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Advanced Circuit Materials

Fabrication
TM 4.4.3

TMM® Temperature Stable Microwave Laminate Bonding Notes

TMM Temperature Stable Microwave Laminates are ceramic thermoset polymer composites for use in high reliability stripline and microstrip applications. TMM laminates combine low thermal coefficient of dielectric constant, a copper matched coefficient of thermal expansion and the best dielectric constant uniformity of any substrate in the market. These properties make TMM laminates ideal for temperature varying applications due to electrical and mechanical stability.

The need for bonded TMM stripline assemblies has led to a study of commercially available bond films. The bond films in the evaluation were the following:

- Dupont FEP Type C20 (both sides cementable)
- Rogers 3001 CTFE film
- Dupont FEP Type A

Unfortunately, these films have a low dielectric constant which will change the overall dielectric constant of the stripline assembly. The effect of the film depends on the circuitry topology, material grade and thickness and will therefore have to be evaluated on a per application basis.

Samples of TMM 3 and TMM 10 were evaluated with all films. Copper was etched off on all samples and baked for one hour at 110°C prior to bonding. TMM laminates do not have to undergo a sodium etch operation like PTFE/Glass laminates in order to render the surface wettable. The films used were two mils thick. Bonding was done in a flat bed press (6"x6") preheated to 300°C for FEP films and 220°C for the CTFE film. Pressure was kept at 200 psi throughout the cycle while soak time was 20 minutes at the above-mentioned temperatures. The samples were divided into three groups and tested after different conditioning. The results of the testing are given in Table I.

Material and Bond Film	Bond Strength (lbs/linear inch) Condition A	Thermal Stress	Temperature/Humidity
TMM 3- FEP C20	12.4	13.5	13.7
TMM 3 - CTFE	10.2	12.4	7.0
TMM 3 - FEP A	6.7	6.4	7.4
TMM 10 - FEP C20	13.6	12.9	13.8
TMM 10 - CTFE	12.3	12.2	6.3
TMM 10 - FEP A	6.5	5.7	6.4

Table I

Sample Preparation After Bonding

1. Condition A (as is).
2. Thermal Stress. Samples were floated for 10 seconds in a 288°C solder pot.
3. Temperature/Humidity Conditioning. Samples were placed in a pressure cooker for two hours after full pressure (17 psi) was reached.

Results indicate that FEP C20 provides best results for all conditioning environments. Rogers 3001 film fared well when conditioning was limited to as is and thermal stress, but should not be used when “hot/wet” testing is required. FEP Type A yielded low peel strength under all conditions and should not be used at all. Table II provides bonding guidelines of TMM Laminates.

Recommended Bonding Guidelines for TMM Temperature Stable Microwave Laminates	
Bond film type	Dupont FEP C20 film, ε_r=2.1 @ 1 KHz
Bond Temperature	300°C
Bond Pressure	200 psi throughout cycle
Cycle time	20 minutes at temperature
Set up	Vacuum bonding or purge with Nitrogen

Table II

PRECAUTIONS:

1. Rapid tool wear while drilling bonded TMM assemblies may result in excessive smearing of the soft fluoropolymer adhesive layers. Hit counts will depend upon dielectric thickness and design requirements and should be determined by inspection of the drilled holes.

2. Even though TMM laminates do not need to go through sodium etching prior to plated through hole processing, once bonded with FEP C20 or Rogers 3001 sodium etching will be necessary. The reason being that electroless copper will not adhere properly to the thin layer of film and will therefore provide a weak link to the hole wall. FEP Type C20 film can be obtained direct from Dupont or:

Saunders (West Coast)
A Division of R.S. Hughes Co., Inc
975 N. Todd Avenue
Azusa, CA 91702
888-932-8836

Saunders (East Coast)
A Division of R.S. Hughes Co. Inc.,
1119 N. Main Street
Lombard, IL 60148
888-932-8836

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Drilling Guidelines for TMM® Temperature Stable Microwave Laminates

Hole quality with TMM® temperature stable microwave laminates has generally been found to be excellent when proper drilling parameters are used. This application note discusses factors which affect tool wear and hole quality. Guidelines which have been found to yield good results with double-sided TMM boards and bonded assemblies are provided along with a quick reference table.

TMM temperature stable microwave materials consist of a hydrocarbon matrix highly filled with ceramic particles. The ceramic filler provides TMM materials with its low thermal expansion and makes it possible to offer a variety of dielectric constant grades.

