



Standard Practice for Preparation of Plastics Materials for Electroplating¹

This standard is issued under the fixed designation B 727; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice is a guide to the surface preparation of plastic materials for decorative and functional electroplating, where the sequence of chemical treatments may include: cleaning, conditioning, etching, neutralizing, catalyzing, accelerating, and autocatalytic metal deposition. Surface preparation also includes electrodeposition of metallic strike coatings immediately after autocatalytic metal deposition. These treatments result in the deposition of thin conductive metal films on the surface of molded-plastic materials, and are described in this practice.

1.2 Once molded-plastics materials have been made conductive, they may be electroplated with a metal or combination of metals in conventional electroplating solutions. The electroplating solutions and their use are beyond the scope of this practice.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. (See Section 4.)*

2. Referenced Documents

2.1 ASTM Standards:²

- B 532 Specification for Appearance of Electroplated Plastic Surfaces
- B 533 Test Method for Peel Strength of Metal Electroplated Plastics
- B 553 Test Method for Thermal Cycling of Electroplated Plastics³
- B 604 Specification for Decorative Electroplated Coatings

¹ This practice is under the jurisdiction of ASTM Committee B08 on Metallic and Inorganic Coatings and is the direct responsibility of Subcommittee B08.02 on Pre Treatment.

Current edition approved April 1, 2004. Published April 2004. Originally approved in 1983. Discontinued January 2004 and reinstated in 2004 as B 727–04.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Withdrawn.

of Copper Plus Nickel Plus Chromium on Plastics

3. Significance and Use

3.1 A variety of metals can be electrodeposited on plastics for decorative or engineering purposes. The most widely used coating consists of three layers—copper plus nickel plus chromium—for decorative applications. However, brass, silver, tin, lead, cadmium, zinc, gold, other metals, and combinations of these are used for special purposes. The key to producing electroplated plastics of high quality lies in the care taken in preparing plastics for electroplating. The information contained in this practice is useful in controlling processes for the preparation of plastics for electroplating.

4. Hazards

4.1 Some chemical solutions are exothermic upon mixing or in use, thereby requiring cooling and proper containment to prevent injury to personnel.

4.2 For details on the proper operation and safety precautions to be followed by vapor degreasing, see ASTM STP 310.⁴

5. General Considerations

5.1 Nature of Plastics Suitable for Electroplating:

5.1.1 Plastics suitable for electroplating may be a combination of one or more polymers so formulated as to allow selective etching of one or more constituents. The most commonly electroplated material, acrylonitrile-butadiene-styrene (ABS), is a terpolymer. During etching, soft butadiene rubber particles dispersed in the acrylonitrile-styrene matrix are selectively attacked. The microscopic pockets formed by the etching process provide sites for the physical interlocking of the plastic substrate and subsequently applied metallic coatings. The resultant mechanical bonding is instrumental in achieving metal to plastic adhesion.

5.2 Plastics Suitable for Electroplating:

5.2.1 The plastics materials commonly used for injection molded articles to be electroplated are:

5.2.1.1 Acrylonitrile-butadiene-styrene (ABS),

5.2.1.2 Polypropylene,

5.2.1.3 Polysulfone,

5.2.1.4 Modified Polyphenylene Oxide,

5.2.1.5 Polycarbonate,

⁴ *Handbook of Vapor Degreasing*, ASTM STP 310A, ASTM, 1976.

5.2.1.6 Polyester, and

5.2.1.7 Nylon.

5.2.2 The preparation of these materials for electroplating generally involves the basic steps described in this practice, but substantial variations may be necessary to achieve optimum results with plastics other than ABS.

5.3 *Molding Considerations:*

5.3.1 The chemical nature of plastics combined with the nature of the injection molding process produces plastic parts that are somewhat heterogeneous in composition and structure. During the molding of ABS, for example, the shape, size, and distribution of butadiene rubber particles may vary considerably within a part and may affect the uniformity of subsequent surface etching treatments. As a result, under- and over-etching of the surface may occur, either of which can interfere with the adhesion of metal coatings. The use of a properly formulated etchant combined with an organic conditioner may overcome problems of nonuniform etching.

