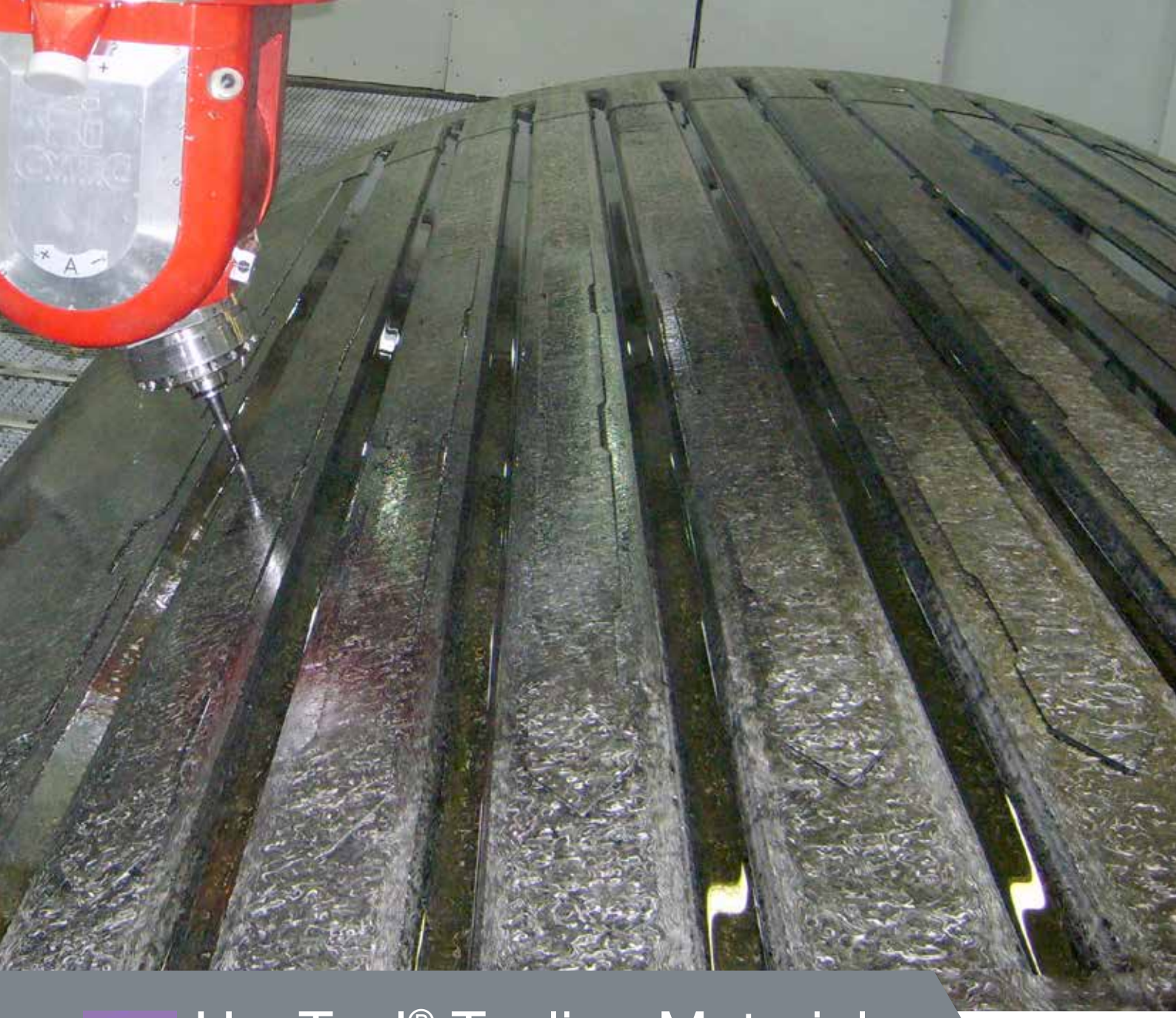

HexTool® Tooling Material
User Guide

HexTool® composite tooling material is redefining the future of composite tooling. With a 50% weight savings over comparable metal tooling, combined with high levels of dimensional stability and the ability to machine in detailed tool face attributes, HexTool® provides OEM's with a proven path from development to production tools.

HEXCEL®

HexTool® tooling material
User Guide

This document is intended as a guide to assist in the construction of quasi-isotropic fiber carbon tools using Hexcel's line of bismaleimide or epoxy HexTool® material. Although great care has been taken to include as much detail as possible, every application is unique and should be thoroughly reviewed with your local Hexcel Sales and Technical Support Engineer.

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M61 HexTool® (BMI Version)

Material Information

Product Format & Definition

- 2000 g/m² (0.41 lbs/ft²) or 4000 g/m² (0.82 lbs/ft²) carbon fiber reinforced mat
- Composed of 8 x 50 mm (0.32 x 1.97 in) prepreg bundles presented in a quasi-isotropic orientation
- High-strength carbon fiber with a nominal laminate fiber volume of 55%
- Bismaleimide (BMI) matrix at 38% resin content (by weight)
- Storage life:
  - 12 months at -18˚C (0˚F) or below
  - 30 days at room temperature
- Autoclave cured at 190˚C (375˚F) under 7 bar (100 psi) pressure
  Out-of-autoclave post-cure at 220˚C (428˚F) required to develop maximum Tg
- Average cured-ply thickness:
  - 2000 g/m²: 1.25 mm (0.05 in)
  - 4000 g/m²: 2.5 mm (0.10 in)
- Machined cured ply thickness:
  - Machined cured-ply thickness is the thickness per ply of material after the machining operation yields a smooth surface. This term is introduced because HexTool® cures with a wavy bag-side surface. Depending on master strategy, you may expect the following cpt yield:
  - 2000 g/m²
    - IML master: 1.27mm (0.05 in)
    - OML master: 0.89mm (0.035 in)
  - 4000 g/m²
    - IML master: 2.54mm (0.10 in)
    - OML master: 2.03mm (0.08 in)

Material: HexTool® M61
Manufacturer: Hexcel- France

European Union (EU) ECCN classification for material: 1C010
European Union (EU) ECCN classification for technology related to production or development of 1C010 material: 1E001

Mechanical & Physical Properties

Table 1: M61 HexTool® Physical Properties

Property	Units	Condition	Method	Value
Rockwell B Hardness		Machined Side	ASTM D785-08	83
		Tool Side		78
Glass Transition Temperature	℃ (℉)	Dry	DMA	275 (527)
		Wet		230 (446)
Coefficient of Thermal Expansion	Expansion x 10^{-6}/℃	X-Y Bias Plane	ASTM E289-90	4
		Z-Axis		47

Table 2: M61 HexTool® Mechanical Properties

Property	Units	Condition	Temperature C°(F°)	Method	Value
Tensile Strength	MPa (ksi)	Dry	23 (73)	ASTM D3039	260 (37.7)
			180 (360)		210 (30.5)
Tensile Modulus	GPa (msi)	Dry	23 (73)	ASTM D3039	41 (5.95)
			180 (360)		40 (5.80)
Compression Strength	MPa (ksi)	Dry	23 (73)	ASTM D6484	300 (43.5)
			180 (360)		270 (39.1)
Compression Modulus	GPa (msi)	Dry	23 (73)	ASTM D695	32 (4.64)
			180 (360)		30 (4.35)
Flexural Strength	MPa (ksi)	Dry	23 (73)	ASTM D790	380 (55.1)
Flexural Modulus	GPa (msi)	Dry	23 (73)	ASTM D790	38 (5.51)
Short Beam Shear Strength	MPa (ksi)	Dry	23 (73)	EN 2563	50 (7.3)
			180 (360)		43 (6.2)

Lay-up Instructions

This section outlines the lay-up for a standard tool with a finished thickness of 9.5 mm (0.375 in).