Due to the abrasive nature of the ceramic filler, some precautions are required when drilling TMM materials. High tool surface speed (>500 SFM) and low chip loads (<0.002"/rev.) should be avoided whenever possible since they produce excessive heat and tool wear.

Surface Speed and Chip Load

Surface speed (SFM) is defined as the velocity (ft./min.) of the outer cutting edge of the tool and is used to calculate the spindle speed:

$$\text{Spindle Speed (RPM)} = \frac{12 \times \text{Surface Speed (ft./min.)}}{\pi \times \text{Drill Bit Diameter (in.)}}$$

Chip load is defined as the depth of penetration per revolution and can be calculated using the following equation:

Infeed Rate (in./min.) = Spindle Speed (RPM) x Chip Load (in./rev.)

Effect of Drilling Parameters on Tool Wear

The tool wear resulting from high surface speed varies with TMM grade and chip load. The lower dielectric constant TMM grades contain a larger fraction of highly abrasive filler. With TMM-3 laminates, surface speeds in excess of 500 SFM will significantly reduce useful tool life. For example, the maximum useful tool life may be as low as 10-20 hits if TMM-3 laminate is drilled with surface speeds in excess of 800 SFM. With TMM-10 laminates, useful tool life drops significantly with surface speeds above 650 SFM. The effects of surface speed on tool wear are more pronounced at lower chip loads (<0.002"/rev.).

The minimum spindle speed available on conventional printed wiring board (PWB) drilling machines is usually 15,000 RPM. For tools larger than 0.127", the minimum spindle speed will yield surface speeds in excess of 500 SFM. If only a small number of large holes are required (i.e. tooling holes), conventional drilling equipment can be used with frequent tool replacement. For some applications, useful tool life can be extended by increasing the depth of penetration into backer material to compensate for the decreasing effective flute length. If a significant number of large holes (>0.100") are required, it may be desirable to use NC machining equipment with lower spindle speed capability to minimize tool costs.

Recommended Drilling Conditions

Chip Load:	0.003" - 0.005" per revolution
Surface Speed:	300 - 400 SFM
Retract rate:	500 - 600 in./min.
Entry/Exit:	Phenolic (0.015" entry, 0.100" backer)
Tools:	Carbide

Calculating the Maximum Recommended Hit Count

The maximum recommended hit count can be calculated by dividing the value shown in the table below by the thickness of the construction (inches). The results are valid for tool sizes between 0.020" and 0.070" with a chip load of 0.003"/rev. and a surface speed of 300 SFM. Tool life may be lower for tool sizes outside this range.

$$\text{Maximum Recommended Hit Count} = \frac{\text{Recommended Tool Life (inches of material)}}{\text{Board thickness (inches)}}$$

Maximum Recommended Tool Life (inches of material)

	TMM-3	TMM-4	TMM-6	TMM-10
Double-Sided Boards	36"	38"	42"	60"
FEP Bonded Assemblies	18"	19"	21"	30"

For example:
The maximum recommended hit count for 0.100" double sided TMM-10 construction would be 600 (60"/0.100" = 600).

Calculating Recommended Spindle Speed and Infeed from Tool Size:

$$\text{Spindle Speed*(RPM)} = \frac{1146}{\text{Tool Diam. (inches)}}$$

$$\text{Infeed* (IPM)} = \frac{3.44}{\text{Tool Diameter (inches)}}$$

A table including recommended spindle speed and infeed for common tool sizes is provided for convenience. If PWB drilling equipment is used to drill larger holes (>0.100"), the minimum spindle speed available should be utilized to minimize surface speed.

Surface speed up to 400 SFM will not generate excessive tool wear. Therefore, use of conventional printed wiring board drilling equipment with tool sizes up to 0.100" will not significantly reduce tool life.

Recommended Spindle Speed and Infeed Table *

Drill Size (#)	Drill Size (in.)	SpindleSpeed (KRPM)	Infeed (in/min)
Parameters for conventional PWB drill equipment (15K-60K spindles)			
76	0.0200"	57.3	172
75	0.0210"	54.6	164
74	0.0255"	50.9	153
73	0.0240"	47.8	143
72	0.0250"	45.8	138
71	0.0260"	44.1	132
70	0.0280"	40.9	123
69	0.0292"	39.2	118
68	0.0310"	37.0	111
67	0.0320"	35.8	107
66	0.0330"	34.7	104
65	0.0350"	32.7	98
64	0.0370"	31.0	93
62	0.0380"	30.1	91
60	0.0400"	28.7	86
59	0.0410"	28.0	84
58	0.0420"	27.3	82
56	0.0465"	24.6	74
54	0.0550"	20.8	63
52	0.0635"	18.0	54
50	0.0700"	16.4	49
48	0.0760"	15.1	45
46	0.0810"	15.0	45
44	0.0860"	15.0	45
42	0.0935"	15.0	45
40	0.0980"	15.0	45
Parameters for NC machining equipment (1K-10Kspindles)			
34	0.1110"	10.0	30
32	0.1250"	9.2	28
30	0.1285"	8.9	27
26	0.1470"	7.8	23
24	0.1520"	7.5	23
20	0.1610"	7.1	21
	0.1875"	6.1	18
	0.2500"	4.6	14

