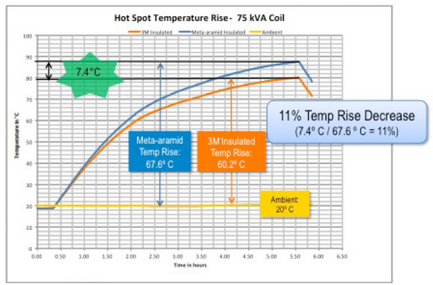
## Thermal Conductivity

3M™ ThermaVolt Calendered Inorganic Insulating Products have excellent thermal conductivity performance, which can increase the heat dissipation required in today's high-efficiency electrical apparatus. The high thermal conductivity helps enable a transformer that has been designed with calendered meta-aramid to run cooler, or if the transformer is redesigned, to potentially reduce size, utilizing less conductor, resulting in a lower total transformer cost.

| | | ASTM Test Method | 3 mil | 5 mil | 7 mil | 10 mil | 15 mil |
|---|---|---|---|---|---|---|---|
| Thermal Conductivity (180ºC) | W/m-K | E-1530 | 0.15 | 0.17 | 0.18 | 0.21 | 0.25 |

For a 75 kVA coil that was designed with minimal cooling ducts, the coil fabricated with a combination of ThermaVolt insulating paper and 3M ThermaVolt AR Electrical Insulating Paper had a maximum temperature rise that was 11% less than the same coil insulated with calendered meta-aramid. In this case, the 3M-insulated coil runs cooler, which results in the insulation having more overload capability and longer life.

*Two identical 75 kVA coils;*
*One with 3M™ Insulation and*
*one with calendared meta-aramid*




Another option is to optimize the coil design for smaller size and lower cost using ThermaVolt insulating paper.

- Reduction in conductor cross sectional area
  - As conductor size decreases, electrical resistance increases, which increases the heat generated. Designs with reduced conductor size and high thermal conductivity insulation may achieve temperature rise equal to designs with larger conductor and lower thermal conductivity insulation.
- Reducing or eliminating air gaps
  - Decreases overall size of coil
  - Decreased circumference results in shorter conductor length

**Example: 75 kVA Transformer Coil**

- Material cost
  - 23% core
  - 73% conductor
  - 4% insulation
- Reduce conductor size by 11% since decrease in temperature rise was 11%
- Result: 8% decrease in total material cost

| | |
|---|---|
| Conductor % of material cost | 73% |
| Reduction in conductor material | x11% |
| Material cost savings | 8% |

**Total System Cost Savings: 8%**
**Exceeds cost of the insulation**
(Calculated cost of savings can vary depending on transformer design.)

## Resistance to Partial Discharge

Most equipment is designed to avoid partial discharge or corona attack that may lead to premature failure. However, there are cases where it is not practical to do so or there are external factors that substantially increase the dielectric stress so materials must be used that are resistant to damage caused by partial discharge.

Made with inorganic material, 3M™ ThermaVolt Calendered Inorganic Insulating Products exhibit excellent resistance to partial discharge and enable long-term voltage endurance.

To understand the level of performance, ThermaVolt insulating paper and calendered meta-aramid insulation were tested through a procedure developed for variable-frequency drives. With a voltage of 180 volts per mil to ensure corona, a 20-kilohertz square wave and a temperature of 150ºC, the test is more severe with an expected shorter time to failure relative to a traditional 60-hertz frequency test. This is due to the voltage cycles being more than 300 times faster, the square wave being more destructive than a sine wave and the increased temperature decreasing insulation life.

The average time to failure for the three calendered, meta-aramid 7-mil thick insulation samples was less than an hour. Three samples of 7-mil ThermaVolt insulating paper were tested for more than two months without failure, at which time the test was stopped.