5.3.2 Although it may be possible to overcome problems of nonuniform etching by suitable chemical treatments, control of the injection molding process is critical if plastic parts are to be electroplated successfully. It is essential that the resin be thoroughly dried before molding. The temperature of the mold and all heating zones, the pressure, the total cycle time, and the fill time must be controlled and monitored. Devices exist for controlling all molding parameters precisely.

5.3.3 The visible defects that may arise in the molding process are described in Specification B 532. Molded parts that are obviously defective should not be processed without the approval of the purchaser.

5.3.4 Mold release agents interfere with the adhesion of metallic coatings on plastic substrates and should not be used.

5.4 *Process Selection:*

5.4.1 Due to the complexity and proprietary nature of commercially available processes for preparing plastics for electroplating, a complete process should be selected for a specific type of plastic, and operated according to the specific instructions of the supplier of the process.

5.5 *Handling of Molded Plastic Parts:*

5.5.1 Molded-plastic parts must be kept clean and carefully handled. It is a common practice to use cotton gloves in removing parts from the mold and for all subsequent handling.

5.5.2 The trimming of plastic parts and the removal of flash and runners should be done with care to avoid introducing surface defects. These and other mechanical finishing operations should be completed before beginning the chemical treatment of parts for electroplating. Runners are sometimes left intact to facilitate racking for electroplating at a later stage.

5.6 *Racking:*⁵

5.6.1 Molded-plastic parts can be prepared for electroplating in barrels, trays, or baskets and then transferred to racks designed specifically for electroplating, or they can be processed on racks that are used in both the preparation and electroplating cycles. Which method of racking to use may be dictated by the size of the parts, by efficiency, and other

considerations. The first is the bulk method; the second is called "through-racking."

5.6.2 *Bulk Method*—Small parts are often processed in polypropylene baskets or plastic-coated steel baskets. Somewhat larger parts can be processed in layered baskets made of stainless steel (UNS Types S30400 or S31600), titanium, or plastic-coated mild steel. Parts are placed as closely as possible compatible with the need to provide for complete solution wetting and drainage.

5.6.3 *Through-Racking:*

5.6.3.1 The design of racks to be used in both preparation and electroplating processes is dictated by the requirements of electroplating and the corrosive nature of the solutions.

5.6.3.2 Rack splines and hooks are generally made of copper or copper alloys. Rack cross bars are made of copper or copper alloys if they are to conduct current from the splines to the contacts, but may be made of steel if their function is solely to strengthen and make the rack rigid. Rack contacts are usually stainless steel, although titanium has also been used. If spring action is necessary, phosphor bronze may be used as the contact member with a short stainless steel piece for the tip.

5.6.3.3 The entire rack is sandblasted, primed, and coated with plastisol before use, except for the stainless steel contacts. During the preparation process, the rack coating may become coated with metal, but this does not usually occur because hexavalent chromium is absorbed in the plastisol and prevents autocatalytic metal deposition from occurring.

5.6.3.4 Control of immersion times in neutralizing, catalyzing, and accelerating steps is critical to prevent metal deposition on the rack coating.

5.6.3.5 Parts are positioned on racks to optimize the thickness and appearance of electrodeposited coatings, and to minimize solution dragout.

5.6.3.6 It may be necessary to use current thieves, shields, or auxiliary anodes to obtain uniform metal distribution. The number of contacts is greater for plastic parts than for comparable metal parts. For example, if the total area being electroplated is less than 0.02 m², one contact point is usually sufficient; if the area is 0.25 to 0.60 m², 16 contact points are recommended.

5.6.3.7 Metal deposited autocatalytically or electrolytically must be chemically removed from contacts after each cycle. This is usually accomplished by using nitric acid-containing solutions, or proprietary rack strippers.

6. Preparation of Plastic Substrates⁶

6.1 *Alkaline Cleaning:*

6.1.1 Cleaning in alkaline solutions is optional. If the parts are carefully handled and kept clean after molding, alkaline cleaning can usually be avoided.