Material Application

- After removal from freezer storage, HexTool® should be allowed to reach room temperature before opening of the protective polyethylene bag (minimum of 12 hours for a 30 kg/60 lb roll).
- The recommended cutting tool is a vibratory saw. An example is the Fein MultiMaster. Recommended blade styles are shown in Figure 1.

Figure 1: Blade suggestions for vibratory saw cutting of HexTool® material.

- Prepare the tool master surface using an appropriate release agent (e.g. Frekote® 700-NC or Cirex 043). A release film such as Tooltec is a recommended release from foam tool masters.

- Lay-up the HexTool® plies directly over the tool master.
  - It is recommended that tools constructed from the 4000 g/m^2 product are made using a tile concept.
  - Plies (tiles) are cut to the full width of the roll (0.47 m or 18.5 in) by a length of 0.3 m (12 in) to 0.6 m (24 in) (Figure 2).
  - Warm tiles in an oven set to 71°C/160°F (or 60°C/140°F if oven is not vented externally). Material can be left in oven for up to 60 minutes. HexTool® tiles should reach 54°C 130°F before being applied to master
  - Pre kitting all tiles greatly increase lay down rate

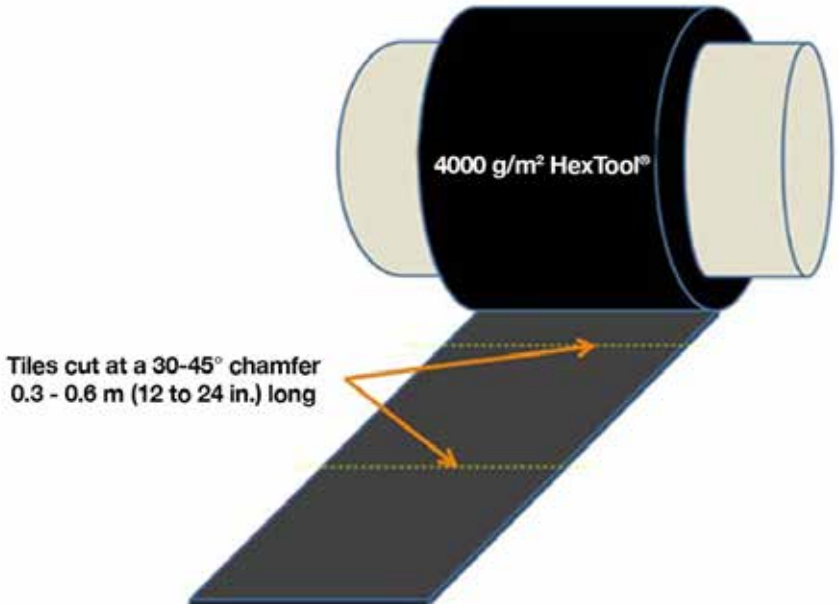

Figure 2: Illustration of cutting HexTool® material into tile pieces from roll.

Figure 3: Chamfered ends of HexTool® plies cut at 30-45° with a vibratory saw. Pre-cut plies off of the master to avoid damage to the master.

- Splices are made by overlapping the edges. Overlaps shall be a minimum of 12 mm (0.5 in) followed by shaving of the overlap hump to a consistent thickness using a vibratory saw. See additional information about shaving HexTool® material below.
- Splices should be shifted 50 mm (2 in) from splices on the layer beneath.

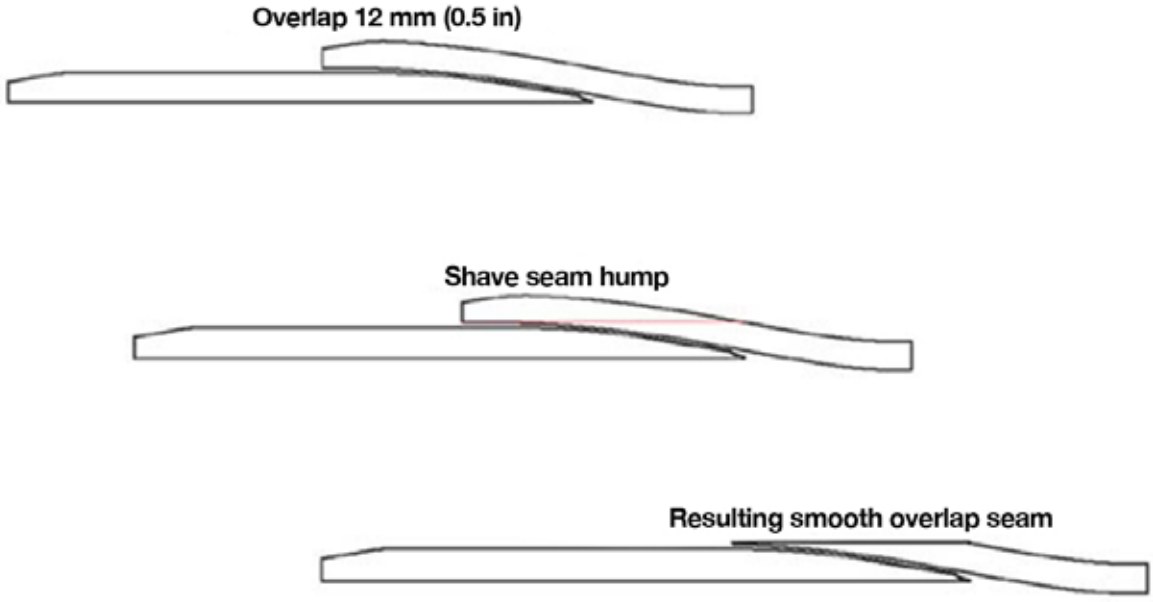

Figure 4: Steps for overlapping tile pieces.

Figure 5: Plies of HexTool® applied to master using the tile concept.

- Debulking after the first ply is highly recommended to promote conformity with the tool master for both 2000 and 4000 g/m² grades of HexTool®. Thereafter, for 4000 g/m² HexTool®, depending on tool size and complexity, debulking is recommended after every 2 plies as shown in Figure 6. Build up plies as required to the desired thickness.
  - See Hot Vacuum Debulk Cycle and Hot Pressure Debulk Cycle below for debulk autoclave or oven cycles.

