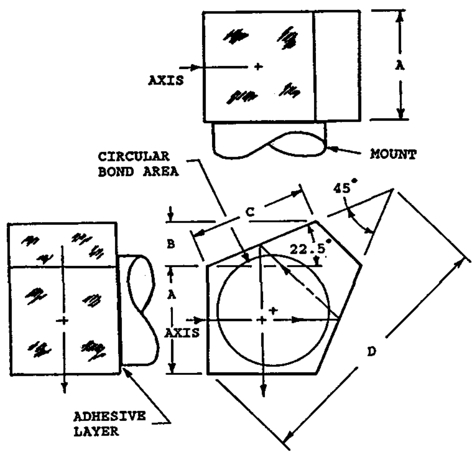
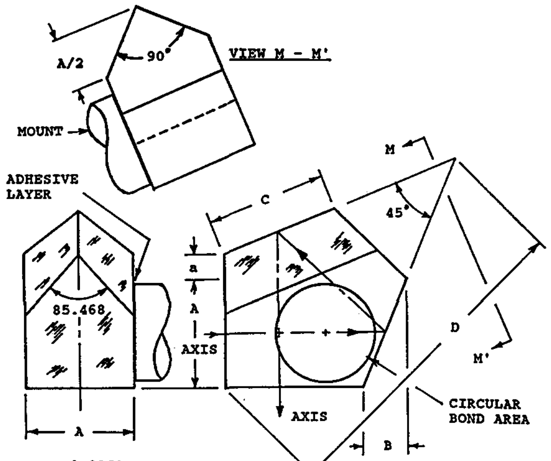


Fig. 7 - Schmidt prism



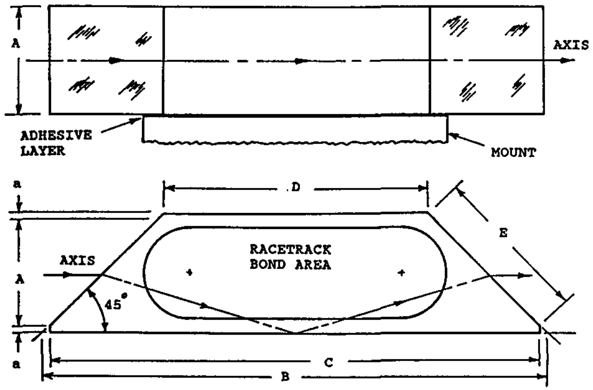
B = 0.4142 A
C = 1.0824 A
D = 2.4142 A

Fig. 8 Penta prism



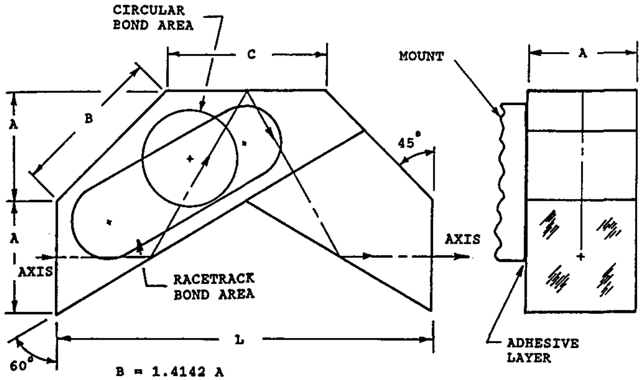
a = 0.2368 A D = 2.9859 A
B = 0.4142 A E = 1.6510 A
C = 1.0824 A

Fig. 9 - Roof penta prism



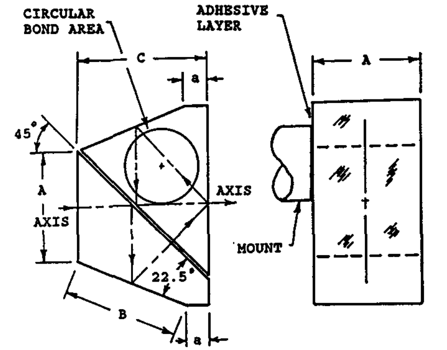
a = 0.0500 A N = 1.5170 (CHOSEN)
B = 4.6498 A D = 2.4498 A
C = 4.5498 A E = 1.4849 A