* Based on 300 SFM and a 3 mil chip load except for tool #'s 40-48 (3 mil chip, <400 SFM).

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Taiwan:	Rogers Taiwan Inc.	Tel: 886-2-86609056	Fax: 886-2-86609057
Korea:	Rogers Korea Inc.	Tel: 82-31-716-6112	Fax: 82-31-716-6208
Singapore:	Rogers Technologies Singapore Inc.	Tel: 65-747-3521	Fax: 65-747-7425

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Routing Guidelines for TMM® Microwave Laminates

TMM® laminates can be successfully routed using conventional carbide tools. With appropriate routing conditions and tool selection, useful tool life in excess of 250 linear inches can be obtained when machining TMM-10 laminates. Tool life is somewhat lower for the lower dielectric constant grades. This application note discusses factors which effect tool wear and routed edge quality. Recommended routing conditions and tool life estimates for various tool sizes and TMM grades are provided in quick reference tables.

TMM® Microwave Materials, consist of a hydrocarbon matrix highly filled with ceramic filler. This provides TMM with its low thermal expansion and makes it possible to offer a wide variety of dielectric constants.

Due to the abrasive nature of the ceramic filler, some precautions are required when routing TMM materials. High tool surface speed (>400 SFM) should be avoided whenever possible to prevent excessive tool wear and reduced edge quality.

Recommendations provided below are based on testing completed using an Excellon EX driller/router. A range of carbide tool geometries from several tool suppliers were evaluated.

TABLE 1
Recommended Routing Parameters

Recommended Tools:	Diamond cut carbide tools or sprial chipbreaker with at least 5 flutes
Lateral Chip Load:	0.0010" - 0.0015"
Surface Speed:	200-400 SFM
Entry:	Phoenolic (0.010"-0.030")
Exit:	Phoenolit (0.100")

Surface Speed and Chip Load:

Surface speed (SFM) is defined as the velocity (ft./min.) of the outer cutting edge of the tool. The following equation can be used to calculate the spindle speed for a particular tool diameter and surface speed.

$$\text{Spindle Speed (RPM)} = \frac{12 \times \text{Surface Speed (ft./min.)}}{\pi \times \text{Tool Diameter}}$$

Chip load is defined as the distance of tool travel per revolution. The following equation can be used to calculate feed rate for a particular chip load and spindle speed.

Lateral Feed Rate = Chip Load x Spindle Speed
(inches/min.) (inches/rev.) (rev./min.)

Recommended TMM Routing Conditions and Tool Life:

Recommended routing conditions and useful tool life estimates provided in Tables 1 and 2 are based on quality considerations such as copper burring, channel width reductions, sidewall roughness as well as the ultimate life of the tool (inches to failure). The ultimate tool life values in the accompanying figures provide a good quantitative basis for comparing tool geometries and routing ocnditions. However, useful tool life can be significantly lower due to edge quality requirements. The useful tool life estimates provided in Table 2 are typically about 50% to 60% of the ultmate tool life. Tools may need to be replaced more frequently for highly demanding applications.

Table 2: Useful Tool Life Estimates (*):
Tool TYPE A - Diamond Cut Router Geometry
Tool TYPE B - Upward Spiral Chipbreaker (³ 5 flutes)

			Tool Diameter - TYPE A			Tool Diameter - TYPE B		
Material	Speed (KRPM)	Lateral Feed Rate (in/min)	1/16'	3/32"	1/8"	1/16"	3/32"	1/8"
TMM 3	15	19	80	120	120	90	100	100
TMM 3	20	25	50	50	50	40	40	40
TMM 3	25	31	30	20	X	30	20	X
TMM 4	15	19	100	140	140	100	120	120
TMM 4	20	25	70	70	70	60	60	60
TMM 4	25	31	45	40	X	45	40	X
TMM 6	15	19	150	180	180	120	150	150
TMM 6	20	25	100	100	100	100	100	100
TMM 6	25	31	70	70	X	70	70	X
TMM 10	15	19	250	250	250	250	250	250
TMM 10	20	25	250	250	250	250	250	250
TMM 10	25	31	250	250	250	250	250	250