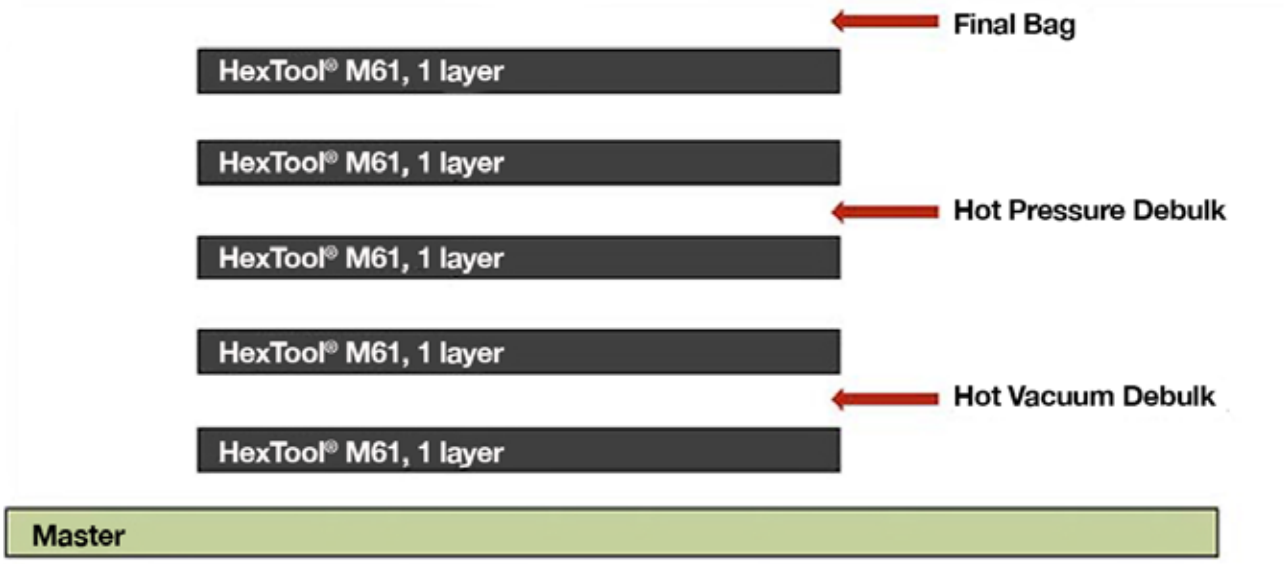

Figure 6: Debulk schedule for standard thickness M61 HexTool® tool

- When applying HexTool® to an outside radius, wrap the material from one side to the other, using your hand to press the ply around the corner to reduce risk of pinching and creases on the corners. This technique is demonstrated below in Figure 7.

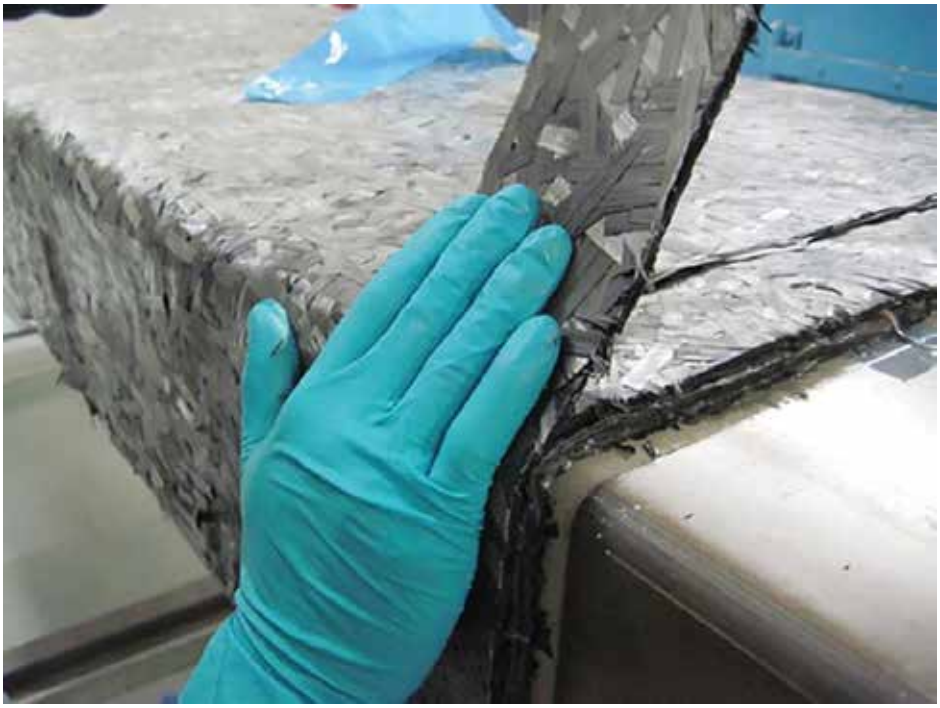

Figure 7: Application of warm HexTool® ply on an outside radius. Apply the material to one side and wrap carefully around the corner.

- If a crease or pinch in material does occur around a radius during a debulk cycle the uncured, consolidated material can be carefully shaved off using a vibratory saw as shown in Figure 8.
- Rubber pressure intensifiers can be used to mitigate pinching during debulks and final cure.

Figure 8: Trimming of high spots or corner pinches/creases with a vibratory saw

- Tile splices should not be placed on a radius because it increases the risk of the splice opening during compaction.
- After debulking a vibratory saw can be used to shave the seams. Seams need shaving or trimming when there is a risk for a resin pocket to form due to bridging of subsequent plies. Examples of areas that need to be shaved or trimmed are shown in Figure 9.

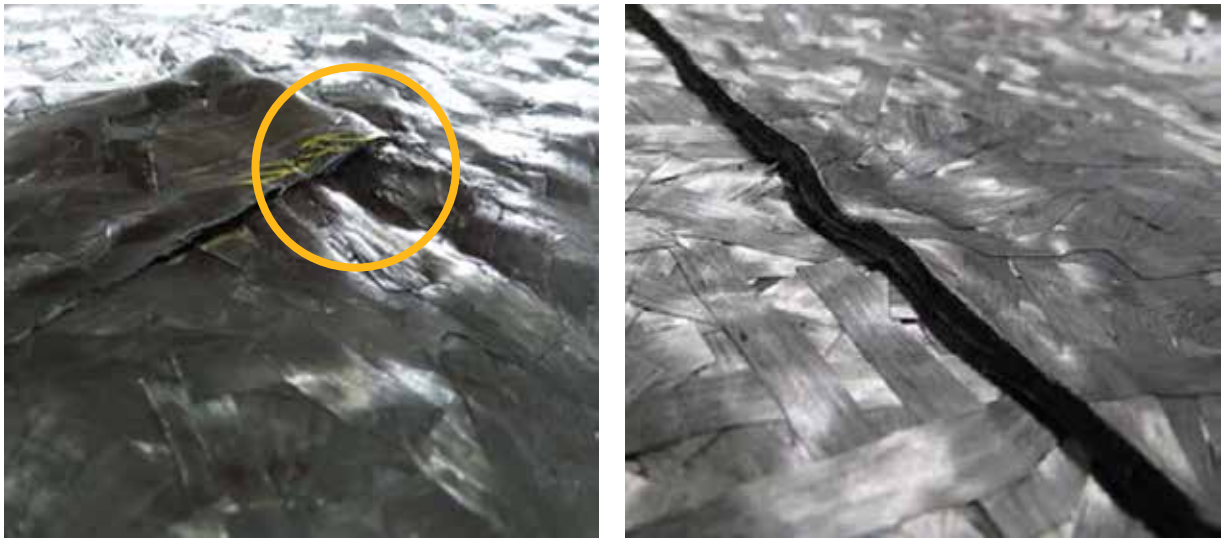

Figure 9: Circled area is at risk for filling with resin due to bridging of the next ply (left).
The tile edge that was cut at 90˚ instead of 30-45˚ should be shaved or trimmed at an angle (right).