Fig. 10 - Harting-Dove prism



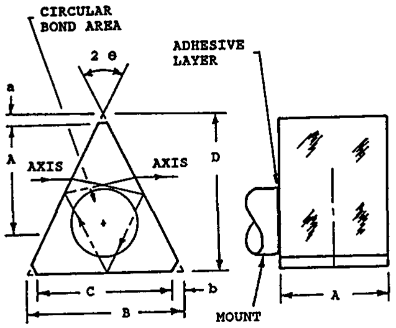
B = 1.4142 A
C = 1.4641 A

Fig. 11 - "Reversion" prism assembly



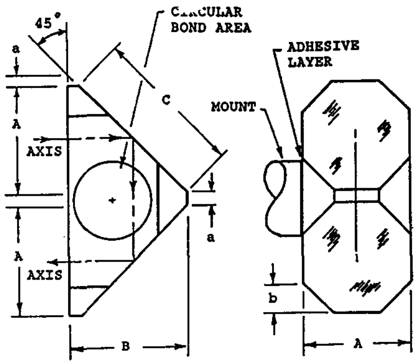
a = 0.2071 A
B = 1.0824 A
C = 1.2071 A

Fig. 12 - Pechan prism assembly



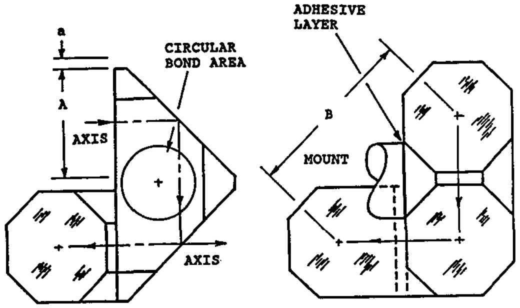
N = 1.7174 (CHOSEN)
a = 0.1000 A
B = 1.4448 A
D = 1.4624 A
θ = 26.228°
b = 0.0880 A
C = 1.2687 A

Fig. 13 - Delta prism



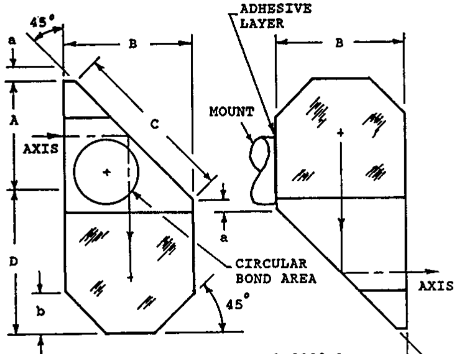
a = 0.1000 A
C = 1.4142 A
B = 1.1000 A

Fig. 14 - Porro prism



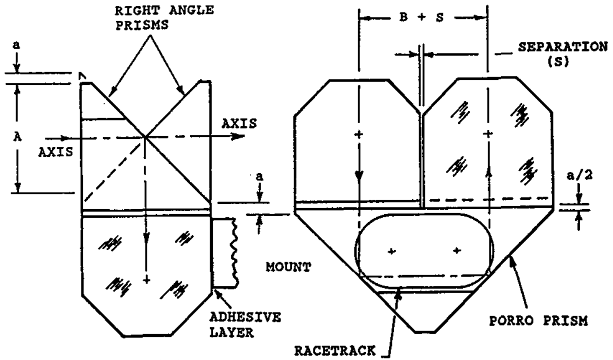
a = 0.1000 A
B = 1.5556 A

Fig. 15 - Porro erecting prism assy.



a = 0.1000 A
B = 1.2000 A
C = 1.5556 A
D = 1.3000 A
b = 0.3515 A

Fig. 16 - Abbe prism



a = 0.1000 A
B = 1.2000 A

Fig. 17 - Abbe erecting prism assy.