



Designation: **D3288/D3288M—15** **D3288/D3288M – 20**

Standard Test Methods for Magnet-Wire Enamels¹

This standard is issued under the fixed designation D3288/D3288M; 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 reappraisal. A superscript epsilon (ε) indicates an editorial change since the last revision or reappraisal.

1. Scope*

1.1 These test methods cover testing liquid enamel coatings used to produce film-insulated magnet wire.

1.2 The values stated in either ~~both~~ metric or SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined

1.3 The test methods appear as follows:

Density
Determined Solids
Effective Solids
Flash Point
Infrared Analysis
Stack Loss
Viscosity

Sections
6 – 10
16 – 22
31 – 37
11 – 15
45 – 50
23 – 30
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1.4 There is no known IEC equivalent document. [7ba89bf8128-415e-b3d4-f01422d880bb/astm-d3288-d3288m-20](https://standards.itih.ai/7ba89bf8128-415e-b3d4-f01422d880bb/astm-d3288-d3288m-20)

1.5 *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~~ safety, health, and health environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*²

- [D29 Test Methods for Sampling and Testing Lac Resins \(Withdrawn 2005\)](#)³
- [D56 Test Method for Flash Point by Tag Closed Cup Tester](#)
- [D476 Classification for Dry Pigmentary Titanium Dioxide Products](#)

¹ These test methods are under the jurisdiction of ASTM Committee [D09](#) on Electrical and Electronic Insulating Materials and are the direct responsibility of Subcommittee [D09.12](#) on Electrical Tests.

Current edition approved Nov. 1, 2015 Aug. 1, 2020. Published November 2015 September 2020. Originally approved in 1973. Last previous edition approved in 2008 2015 as [D3288 – 08](#) [D3288/D3288M – 15](#). DOI: [10.1520/D3288_D3288M-15-10.1520/D3288_D3288M-20](https://doi.org/10.1520/D3288_D3288M-15-10.1520/D3288_D3288M-20).

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 The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard**



- D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
- D1475 Test Method for Density of Liquid Coatings, Inks, and Related Products
- D1711 Terminology Relating to Electrical Insulation
- D5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation
- E131 Terminology Relating to Molecular Spectroscopy
- E168 Practices for General Techniques of Infrared Quantitative Analysis
- E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
- E2975 Test Method for Calibration or Calibration Verification of Concentric Cylinder Rotational Viscometers

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in these test methods, refer to Terminology ~~D1711~~.

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3.2 *Definitions of terms specific to this standard:*

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4. Significance and Use

4.1 These tests are useful for specification and control purposes during the manufacture, purchase, and use of the magnet-wire enamels, and for determining uniformity of batches.

5. Sampling

5.1 Take a representative sample of liquid enamel and store for future testing. Store the sample at room temperature in a tightly sealed, nearly full container, unless otherwise specified. Use a container that is inert and impermeable to the wire enamel. These precautions avoid either the escape of solvent or reaction with the container and atmosphere. Glass and some metals are suitable materials. Copper, iron, and aluminum are unsatisfactory. After removing test specimens, use care to restore these storage conditions.

DENSITY

6. Scope

6.1 This test method covers the determination of the density of magnet-wire enamel in terms of specific gravity or weight per gallon.

7. Significance and Use

7.1 Density is useful for specification and control purposes during the manufacture and use of magnet-wire enamel.

7.2 The preferred method is Procedure A, hydrometer method.

8. Procedure A—Hydrometer Method

8.1 Determine the specific gravity of the magnet-wire enamel in accordance with Test Method ~~D1298~~ at $25.0 \pm 0.1^\circ\text{C}$.



8.2 If weight per gallon is required, multiply the specific gravity by the weight per gallon of distilled water at the same temperature (8.31 lb/gal at $25.0 \pm 0.1^\circ\text{C}$ ($77.0 \pm 0.1^\circ\text{F}$)).

9. Procedure B—Weight per Gallon Method

9.1 Determine the weight per gallon of the magnet-wire enamel in accordance with Test Method D1475 at $25.0 \pm 0.1^\circ\text{C}$ ($77.0 \pm 0.1^\circ\text{F}$).

10. Report

10.1 Report the following information:

10.1.1 Identification of the magnet-wire enamel, and

10.1.2 When using Procedure A, report the specific gravity to the third decimal place, or

10.1.3 When using Procedure B, report the weight per gallon.

FLASH POINT

11. Scope

11.1 This test method covers the determination of the flash point of magnet-wire enamel.

12. Terminology

12.1 *Definitions of Terms Specific to This Test Method:*

12.2 *flash point, of magnet-wire enamel, n*—the lowest temperature at which magnet-wire enamel gives off flammable vapor in sufficient quantity to ignite in air on application of a flame under specified conditions.