- Shaving and trimming technique shown in Figure 10.
  - Shaving or chamfering may be performed directly on the tool but care must be made to not cut into the tool master.

Figure 10: Examples of shaving and trimming material after it has been placed on a tool master (left) and finished appearance (right).

- Sometimes small, thin patches are required to reduce risk of bridging or fill a small space. HexTool® can be peeled apart to make thinner pieces which are easier to push into small spaces (shown in Figure 11). Patches can either be heated in an oven or softened with a heat gun directly on the tool master.

Figure 11: A HexTool® piece is peeled apart to use for patching.

Thermocouple Placement

- For small tools less than 0.74 m^2 (8 ft^2) in surface area a minimum of four thermocouples (TC) will be used; an additional two TC's will be used for each additional 0.93 m^2 (10 ft^2) of surface area.
- Thermocouples shall be placed to measure leading and lagging tool temperatures; placement of thermocouples shall be such that the tool's thermal gradient is accurately captured during the cure.
- Leading tool temperature is typically the outer or bag surface directly in the air flow path of the autoclave.
- In cases with a foam tool master, the lagging tool temperature is typically located between the inside plies and the master. In the case of curing against a metal or composite master lagging temperature will typically be at the mid ply or half the total thickness of the thickest area of the tool.
- For both leading and lagging TC placement, the probe end shall be placed a minimum of three inches from the edge of the tool.
- Distribution of leading and lagging TC's shall be such that reasonable areas of the tool surfaces are surveyed.
- Actual placement will depend on factors such as tool geometry, tool thickness variation and curing systems air flow. Please contact Hexcel Technical Support if additional help is required for your particular tool.

Debulking HexTool® (4000 g/m² grade)
Refer to Figure 6 for debulking schedule.

Hot Vacuum Debulk Cycle (HVD)
Bagging for HVD

1. Perforated FEP release film should be placed on top of the HexTool® material.
2. A layer of N10 breather cloth should be placed on top of the perforated FEP film.
3. A nylon BMI-resistant vacuum bag is placed on top of the N10 breather and sealed to the master or project plate using temperature-appropriate sealant tape.
4. Bagging scheme for HVD shown in Figure 12.

HexTool® M61 Hot Vacuum Debulk Bagging Scheme

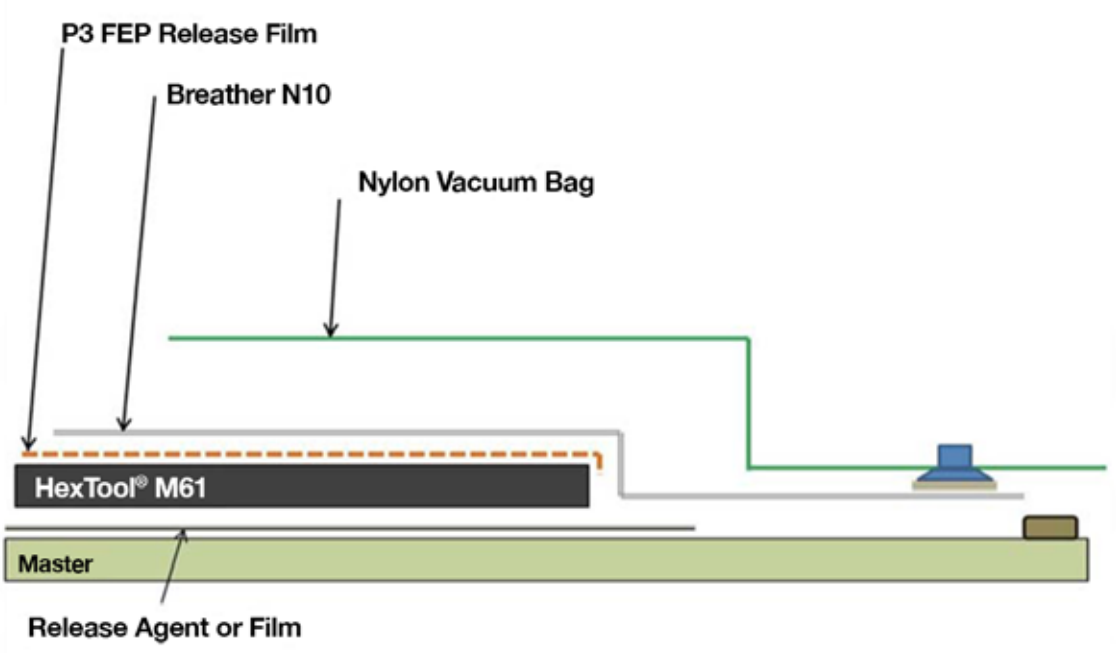

Figure 12

HVD Oven or Autoclave Cycle

- Minimum vacuum requirement of 0.75 bar (22 inHg) when measured mid-span with vacuum applied at the ends.
- Oven Temperature Profile* shown in Figure 13.
  - Heat to 93˚C (200˚F) at 1.7-2.8 ˚C/minute (3-5 ˚F/minute).
  - Start one hour dwell when lagging TC reaches 88˚C (190˚F) for a maximum dwell of 60-90 minutes.
  - Cool down at 2.8 ˚C/minute (5 ˚F/minute) to 49˚C (120˚F).
  - Opening of oven doors to accelerate cool down is allowed.
- Disconnect vacuum and end cure when lagging TC is below 49˚C (120˚F).
- Recommended Inspection Requirements:
  - Verify lagging TC achieves minimum time at dwell temperature and doesn't exceed maximum dwell temperature.
  - Verify air TC doesn't exceed 99˚C (210˚F).

* If vacuum is not vented externally temperature should not exceed 60˚C (140˚F).