(*) Notes:

1. This table is based on 0.060" thick constructions. Useful tool life will be significantly lower for thicker constructions. For example, tool life can drop by as much as 50%-60% if the construction thickness is doubled (0.120").
2. To maximize tool life and edge quality, the higher spindle speeds listed (20K RPM and 25K RPM) should not be used if lower spindle speeds are available.
3. This table assumes a minimum spindle speed of 15K RPM. If available, lower spindle speeds should be used when routing with larger tools (>100"). should be used when routing with larger tools (>100").

Factors Effecting Tool Life:

There are a variety of factors which effect useful tool life when machining TMM® laminates or bonded assemblies. They include TMM grade, surface speed, tool geometry, chip load, tool size and stack height.

TMM Grade:

The lower dielectric constant TMM grades contain a larger fraction of highly abrasive filler. Therefore, TMM-3 yields a shorter tool life then TMM-10. When appropriate routing conditions and tool geometries are used, TMM-3 can yield a useful tool life of about 120 linear inches. With TMM-10, useful tool life can exceed 250 linear inches.

Tool Surface Speed:

The effect of surface speed on ultimate tool life is shown in Figure #1 for TMM-3 machined with a variety of tool geometries. For all geometries tested, ultimate tool life decreased with increasing surface speed. The spindle speed examined ranged from 15K RPM to 25K RPM (3/32" tool).

Tool Geometry:
The tool geometries which were evaluated are listed in Table 3. Due to practical considerations, this study only included tools from three suppliers. However, similar tool geometries from other suppliers should provide similar results.

In general, tools with a larger number of cutting edges offered superior tool life. As shown in figure #1, the Precision Carbide R1U, R1D and Megatool RCS geometries offered the best ultimate tool life. These tools are typically used for routing conventional PWB materials such as FR4. Tool geometries which are typically used for routing PTFE based laminates such as the Presicion Carbide EM2 cutter yielded poor ultimate tool life due to their relatively small cross-sectional area.

Lateral Feed Rate (Chip Load):
The effect of chip load on ultimate tool life is shown in Figure #2 for various tool geometries. As chip load increases, the ultimate tool life decreases. However, very low chip loads (<0.001"/rev.) sould be avoided due to a significant increase in copper burring.

Table 3
Tool Geometries Evaluated
(in order of decreasing tool life)

Abbreviation	Generic Description	Vendor
PCR1D	Diamond Cut (down-draft)	Precision Carbide
PCR1U	Diamond Cut (up-draft)	Precision Carbide
Mega RCS	Diamond Cut (up-draft)	Megatool
Tulon 44	Spiral Chip Breaker (5 flute)	Tuflon
Mega RI	Straight Endmill (3 flute)	Megatool
PCEM2	Sprial Endmill (2 flute)	Presicion Carbide

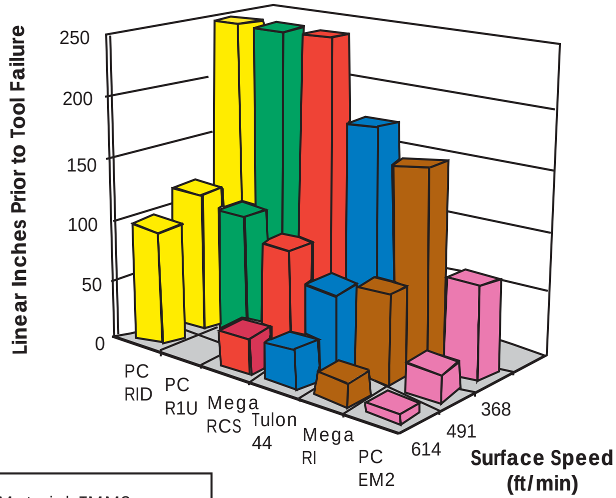
Table 4
Tool Surface Speed (ft./min.)

Spindle Speed (RPM)	1/16" Tool	3/32" Tool	1/4" tool
15K	245	368	491
20K	327	491	654
25K	409	614	818

Tool Size:
As seen in Figure #3, larger tools typically yield better ultimate tool life at a given surface speed due to the increased tool crossectional area. Therefore, smaller tools often need to be replaced more frequently.