6.1.2 Fingerprints, grease, and other shop soil should be removed by soaking plastic-molded parts in mild alkaline solutions that are commercially available. A suitable solution may contain 25 g/L of sodium carbonate and 25 g/L of

⁵ *Standards and Guidelines—Electroplated Plastics*, American Society of Electroplated Plastics, Washington, DC, Second Edition, 1979.

⁶ Adcock, J. L., "Electroplating Plastics—an AES Illustrated Lecture," American Electroplaters' Society, Inc., Winter Park, FL, 1978.

trisodium phosphate operated at 55 to 65°C. Parts are immersed in the solution for 2 to 5 min (see Note 1).

NOTE 1—Thorough rinsing after alkaline cleaning and after each of the following processing steps is essential. Multiple water rinses are recommended.

6.2 Conditioning:

6.2.1 Conditioning is an optional step that precedes the etching step. Conditioning can eliminate adhesion problems associated with inadequate etching. The conditioner may be a solution of chromic and sulfuric acids, or it may contain an organic solvent. Proprietary solutions are available and should be operated according to supplier's directions.

6.2.2 *Chromic/Sulfuric Acid Type*—This type of conditioner may contain 30 g/L of chromic acid and 300 mL/L of sulfuric acid (93 mass %; density 1.83 g/mL) dissolved in water and is maintained at a temperature of 60°C ± 3°C. Parts are immersed in the solution for 1 to 2 min. Because of the relatively large amount of sulfuric acid in the solution, the acrylonitrile-styrene matrix, as well as the butadiene phase, are attacked.

6.2.3 *Organic Solvent Type*—This type of conditioner is a solution of an organic solvent in deionized water. The organic solvent may be acetone or other ketone; for example, 2,4-pentadione is sometimes used.⁷ The solution may contain 100 to 125 mL/L of the appropriate organic solvent and is maintained at a temperature of 40 to 45°C. Treatment is by immersion of the plastic parts for 2.0 to 2.5 min (see Note 2 and Note 3).

NOTE 2—Solutions containing volatile organic solvents require adequate ventilation and must not contact metals. These materials chelate ionic metal contaminants. Annealed polypropylene tanks are therefore used to hold this type of solution.

NOTE 3—Multiple hot water rinses are required after using the organic solvent-type conditioner. Because organic solvents soften and swell the plastic surface, time of immersion and of transfer to rinse tanks may affect the appearance of the final product, and should be controlled.

6.3 Etching:

6.3.1 Etchants are strong oxidizing solutions that microroughen and chemically alter the surface of molded plastic parts. The etching step is the most important step in achieving serviceable adhesion of metals to plastics. Commercially used etchants are either chromic acid types, chromic/sulfuric acid types, or chromic-sulfuric-phosphoric acid types.

6.3.2 *Chromic Acid Type*—Concentrated etchants usually contain greater than 850 g/L of chromic acid and as much as 1200 g/L.^{8,9} The temperature of the solution is maintained at 50 ± 3°C and treatment is by immersion for 8 to 10 min. Concentrated solutions of chromic acid tend to oxidize butadiene rubber particles in the case of ABS, selectively.

6.3.3 *Chromic/Sulfuric Acid Type*—This type of etchant may contain 250 to 350 g/L of chromic acid and 200 to 250 mL/L of sulfuric acid (93 mass %, density 1.83 mL/L) dissolved in water. Immersion times of 5 to 10 min at a solution

temperature of 65 ± 5°C are commonly used. Several proprietary baths are available.

6.3.4 *Chromic-Sulfuric-Phosphoric Acid Type*¹⁰—This type of etchant solution normally consists of 3 % by mass chromic acid, 56 % by mass sulfuric acid (density 1.83 g/mL), 10.5 % by mass phosphoric acid (density 1.87 g/mL), and the balance water. An immersion time of about 3 min at 74 to 77°C is commonly used.

6.4 Neutralizing (Sensitizing):

6.4.1 After thorough rinsing, all residual chromic acid must be chemically removed from the surface of the molded-plastic parts. Neutralizers are used and are typically mild acid or alkaline solutions containing complexing or reducing agents. In the case of ABS, it is common to use a solution containing a mixture of an acidsalt and a reducing agent, such as sodium bisulfite, to eliminate all traces of chromic acid. Typical processing conditions are 1 to 2 min immersion at 40°C.