Inorganic-based materials can enable:

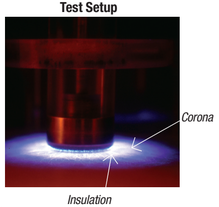
- Long-Term Voltage Endurance
  - Resists partial discharge/corona
  - Greater electrical insulation reliability

**Voltage Endurance**
Dielectric stress, w/mil (kV/mm): 180 (7.0)
Frequency: 20-kHz/temperature: 150ºC
3 samples each insulation

| | Mean Time to Failure (in minutes) |
|---|---|
| Meta-aramid Insulation | 22 |
| 3M™ ThermaVolt Insulation | >98,940* |

*No failures, stopped test

**Voltage Endurance Test Setup**




| | Calendered Meta-aramid Insulation 7-mil | 3M™ ThermaVolt Insulation 7-mil |
|---|---|---|
| Sample 1** | 24 | *98,940 |
| Sample 2** | 20 | *98,940 |
| Sample 3** | 22 | *98,940 |
| AVERAGE (minutes) | 22 | >98,940 |

*Test terminated (no failure)
**Test conducted by third party, 2013



**Electrical Markets Division**
6801 River Place Blvd.
Austin, TX 78726-9000
855 293 6018
Fax 800 245 0329
electricaloem@3M.com
www.3M.com/flexibleinsulation

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# High Performance for High Expectations

## 3M™ ThermaVolt Calendered Inorganic Insulating Paper

3M™ ThermaVolt Insulating Paper meets the high performance requirements for high-temperature, dry-type transformers as major ground insulation in electrical systems rated through Class 220(R). ThermaVolt paper offers good dielectric characteristics, excellent partial discharge resistance and high thermal conductivity – making it especially suitable for use as interwinding insulation in strip-wound coils. ThermaVolt paper also is available bonded with polyester (PET) film for applications that require enhanced stiffness and formability, such as ground and layer insulation.

ThermaVolt insulating paper, made with inorganic material, has higher thermal conductivity than meta-aramid fiber insulation and can enable coil performance improvement. As an example, an existing coil design may have a lower temperature rise at the same power level or the coil load may be increased while the temperature rise is held constant. If the coil design is optimized for higher thermal conductivity, this may result in smaller conductor size and lower overall material cost, and potentially higher efficiency, depending upon the coil design.

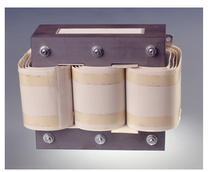
ThermaVolt insulating paper and laminates are RoHS & REACH Compliant.

### Applications

Open ventilated dry-type transformers rated through Class 220(R)

Major Insulation
- Ground insulation
- Core and outer wrap
- Interwinding (or high-low) insulation
- Turn insulation

Minor Insulation
- Layer insulation



| Features | Advantages | Benefits |
|---|---|---|
| High thermal conductivity | May lower coil temperature rise | Potentially longer transformer life and greater overload capability |
| | Can decrease coil size for the same power rating and temperature rise | Reduced conductor size and reduced or eliminated air gaps result in lower cost for same power rating |
| Long-term voltage endurance | Resists partial discharge damage | Longer insulation life during partial discharge |
| Low moisture absorption | Can improve dimensional stability | Coil assembly with reduced humidity control concerns |
| RoHS & REACH Compliant | Meets global environmental, health and safety standards | Reduced human and environmental impact |
| UL 94 V0 Rating* | Ensures resistance to ignition and flame spread | Excellent flammability performance |

*ThermaVolt insulating paper only. Does not include ThermaVolt Laminates.

## 3M™ ThermaVolt Calendered Inorganic Insulating Paper Typical Mechanical and Electrical Properties

Not for specifications. Values are typical, not to be considered minimum or maximum.
Properties measured at room temperature 73ºF (~23ºC) unless otherwise stated.

3M™ ThermaVolt Insulating Paper is qualified for use as major ground insulation in electrical insulation systems rated through Class 220(R) per UL 1446 and IEC Std. 61857.