HexTool® M61 Hot Vacuum Debulk Bagging Cycle

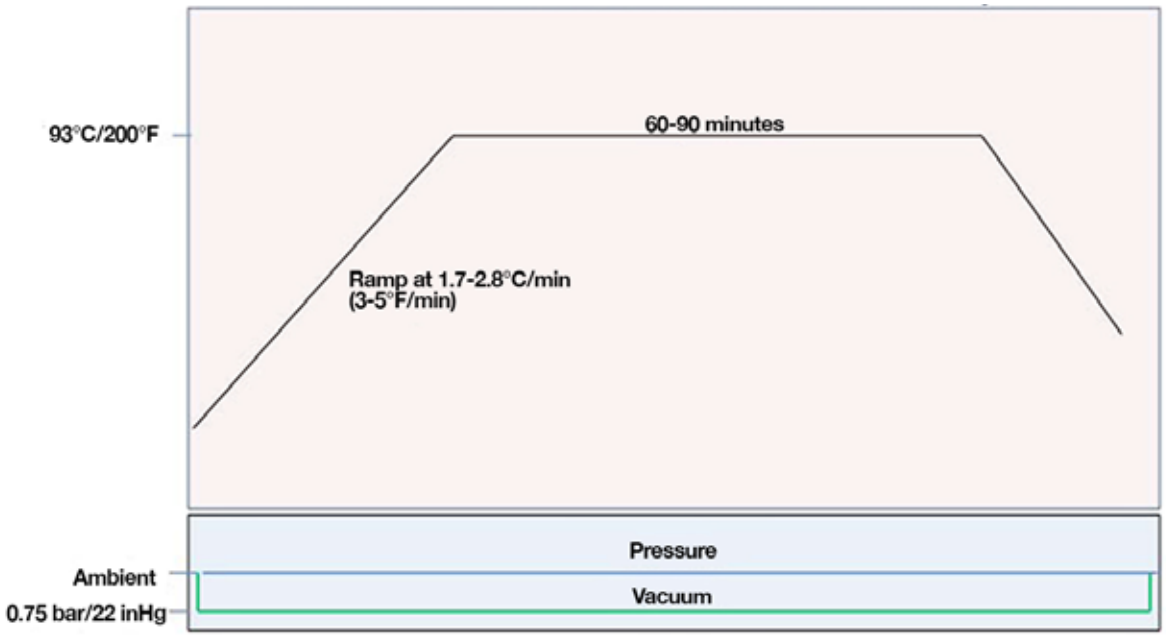

Figure 13

Hot Pressure Debulk Cycle (HPD)

Bagging for HPD

1. Perforated FEP release film should be placed on top of the HexTool® material.
2. A layer of N10 breather cloth should be placed on top of the perforated FEP film.
3. A layer of solid FEP release film should be placed over the N10 breather.
4. A nylon BMI-resistant vacuum bag is placed on top of the N10 breather and sealed to the master or project plate using temperature-appropriate sealant tape.
5. Bagging scheme for HPD shown in Figure 14.

HexTool® M61 Hot Pressure Debulk Bagging Scheme

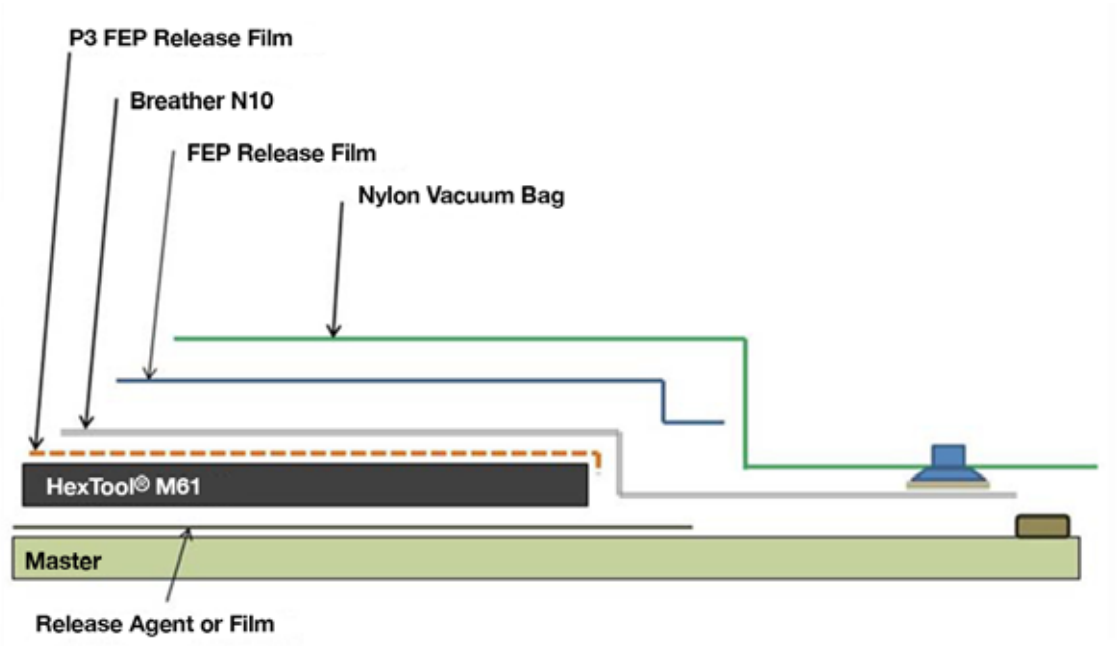

Figure 14

HPD Autoclave Cycle

- Minimum vacuum requirement of 0.75 bar (22 inHg) when measured mid-span with vacuum applied at the ends.
- 5.86 - 7 bar (85 - 100 psi) autoclave pressure.
- Autoclave Temperature Profile* shown in Figure 15.
  - Heat to 93°C (200°F) at 1.7-2.8 °C/minute (3-5 °F/minute).
  - Start one hour dwell when lagging TC reaches 88°C (190°F) for a maximum dwell of 60-90 minutes.
  - Cool down at 2.8 °C/minute (5 °F/minute) to 49°C (120°F).
  - Opening of oven doors to accelerate cool down is allowed.
- Disconnect vacuum and end cure when lagging TC is below 49°C (120°F).
- Recommended Inspection Requirements:
  - Verify lagging TC achieves minimum time at dwell temperature and doesn't exceed maximum dwell temperature.
  - Lagging TC is based on TC wire #1, 2, or 3 being operational.
  - Verify air TC doesn't exceed 99□C (210□F).
  - Typical HexTool® laminate after hot pressure debulk shown in Figure 16.

* If vacuum is not vented externally temperature should not exceed 60°C (140°F).

HexTool® M61 Hot Pressure Debulk Bagging Cycle

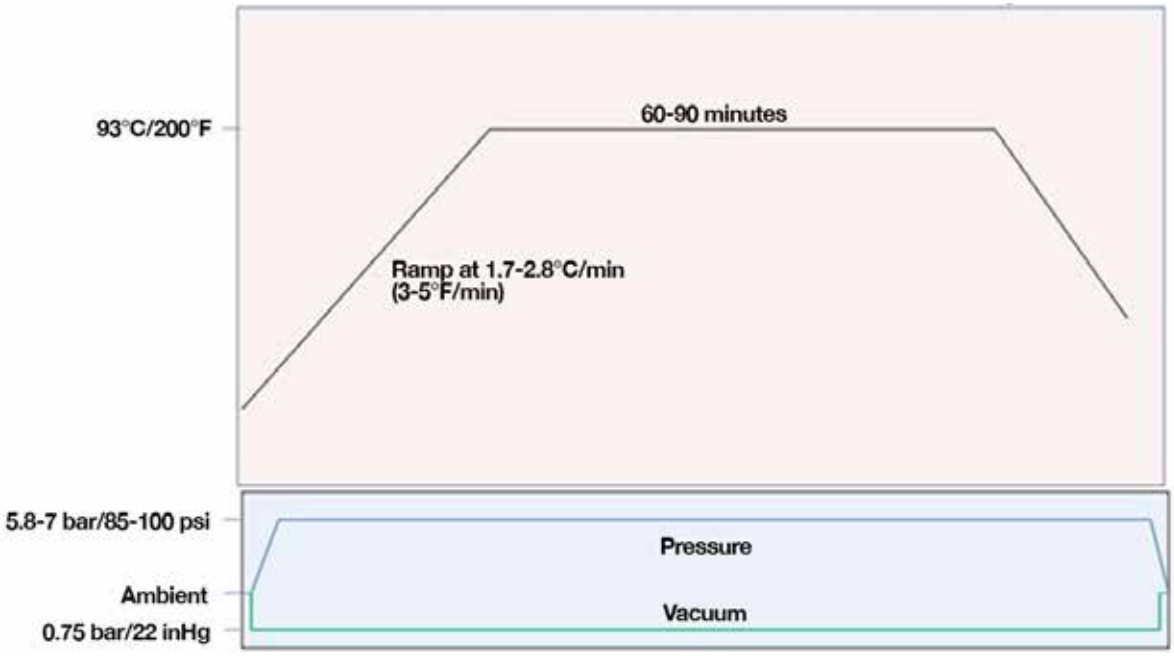

Figure 15

Figure 16: Seven debulked plies of HexTool® on an epoxy foam master with Tooltec release.