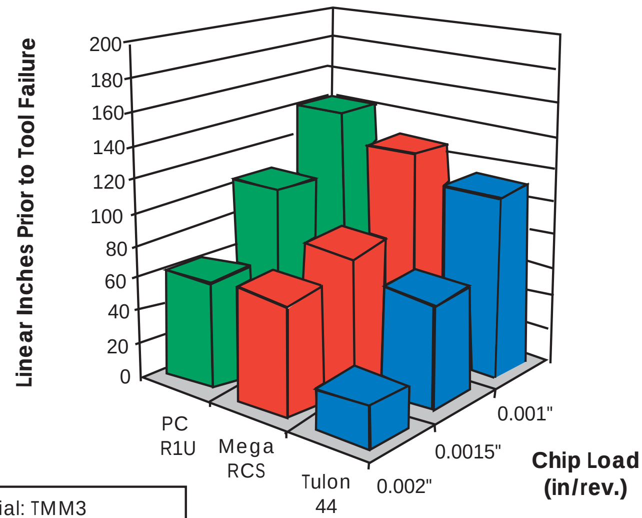
Stack Height:
The ultimate tool life also decreases with increased stack height (Figure #4). This is due to the increased lateral stress on the tool. As stack height increases, tools should be replaced more frequently.

Figure #1
Ultimate Tool Life as a Function of Surface Speed



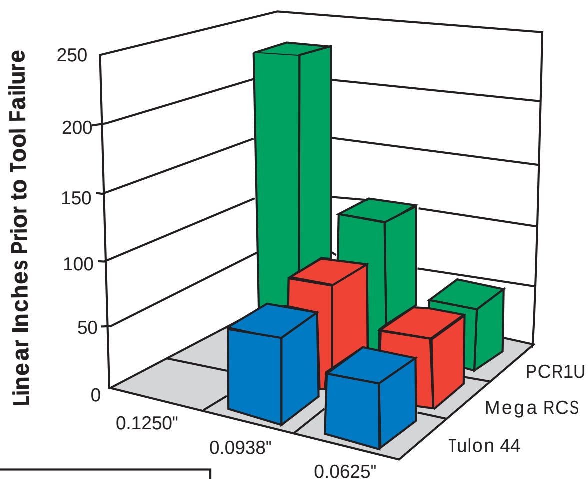
Material: TMM3
Chip Load: 0.0015/rev.
Tool Size: 3/32

Figure #2
Ultimate Tool Life as a Function of Chip Load



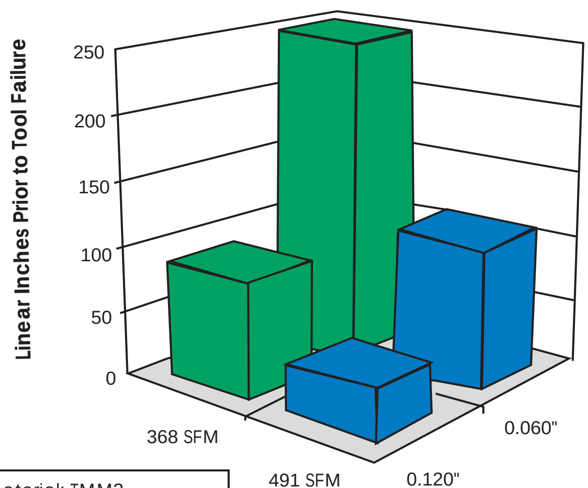
Material: TMM3
Surface Speed: 491 SFM
Tool Size: 3/32

Figure #3
Ultimate Tool Life as a Function of Tool Size



Material: TMM3
Surface Speed: 491 SFM
Chip Load: 0.0015"/rev.

Figure #4
Ultimate Tool Life as a Function of Stack Height



Material: TMM3
Chip Load: 0.0015"/rev
Tool Type: PCR1U (3/32")

Note: Prolonged exposure in an oxidative environment may cause changes in the dielectric properties of all hydrocarbon based dielectric materials, including TMM high frequency dielectric materials. Changes may be exacerbated by increased thermal exposure. Whether or not such changes occur, and whether or not they might result in a functional impact on a finished product, depends on a complex set of variables related to factors such as circuit design, functional tolerances, operating conditions and other circumstances that are unique to each product design. Although Rogers continues to seek ways to minimize the naturally occurring effects of oxidation by developing improved anti-oxidant formulations for the TMM family of high frequency materials, Rogers, as always, recommends that the circuit designer and/or the end user test the properties and performance of these materials in each proposed application to determine their fitness for use over the entire product life.

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