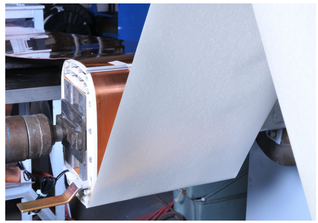
| | | ASTM Test Method | 3 mil | 5 mil | 7 mil | 10 mil | 15 mil |
|---|---|---|---|---|---|---|---|
| Nominal Thickness | mm | D-645 | 0.08 | 0.13 | 0.18 | 0.25 | 0.38 |
| | mil | | 3 | 5 | 7 | 10 | 15 |
| Basis Weight | g/m² | D-202 | 103 | 195 | 274 | 366 | 561 |
| | lb/yd² | | 0.19 | 0.36 | 0.49 | 0.67 | 1.04 |
| Density | g/cc | | | 1.4 | 1.5 | 1.5 | 1.5 |
| Tensile Strength, MD | lb/inch | D-828 | 17 | 31 | 41 | 53 | 100 |
| | N/cm | | 30 | 54 | 72 | 93 | 175 |
| Tensile Strength, CD | lb/inch | D-828 | 8 | 16 | 22 | 34 | 58 |
| | N/cm | | 14 | 28 | 39 | 60 | 102 |
| Elongation to Break, MD | % | D-828 | 1.5 | 1.5 | 1.5 | 1.5 | 2.0 |
| Elongation to Break, CD | % | D-828 | 1.1 | 1.1 | 1.1 | 1.1 | 2.0 |
| Elmendorf Tear, MD | g | D-689 | 40 | 108 | 172 | 280 | 534 |
| | N | | 0.4 | 1.1 | 1.7 | 2.7 | 5.2 |
| Elmendorf Tear, CD | g | D-689 | 60 | 142 | 302 | 354 | 734 |
| | N | | 0.6 | 1.4 | 3.0 | 3.5 | 7.2 |
| Dielectric Breakdown Strength | kV | D-149 | 1.1 | 3.0 | 3.3 | 5.0 | 8.0 |
| | V/mil | | 365 | 590 | 470 | 500 | 530 |
| | kV/mm | | 14.4 | 23.2 | 18.5 | 19.7 | 20.9 |
| Dielectric Constant 23ºC, 50% RG, 50 Hz | | D-150 | 3.5 | 3.9 | 4.0 | 4.0 | 4.0 |
| Dissipation Facor 23ºC, 50% RH, 50Hz | % | D-150 | 7 | 7 | 7 | 7 | 7 |
| Moisture Absorption | % | D-644 | <1 | <1 | <1 | <1 | <1 |
| Flame Rating | UL File | UL94 | V-0, 5VA | V-0, 5VA | V-0, 5VA | V-0, 5VA | V-0, 5VA |
| | E65069 | | | | | | |
| Available Roll Sizes* | Sq yd | | 1090 & 2960 | 650 & 1775 | 465 & 1270 | 325 & 890 | 220 & 590 |
| | Sq m | | 910 & 2475 | 545 & 1485 | 390 & 1060 | 270 & 745 | 185 & 495 |

*Roll width: 36 inches (914 mm). Roll thickness, size and weight are for guideline purposes only, as they can vary by +/- 15%.
Product is also available in 8.5" x 11", 24" x 36" or 36" x 36" sheets.

## 3M™ ThermaVolt Calendered Inorganic Insulating Paper and TvF Laminates Typical Mechanical and Electrical Properties

Not for specifications. Values are typical, not to be considered minimum or maximum.
Properties measured at room temperature 73ºF (~23ºC) unless otherwise stated.

3M™ ThermaVolt TvF Laminate is ThermaVolt Inorganic Calendered Insulating Paper bonded to one layer of polyester (PET) film. This laminate exhibits superior mechanical and dielectric strength while maintaining excellent long-term performance and low moisture absorption. It is qualified for use as major ground insulation in electrical insulation systems rated through Class 220(R) per UL 1446 and IEC Std. 61857.