Bagging for Final Cure

- The following bagging materials are required. Recommended products and generic requirements for alternatives are in Table 3.
  - Sealant tape to withstand autoclave temperatures of 200˚C (400˚F)
  - Perforated and non-perforated release films
  - Breather/bleeder materials
  - BMI resistant vacuum bag
- A typical bagging assembly is outlined in Figure 17.
- If you are using materials not listed in the table below please contact your Technical Support representative.

Table 3: Recommended bagging materials for use with M61 HexTool® and requirements for suitable alternatives.

Material	Recommended Material Part Number	Source	Generic Requirements
Nylon Vacuum Bag	WL7400 DP 1000 WL8400 HS8171 HS9171	AirTech Solvay	BMI resistant
			177-204˚C (350-400˚F) service
			Suitable for long duration temperature and pressure
Solid Release Film	Wrightlon 5200 HT-7000	AirTech Solvay	BMI resistant, 0.05 mm (0.002 in) thick
			204˚C (400˚F) service
Breather (outer bag)	Ultraweave 1332 RC-3000-20	AirTech Solvay	204˚C (400˚F)/ 7 bar (100 psi) service
			Suitable for long duration temperature and pressure
Breather / Bleeder/ (inner bag)	N 10 RC-3000-10	AirTech Solvay	339 g/m^2 (10 oz/yd2) polyester non-woven
Perforated Release	5200 P3 HT-7000 P1	AirTech Solvay	BMI resistant
			204˚C (400˚F) service
			clean punched holes 0.38 mm diameter (0.015 in) on 6.35-12.7 mm (0.25-0.5 in) centers
Glass Breather String	ECG 37 1/4 dry glass tow		Glass tow of equivalent size

- Contact between the matrix resin and the vacuum bag must be prevented.
  - To achieve this, the non-perforated release film used in the bagging scheme, must be sealed to the tool during lay-up. In effect, this will create an isolated interior bag. The BMI resin will have no adverse effect on this non-reactive and stable release material.
- Glass strings (or strips of PTFE/Teflon coated glass) are used to connect the interior bag to the exterior vacuum source. These should be positioned around the perimeter of the tool at approximately 30 cm (12 inches) spacing and they should pass over the interior bag vacuum tape.
- As an extra precaution, an additional layer of non-perforated release film can be placed over the breather fabric.

These steps are expanded upon below in the Step-by-step Bagging Instructions.

HexTool® M61 Final Cure Bagging Scheme

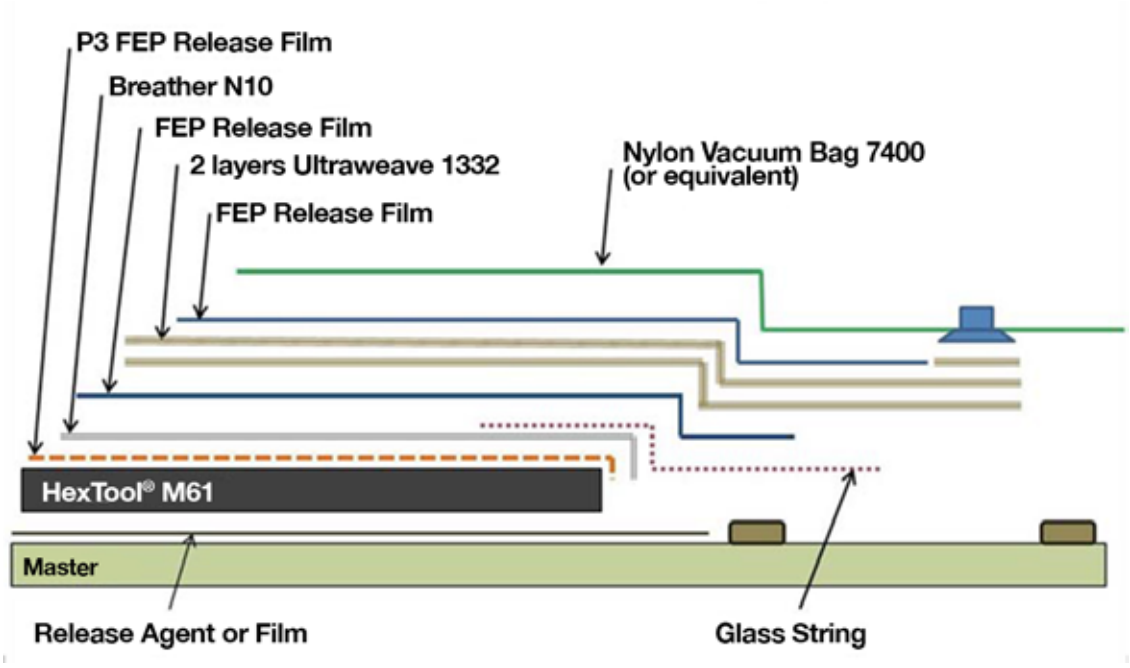

Figure 17

Step-by-Step Bagging Instructions

Do not skip steps in these instructions. Each step is critical to successful cure of the HexTool® tool.

1. Apply sealant tape to tool master around perimeter of the HexTool® material.
   - This sealant tape will serve as an attachment and sealing point for the inner bag.
2. Apply a layer of perforated FEP film directly over the HexTool®.
   - Use Teflon tape to attach the perforated FEP to the tool master to prevent it from shifting during subsequent bagging steps or cure.