6.4.2 Neutralizers may also contain ionic surfactants to increase the adsorption of catalyst. The use of surfactants, however, can lead to activation of the rack coating and subsequent metal deposition on the rack. Surfactants should therefore be used with caution. Ionic surfactants are not normally used in processing ABS (see Note 4).

NOTE 4—Some plastics, for example, polyphenylene oxide, may require treatment in dilute solutions of ethylenediamine after neutralization to insure adequate adsorption of the catalyst.

6.5 Catalyzing (Activating):

6.5.1 Small amounts of palladium are chemically deposited on the surface at this stage of processing. Palladium functions as a catalyst for autocatalytic deposition of copper or nickel to follow. Palladium is deposited either by the older, two-step procedure or by the more reliable one-step procedure.

6.5.2 *Two-Step Procedure*—The molded-plastic parts are first immersed in a solution of stannous chloride, 6 to 10 g/L, operated at pH 1.8 to 2.4 (pH adjusted with hydrochloric acid), and at 20 to 25°C for 1 to 3 min. The parts are then rinsed thoroughly to remove excess hydrochloric acid and transferred to a solution containing 0.1 to 1.0 g/L of palladium chloride dissolved in water at a pH of 1.6 to 2.0 adjusted with sulfuric acid. The palladium ions adsorbed on the surface react with stannous ions to form palladium metal and stannic chloride in the interstices of the etched plastic components. After thorough rinsing, the parts can be coated with nickel or copper by autocatalytic deposition.

6.5.3 *One-Step Procedure*—The molded-plastic parts are immersed in a solution of colloidal stannous chloride and palladium chloride containing excess hydrochloric acid. The stannous chloride concentration is 120 to 140 g/L, the palladium metal concentration is 0.05 to 0.15 g/L, and the hydrochloric acid concentration is approximately 3.0 N (see Note 5). The solution is maintained at 20 to 30°C and the parts are immersed in the solution for 1 to 3 min. Rinsing in water leads to the formation of metallic palladium nuclei on the surface

⁷ The use of 2,4-pentadione is patented.

⁸ The use of concentrations greater than 900 g/L has been patented. See U.S. Patent Numbers: 3,668,130; 3,708,430.

⁹ See U.S. Patent Numbers: 3,142,582; 3,370,974; 3,515,649.

¹⁰ This is commercially used for polysulfone printed circuit boards, but may be used with ABS and polypropylene plastics.

surrounded by stannic hydroxide. The stannic hydroxide is removed in the acceleration step prior to autocatalytic deposition.

NOTE 5—These solutions are proprietary and considerably more difficult to prepare than implied in this section.¹¹

6.6 Acceleration:

6.6.1 Stannous hydroxide is removed by treatment in a dilute solution of hydrochloric acid, or a solution of an acid salt. Fluoride or fluorinated compounds are often added to increase the effectiveness of the acceleration process. In most cases, a solution containing 1.0 *N* hydrochloric acid maintained at a temperature of 50°C, agitated with air, in which parts are immersed for 30 to 60 s adequately removes excess stannous chloride and stannic/stannous hydroxide remaining on the surface after the one-step palladium activation procedure.

6.7 Autocatalytic Deposition:

6.7.1 Solutions for the autocatalytic deposition of either copper or nickel are used to render plastic parts conductive. The solutions contain a metal salt, a reducing agent, a complexant, a stabilizer, and buffers to control pH. The palladium on the surface of the plastic parts acts as a catalyst to initiate deposition after which the autocatalytic reduction of the metal occurs. A uniform metal film about 0.25 to 0.5- μ m thick is deposited (see Note 6).

6.7.2 *Autocatalytic Nickel*—The commercially available processes for autocatalytic nickel deposition on plastics commonly use sodium hypophosphite as the reducing agent. The solutions are operated at 30 to 35°C, at pH 10 to 11, and produce a nickel deposit with 2 to 6 % phosphorous. Parts are kept immersed in the solution for 5 to 10 min to achieve the desired thickness of metal. Although there may be considerable variation in bath formulations, autocatalytic nickel solutions may contain nickel sulfate, sodium citrate, ammonium chloride, ammonium hydroxide, sodium hypophosphite, and sodium hydroxide. Stabilizers are used to prevent spontaneous decomposition of the solution and to control the deposition rate.