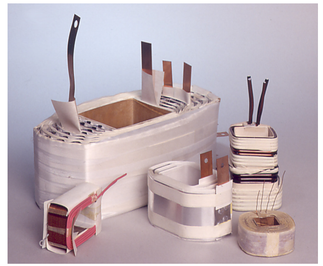
| | | ASTM Test Method | TvF 3+1 | TvF 3+2 | TvF 4+1 | TvF 4+2 | TvF 5+1 | TvF 5+2 | TvF 7+1 | TvF 7+2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Nominal Thickness | mm | D-645 | 0.10 | 0.13 | 0.13 | 0.15 | 0.15 | 0.18 | 0.20 | 0.23 |
| | mil | | 4 | 5 | 5 | 6 | 6 | 7 | 8 | 9 |
| Basis Weight | g/m² | D-202 | 143 | 180 | 196 | 233 | 235 | 272 | 314 | 351 |
| | lb/yd² | | 0.264 | 0.33 | 0.36 | 0.43 | 0.43 | 0.50 | 0.58 | 0.65 |
| Density | g/cc | | 1.4 | 1.4 | 1.5 | 1.5 | 1.5 | 1.5 | 1.6 | 1.5 |
| Tensile Strength, MD | lb/inch | D-828 | 31 | 53 | 39 | 61 | 44 | 63 | 60 | 68 |
| | N/cm | | 54 | 93 | 68 | 107 | 77 | 285 | 105 | 119 |
| Tensile Strength, CD | lb/inch | D-828 | 30 | 60 | 27 | 58 | 30 | 55 | 42 | 56 |
| | N/cm | | 53 | 105 | 47 | 102 | 53 | 96 | 74 | 98 |
| Elongation to Break, MD | % | D-828 | 2 | 9 | 4 | 3 | 4 | 3 | 4 | 4 |
| Elongation to Break, CD | % | D-828 | 7 | 6 | 6 | 4 | 6 | 4 | 6 | 8 |
| Elmendorf Tear, MD | g | D-689 | 76 | 120 | 92 | 150 | 108 | 172 | 160 | 224 |
| | N | | 0.7 | 1.2 | 0.9 | 1.5 | 1.0 | 1.7 | 1.6 | 2.2 |
| Elmendorf Tear, CD | g | D-689 | 98 | 157 | 119 | 220 | 140 | 232 | 232 | 256 |
| | N | | 0.9 | 1.5 | 1.2 | 2.2 | 1.4 | 1.9 | 2.3 | 2.5 |
| Dielectric Breakdown Strength | kV | D-149 | 6 | 8 | 6 | 8 | 6 | 9 | 6 | 9 |
| | V/mil | | 1500 | 1600 | 1200 | 1300 | 1000 | 1300 | 750 | 1000 |
| | kV/mm | | 59 | 63 | 47 | 51 | 39 | 51 | 30 | 39 |
| Moisture Absorption | % | D-644 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Available Roll Sizes* | Sq yd | | 815 & 2220 | 650 & 1775 | 650 & 1775 | 545 & 1480 | 545 & 1480 | 465 & 1270 | 410 & 1100 | 360 & 990 |
| | Sq m | | 680 & 1860 | 545 & 1485 | 545 & 1485 | 455 & 1235 | 455 & 1235 | 390 & 1060 | 345 & 930 | 300 & 830 |

*Roll width: 36 inches (914 mm). Roll thickness, size and weight are for guideline purposes only, as they can vary by +/- 15%.
Product is also available in 8.5" x 11", 24" x 36" or 36" x 36" sheets.

## 3M™ ThermaVolt Calendered Inorganic Insulating Paper and TvFTv Laminates Typical Mechanical and Electrical Properties

Not for specifications. Values are typical, not to be considered minimum or maximum.
Properties measured at room temperature 73ºF (~23ºC) unless otherwise stated.