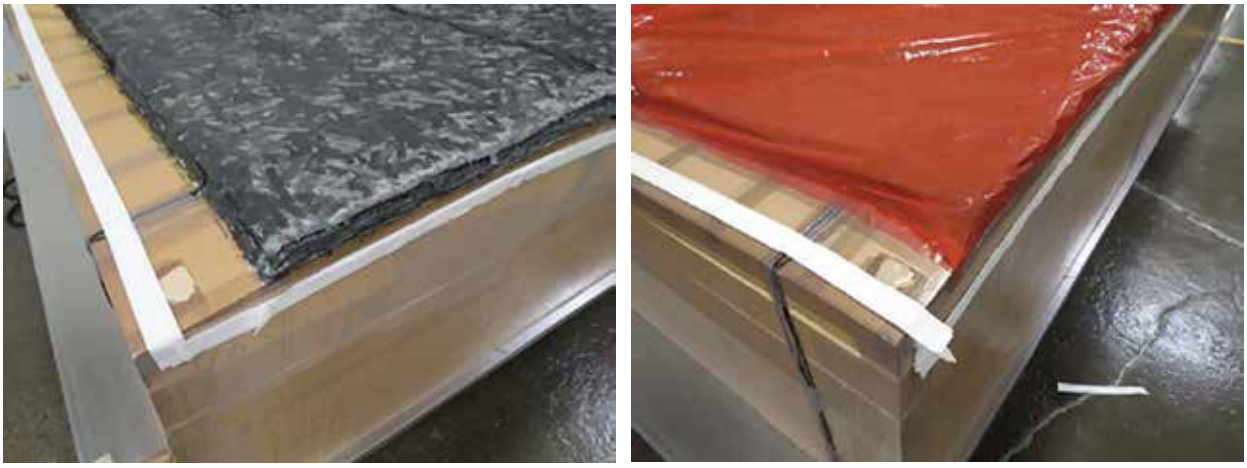

Figure 18: Vacuum sealant tape is placed around the perimeter of the HexTool® tool (left). Perforated FEP film is placed on the HexTool® tool and taped to the master (to prevent shifting during subsequent bagging steps and cure) using Teflon tape (right).

3. Apply a single layer of breather material over the perforated FEP.
   - One layer of N10 or equal weight of polyester non-woven bleeder should with every 5 layers of HexTool® M61 4000
   - If less than 5 layers of HexTool® M61 4000 is cured then the following bleeder packs should be substituted:

Tooling Material	No. of Layers Cured	Bleeder Material
HexTool® M61, 4000	Every 5 Layers	1 ply of N10
	2-4 Layers	1 ply of N4
	1-2 Layers	1 play of 2 oz./sq. yd Peel Ply

Figure 19: Application of first layer of breather over perforated FEP

4. Apply breather strings approximately every 30 cm (12 inches) around the perimeter of the tool. The strings provide a pathway to connect the inner bag to the outer vacuum supply to remove air from the laminate and get optimum consolidation of the HexTool® while protecting the outer bag from aggressive BMI resin.

   To apply these strings:

   - Cut a length of fiberglass bundle approximately 60 cm (24 inches) long.
   - Fold the string in half. Tape the loop at the top to the breather, allowing approximately 15 cm to 22.5 cm (6-8 inches) of string to hang over the edge of the sealant tape.
   - Rip the sealant tape paper covering where the string runs over the tape and press the tow down into the tape.
   - Place the paper covering back over the tape to prevent debris from sticking to the tape before the inner bag is applied.

   If there is not enough room on the tool master to leave the breather strings hanging the ends can be taped on top of the inner bag once it has been applied to the tool.

   See Figure 20 for illustration of the above steps.

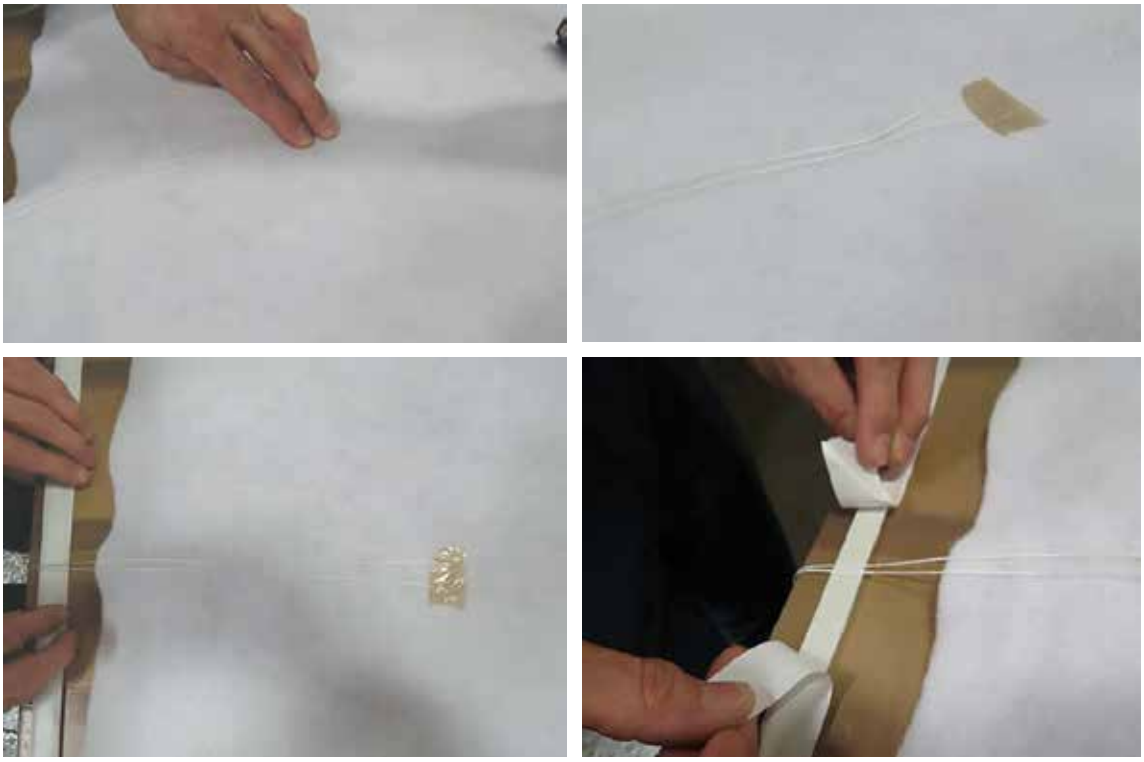

Figure 20: Steps for applying breather strings.

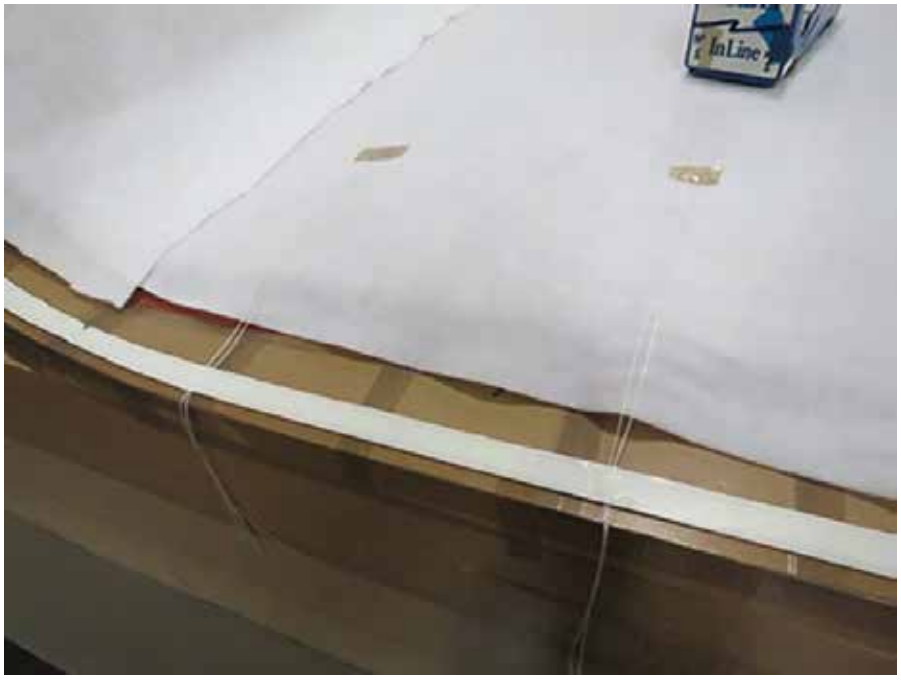

Figure 21: Installed breather strings spaced out approximately 30 cm (12 inches).