6.7.3 *Autocatalytic Copper*—The commercially available processes for autocatalytic deposition of copper on plastics use formaldehyde as the reducing agent. Room temperature processes are used, as well as high temperature ones. Each produce deposits of pure copper. Parts are immersed in the solution for 5 to 10 min.

NOTE 6—Autocatalytic nickel or copper is used commercially in the preparation of plastics, and either may give acceptable results. The use of autocatalytic copper, however, may improve the performance of electroplated plastics in wet corrosive environments. Parts that are inadequately etched or that are made from grades of plastics that are difficult to etch are less likely to fail in severe corrosive environments when autocatalytic copper is used.^{12,13,14}

6.8 Electrodeposited Strikes:

¹¹ See U.S. Patent Numbers: 3,011,920; 3,874,882; 3,904,792; 3,672,923; 3,672,938; 3,682,671; 3,960,573; 3,961,109.

¹² Di Bari, G. A., "Performance of Decorative Copper-Nickel-Chromium Coatings on Plastics—Final Report of Corrosion Programs Conducted by ASEP and ASTM," copies of the report may be requested by writing to ASTM Headquarters.

¹³ Wedel, R. G., "Characteristics of Corrosion-Associated Blisters on Plated Plastics," *Plating and Surface Finishing*, January 1975.

TABLE 1 Typical Strike Solution Compositions

Strike Solution	Composition
<i>Copper Strike:</i>	
Pyrophosphate Type:	
Copper (Cu)	24–37 g/L
Pyrophosphate (P ₂ O ₇ ⁻⁴)	185–250 g/L
Nitrate (NO ₃ ⁻¹)	5–10 g/L
Ammonia (NH ₃)	1–4 g/L
pH	8.4–8.8 g/L
Temperature	50–55°C
Voltage, d-c	2–3 V
Current density	250–400 A/m ²
Acid Copper Sulfate Type:	
Copper sulfate (CuSO ₄ ·5H ₂ O)	210–225 g/L
Sulfuric acid (H ₂ SO ₄)	45–60 g/L
Temperature (room)	18–22°C
Voltage, d-c	2.5–3.0 V
Current density	250–400 A/m ²
<i>Nickel Strike:</i>	
<i>Watts Type:</i>	
Nickel sulfate (NiSO ₄ ·6H ₂ O)	300–340 g/L
Nickel chloride (NiCl ₂ ·6H ₂ O)	30–60 g/L
Boric acid (H ₃ BO ₃)	30–40 g/L
pH	3–4 g/L
Temperature	60–65°C
Voltage, d-c	2.5–3.0 V
Current density	250–600 A/m ²
<i>Sulfamate Type:</i>	
Nickel sulfamate ^A	30–45 g/L
Boric acid (H ₃ BO ₃)	3.0–4.5 g/L
pH	45°–55°C
Temperature	250–600 A/m ²
Current density	

^A Usually available as a liquid concentrate.

6.8.1 Additional thicknesses of either copper or nickel are applied by low-current density electrodeposition from suitable strike baths. Metal thickness is increased to 2.5 to 4.0 μ m to facilitate electrodeposition of decorative or functional coatings by conventional means.

6.8.2 Typical copper and nickel strike solutions are given in Table 1.

6.8.3 The most commonly applied decorative coating consists of layers of copper, nickel, and chromium, but other metals may be combined to achieve decorative effects.

7. Process Control

7.1 General:

7.1.1 The pH, temperature, and composition of the solutions used in preparing plastics for electroplating must be carefully controlled to achieve satisfactory results. Conventional analytical and other measuring techniques may be used. Suppliers can provide instructions for control of proprietary processes.