13. Significance and Use

13.1 The flash point reveals the upper temperature limit that is permissible for storage or use of a magnet-wire enamel without presenting a fire hazard.

14. Procedure

14.1 Determine the flash point in accordance with Test Method D56.

15. Report

15.1 Report the following information:

15.1.1 Identification of magnet-wire enamel, and

15.1.2 Flash point, degrees Celsius or Fahrenheit, preferably in degrees Fahrenheit.

DETERMINED SOLIDS

16. Scope

16.1 This test method covers the determination of a particular measured value for the solids content in a magnet-wire enamel.



17. Terminology

17.1 Definitions of Terms Specific to This Test Method:

17.2 *determined solids, of magnet-wire enamel, n*—the portion of a magnet-wire enamel which is not volatilized when exposed to specified conditions.

18. Significance and Use

18.1 Determined solids is one of the critical factors in a magnet-wire enamel that affects film build on a conductor.

18.2 The determined solids is also useful for control purposes during the manufacture and use of magnet-wire enamel and in determining uniformity of batches.

18.3 The stack loss (see 27.3) requires the Determined Solids value as an input.

19. Apparatus

19.1 ~~Forced-Convection~~*Forced-convection* Oven, capable of maintaining $200 \pm 3^{\circ}\text{C}$ 3°C at the specified specimen location. Refer to Specification D5423 Type II for a representative oven.

19.2 *Weighing Dishes*, aluminum, approximately ~~2 in. (51 mm)~~ 51 mm [2 in.] in diameter, and ~~16 mm [$\frac{5}{8}$ in. (16 mm)~~ in.] height.

19.3 *Analytical Balance*, capable of weighing to $\pm 0.1 \pm 0.1$ mg.

20. Procedure

20.1 Preheat dishes to remove oil. Five minutes at $200 \pm 3^{\circ}\text{C}$ 3°C is adequate.

20.2 Test a minimum of two specimens.

20.3 Place a 2.0 g specimen (± 0.1 mg) ± 0.1 mg specimen into a tared aluminum dish and weigh immediately.

20.4 The weighed specimen must thoroughly cover the entire bottom surface of the weighing dish. Accomplish this by warming the more viscous materials.

20.5 Place the dish and its contents in a $200 \pm 3^{\circ}\text{C}$ 3°C forced-convection oven for 2 ± 0.1 h.

20.6 Remove the dish from the oven and cool to room temperature in a desiccator.

20.7 Weigh the dish and its contents (± 0.1 (± 0.1 mg)).

21. Report

21.1 Report the following information:

21.1.1 Ratio of the weight of residue to that of the specimen, expressed as a percentage, as the determined solids content, *S*, calculated as follows:

$$S = (\text{Weight of residue/weight of specimen}) \times 100 \quad (1)$$

$$S = (\text{weight of residue/weight of specimen}) \times 100 \quad (1)$$

21.1.2 Number of tests and individual values,

21.1.3 Average determined solids of all tests made, and



21.1.4 Identification of the magnet-wire enamel.

22. Precision and Bias

22.1 *Precision:*

22.1.1 The results of all measurements on the sample typically agree within $\pm 0.5\%$; $\pm 0.5\%$.

22.2 *Bias:*

22.2.1 Statements of bias are not applicable in view of the unavailability of a standard reference material for this property.

STACK LOSS

23. Scope

23.1 This test method covers the determination of the stack loss of magnet-wire enamel applied to AWG No. 18 (~~1.02 mm~~) (1.02 mm) electrical conductor using an inorganic material as a reference.

NOTE 1—With other sizes of electrical conductor, expect a variation in stack loss. This is particularly true with smaller diameter wire. Expect difficulty in removing the coating from fine wire.

24. Terminology

24.1 *Definitions of Terms Specific to This Test Method:*

24.2 *stack loss, of magnet-wire enamel, n*—that portion of the magnet-wire enamel solids which are lost during the conductor-coating process.

25. Significance and Use

25.1 The stack loss of magnet-wire enamel will affect the increase in dimensions, the amount of enamel used, the weight increase, and the economics of applying the enamel to the conductor.

26. Apparatus and Reagent

26.1 *Laboratory ~~Magnet-Wire-Coating~~ Magnet-wire Coating Equipment*, that will duplicate production application conditions and a supply of bare conductor to be used for the test.

26.2 *Laboratory Mixer or Drill Press.*

26.3 *Muffle Furnace*, capable of maintaining ~~600°C~~; 600 °C.

26.4 *Oven*, forced-convection, capable of maintaining $110 \pm 2.5^\circ\text{C}$; 2.5 °C (refer to Specification **D5423** Type II).

26.5 *Analytical Balance*, capable of weighing to the nearest 0.1 mg.

26.6 *Balance*, capable of weighing 2 kg (~~$\pm 1\text{ g}$~~) $\pm 1\text{ g}$.