3M™ ThermaVolt TvFTv Laminates have ThermaVolt paper bonded to both sides of the polyester (PET) film, which maximizes the amount of ThermaVolt material exposed in a laminate configuration. This laminate exhibits very high mechanical and dielectric strength while maintaining excellent long-term performance and low moisture absorption. It is qualified for use as major ground insulation in electrical insulation systems rated through Class 220(R) per UL 1446 and IEC Std. 61857.



| | | ASTM Test Method | TvFTv 3+1+3 | TvFTv 3+3+3 | TvFTv 3+5+3 | TvFTv 4+2+4 | TvFTv 5+1+5 | TvFTv 5+2+5 | TvFTv 5+5+5 | TvFTv 5+7.5+5 | TvFTv 7+1+7 | TvFTv 7+2+7 | TvFTv 7+14+7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal Thickness | mm | D-645 | 0.18 | 0.23 | 0.28 | 0.25 | 0.28 | 0.30 | 0.38 | 0.45 | 0.38 | 0.41 | 0.71 |
| | mil | | 7 | 9 | 11 | 10 | 11 | 12 | 15 | 17.5 | 15 | 16 | 28 |
| Basis Weight | g/m² | D-202 | 254 | 327 | 391 | 388 | 430 | 454 | 570 | 664 | 600 | 627 | 1050 |
| | lb/yd² | | 0.47 | 0.60 | 0.72 | 0.71 | 0.79 | 0.84 | 1.05 | 1.22 | 1.11 | 1.16 | 1.94 |
| Density | g/cc | | 1.4 | 1.4 | 1.4 | 1.6 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Tensile Strength, MD | lb/inch | D-828 | 52 | 101 | 120 | 87 | 60 | 97 | 142 | 195 | 95 | 149 | 327 |
| | N/cm | | 91 | 178 | 210 | 152 | 105 | 170 | 249 | 341 | 166 | 261 | 572 |
| Tensile Strength, CD | lb/inch | D-828 | 33 | 77 | 143 | 63 | 40 | 67 | 118 | 220 | 62 | 100 | 269 |
| | N/cm | | 58 | 135 | 250 | 110 | 70 | 117 | 207 | 385 | 109 | 175 | 471 |
| Elongation to Break, MD | % | D-828 | 2 | 3 | 4 | 3 | 3 | 3 | 3 | 4 | 2 | 2 | 4 |
| Elongation to Break, CD | % | D-828 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 2 | 2 | 4 |
| Elmendorf Tear, MD | g | D-689 | 170 | 480 | 484 | 400 | 250 | 350 | 552 | 740 | 380 | 800 | 1270 |
| | N | | 1.7 | 4.7 | 4.8 | 3.9 | 2.5 | 3.4 | 5.4 | 7.3 | 3.7 | 7.8 | 12.4 |
| Elmendorf Tear, CD | g | D-689 | 200 | 588 | 676 | 498 | 300 | 464 | 648 | 896 | 540 | 1000 | 2050 |
| | N | | 1.9 | 5.8 | 6.7 | 4.9 | 2.9 | 4.6 | 6.4 | 8.9 | 5.3 | 9.8 | 20.1 |
| Dielectric Breakdown Strength | kV | D-149 | 7.6 | 11 | 15 | 11 | 9.5 | 12 | 15 | 18 | 11 | 12 | |
| | V/mil | | 1100 | 1200 | 1400 | 1100 | 860 | 1000 | 1000 | 1000 | 730 | 750 | NA |
| | kV/mm | | 43 | 47 | 55 | 43 | 34 | 39 | 39 | 39 | 29 | 30 | |
| Moisture Absorption | % | D-644 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Available Roll Sizes* | Sq yd | | 465 & 1270 | 360 & 990 | 300 & 805 | 325 & 890 | 300 & 805 | 270 & 740 | 220 & 590 | 185 & 510 | 220 & 590 | 205 & 555 | 115 & 315 |
| | Sq m | | 390 & 1060 | 300 & 830 | 250 & 875 | 270 & 745 | 250 & 875 | 225 & 620 | 185 & 495 | 155 & 425 | 185 & 495 | 170 & 465 | 95 & 265 |

*Roll width: 36 inches (914 mm). Roll thickness, size and weight are for guideline purposes only, as they can vary by +/- 15%.
Product is also available in 8.5" x 11", 24" x 36" or 36" x 36" sheets.