7.2 Etchants:

7.2.1 The concentration of trivalent chromium increases with continuous use of chromic acid-containing etchants. Trivalent chromium reduces the ability of the etchant to oxidize the surface of the plastic. The maximum tolerable concentration of trivalent chromium is 20 g/L in etchants containing about 350 g/L of chromic acid, and 90 g/L in etchants containing 1200 g/L of chromic acid. The trivalent chromium concentration can be adjusted by removing a portion

¹⁴ Wedel, R. G., "A Mechanism for Corrosion-Associated Blisters on Plated Plastics," *Plating and Surface Finishing*, March 1975.

of the solution and adding proper amounts of chromic acid and water to compensate for quantities removed. Trivalent chromium can also be converted to hexavalent chromium by electrolytic oxidation.

7.3 Catalysts:

7.3.1 The stability of the solution used in the one-step procedure for chemically depositing palladium on plastics is dependent on the chloride concentration. The chloride concentration is controlled by additions of hydrochloric acid or sodium chloride.

7.3.2 Hexavalent chromium ions carried over from etchants and from other sources interfere with the functioning of the catalyst.

7.4 Accelerators:

7.4.1 Accelerators are especially sensitive to contamination by hexavalent chromium that may be carried over from the etchant solutions. The mineral acid types can tolerate a maximum of 10 ppm. Acid salt types can tolerate a maximum of 300 ppm. Reducing agents, such as stannous chloride and sodium bisulfite, are sometimes used to convert hexavalent chromium to trivalent chromium and prolong the life of the accelerator.

7.5 Appearance:

7.5.1 The appearance of plastic parts changes during processing and these changes can be used to control the process to some extent:

7.5.1.1 After alkaline cleaning and rinsing, plastic parts should be uniformly covered with a film of water.

7.5.1.2 After conditioning, plastic parts should appear slightly dull.

7.5.1.3 After etching, plastic parts should have lost their original glossy appearance, and should be uniformly wetted with water after rinsing. Variations in surface finish at this stage are usually attributed to variations in stress within the part.

7.5.1.4 Adsorption of the catalyst causes the parts to appear light tan in color. The absence of surface coloring is evidence of improper processing that may lead to incomplete coverage and poor adhesion at later stages.

7.5.1.5 Accelerators cause the parts to be only slightly lighter in color than in the previous step.

7.5.1.6 After autocatalytic deposition, the plastic parts should be uniformly and completely covered by the metallic deposit.

TABLE 2 Range of Peel Strength Values for Electrodeposited Copper and Nickel on Various Plastics

Type of Plastic	Peel Strength, ^A N	
	Copper	Nickel
ABS	40–110	40–110
Modified polyphenylene oxide	10–50	10–50
Polypropylene	20–110	70–125
Impact styrene	9–20	9–50
Polysulfone	20–100	20–100
Polycarbonate	10–50	10–50

^A Measured on 25-mm wide strips. The thickness of the electrodeposited metal was $35 \pm 5 \mu\text{m}$, as recommended in Test Method B 533.

7.6 Adhesion Tests:

7.6.1 A qualitative adhesion test may be used on production parts to judge the effectiveness of the preparation process. After autocatalytic deposition, rinsing, and drying, apply a strip of pressure-sensitive tape¹⁵ smoothly on the surface pressing the tape firmly to eliminate all air bubbles. Quickly pull the tape off at a 90° angle. Appearance of metal particles on the tape indicates poor surface preparation.

7.6.2 Test Method B 533 provides methods for the measurement of the peel strength of electroplated plastics using standard plaques. The methods can be used to monitor the effectiveness of the preparation process and changes that occur during use. Standard plaques available from various sources are processed and then electroplated with $35 \pm 5 \mu\text{m}$ of copper or nickel. The peel strength can be measured in various ways as discussed in Test Method B 533. Typical values of peel strength are given in Table 2.

7.6.3 The thermal cycle tests described in Test Method B 553 and in Specification B 604 can be used to evaluate the adhesion of metals electrodeposited on plastics and thus, the effectiveness of the entire process, including the chemical preparation treatments covered in this practice.

8. Keywords

8.1 activation; cleaning; deoxidizing; plastics; preparation; striking

¹⁵ Pressure-sensitive tape, No. 710 available from the 3M Company, 3M Center, St. Paul, MN 53216 has been found suitable.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).