26.7 *Weighing Bottles*, tall-form cylindrical, glass.

26.8 *Crucibles*, high-form, high-temperature.



26.9 *Container*, at least 2 L in capacity.

26.10 *Titanium Dioxide* (TiO₂), meeting the specifications outlined in Specification D476, Type III.

27. Procedure

27.1 Determine the optimum conditions for applying the magnet-wire enamel using laboratory coating equipment.

27.2 Condition the crucible in a muffle furnace maintained at $600 \pm 20^\circ\text{C}$ to a constant weight (Note 2), and immediately place it in a desiccator for storage.

NOTE 2—In practice, crucibles will come to constant weight at 600°C , if held in the muffle furnace for 14 to 16 h (overnight).

27.3 Measure the determined solids of the magnet-wire enamel in accordance with Sections 16 – 22, and the ash content of the solids in accordance with Test Methods D29.

27.4 Weigh into the container 1000 ± 1 g of the magnet-wire enamel.

27.5 Weigh into the container an amount of TiO₂ equal to the weight (± 1.0 g) of the solids in the 1000 ± 1 g specimen of the magnet-wire enamel.

27.6 Mix the contents in the container until the TiO₂ is completely dispersed in the wire enamel.

27.7 Apply this enamel in accordance with 27.1, using the same conditions and obtaining the same increase in build. Within 2 h of applying the enamel to the conductor, completely stir the enamel to ensure dispersion.

27.8 Remove this coating from the wire by snapping and twisting the wire or by other suitable means. Place the removed coating in a weighing bottle. For the coatings that are difficult to remove, try chilling the wire before snapping. In all cases, take care to prevent including any of the metal conductor.

<https://standards.iteh.ai/catalog/standards/sist/f7ba89bf-8128-415e-b3d4-f01422d880bb/astm-d3288-d3288m-20>

27.9 To remove moisture, place the weighing bottle containing the coating in a $110 \pm 2.5^\circ\text{C}$ forced-convection oven for 60 ± 2 min.

27.10 Remove the weighing bottle and contents from the oven and allow it to cool to room temperature in a desiccator.

27.11 Weigh two conditioned crucibles and weigh into each 0.5 to 0.6 g of the dried coating from the weighing bottle. Make all weighings to the nearest 0.1 mg.

27.12 Weigh two conditioned crucibles and weigh into each 0.5 to 0.6 g of TiO₂.

27.13 Place all four crucibles in the cold muffle furnace. Start the furnace, allowing the temperature to come to 600°C in 1 to 2 h.

27.14 Leave the crucibles in the muffle furnace at $600 \pm 20^\circ\text{C}$ until they reach a constant weight (Note 2). Remove the crucibles and allow them to cool in a desiccator to room temperature.

27.15 Weigh the crucibles.

28. Calculation

28.1 Calculate the percent stack loss, *L*, of the magnet-wire enamel as follows:



$$\text{Let } F = (EA)/(AB+CD)$$

(2)

$$\text{Let } R = (100/F)(G - F)$$

$$\text{Then } L = 100 - R$$

where:

- A = TiO₂ mixed with the wire enamel, g,
- B = percent of TiO₂ ash, expressed as a decimal,
- C = solids in the wire-enamel specimen, g,
- D = percent ash of the wire-enamel solids, expressed as a decimal,
- ~~E = weight of ash in the coating specimen, g~~
- E = weight of ash in the coating specimen, g,
- F = corrected ash weight, g,
- G = original weight of coating specimen before ashing, g, and
- R = retention of coating.

29. Report

29.1 Report the following information:

29.1.1 Identification of magnet-wire enamel,

29.1.2 Determined solids content of the magnet-wire enamel,

29.1.3 Percent ash content of the magnet-wire enamel ~~solids~~ solids,

29.1.4 Average percent retention of coating to two decimal places, and

29.1.5 Average percent stack loss to two decimal places.

30. Precision and Bias

30.1 This test method has been in use for many years, but no statement of precision has been made and no activity is planned to develop such a statement.

EFFECTIVE SOLIDS

31. Scope

31.1 This test method covers the determination of the percentage of liquid enamel that will be retained on the metal conductor in the finished product.

32. Terminology

32.1 *Definitions of Terms Specific to This Test Method:*

32.2 *effective solids, of magnet-wire enamel, n*—the percentage of the liquid enamel retained after the removal of the solvents and the additional oven bakes that simulate the stack loss that occurs during the enameling manufacturing process for magnet wire.

32.3 *evaporative solids, of magnet wire enamels, n*—the percentage of liquid enamel that will be retained after removal of the solvents according to step 35.1 of this test procedure.

32.4 *simulated stack loss, n*—the percentage change in evaporative solids after additional lab oven heat exposures as described in step 35.2 of this procedure.