5 After all layers of breather/bleeder and strings have been applied to the tool the inner bag made of solid FEP film can be installed. It should be sealed to the master using the layer of sealant tape that had previously been applied. See Figure 22.

Figure 22: Solid FEP film inner bag installed on HexTool® tool and sealed.
Note how breather string hangs outside of bag.

- When seaming two smaller pieces of FEP or bag film together to make a larger piece, the vacuum tape should be positioned between the faces like pages between book covers; see Figure 23 and Figure 24 below. This allows for complete sealing of seam to perimeter vacuum tape.

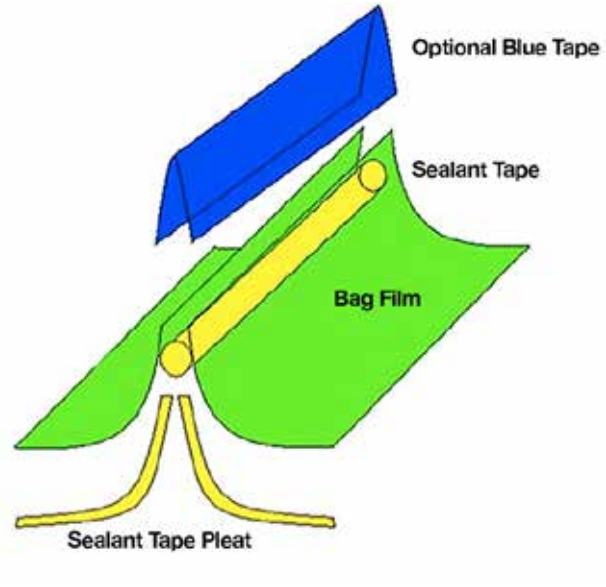

Figure 23: Illustration for bag film seaming method.

Figure 24: Example of preferred bag film seaming method.

Left: Pieces of bag film to be joined are placed next to each other. Then a fold slightly wider than the width of the sealant tape is created on the left side bag film.

Middle: Sealant tape is placed on the folded over surface of the bag film on the left side and then the bag film is applied to the sealant tape.

Right: Cross-section view of the seam alone and then applied to sealant tape on the tool.

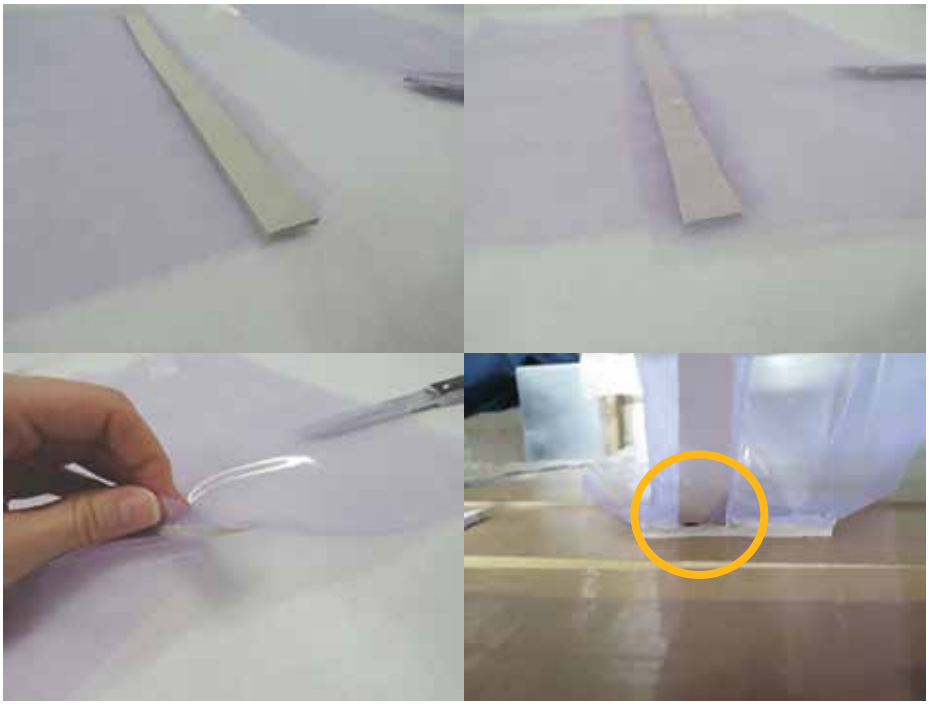

Figure 25: Incorrect method for making a bag seam. Film is seamed using a lap joint. Note space between bag seam and sealant tape in bottom right photo.

6. Two layers of Ultraweave 1332 should next be applied to the HexTool® on top of the solid FEP inner bag. Additional strips should be applied on corners and edges to prevent damage to the vacuum bag.

Figure 26: Ultraweave 1332 breather placed on top of solid FEP film with extra strips installed on corners and edges to protect final bag.

7. Place a second layer of solid FEP on top of the breather cloth to further protect the final nylon vacuum bag from the BMI resin.

8. Vacuum ports should be installed on top of the last layer of solid FEP.
   - A minimum of 4 ports (3 vacuum supplies and 1 monitor).
   - For larger tools, the suggested quantity of vacuum ports is 1 port per 0.92-1.39 m^2 (10-15 ft^2) of Hex-Tool® tool area.
   - The vacuum ports should be connected to each other underneath the bag by strips of breather or some other non-collapsing, highly permeable material. An example of installation of vacuum ports is shown below in Figure 27.

Figure 27: Installed vacuum ports.

1. *Breather strips connect all vacuum ports to each other.*
2. *Woven glass cloth wrapped in breather with port attached. Strip is inserted into a slit in solid FEP to connect tool to vacuum source.*
3. *Highly permeable, non-collapsing flow media wrapped in breather cloth to connect all vacuum ports to each other.*

9. Place strip of vacuum sealant tape onto project plate or master (if master has high vacuum integrity).
10. Install final bag. Bag should be large enough to prevent bridging. If vacuum ports were installed as shown above the flap with the port attached can be placed in a large bag pleat as shown in Figure 28.

Figure 28: Vacuum port in bag pleat of final bag.

Curing

Autoclave Cycle
Illustrated in Figure 29.

- Establish a minimum vacuum of 0.75 bar (22 inHg).
- Maximum allowed vacuum bag leak is 0.067 bar (2 inHg) in10 minutes.
- Begin heating at 0.27-0.55 ˚C/minute (0.5-1.0 ˚F/minute) to 107˚C (225˚F).
- Increase pressure to 6.89±0.69 bar (100±10 psi).
- Dwell at 107±2.8˚C (225±5˚F) based on lagging thermocouple for 30+10/-0 minutes.
- Continue to heat 0.27-0.55 ˚C/minute (0.5-1.0 ˚F/minute) to 135˚C (275˚F).
- Dwell at 135±2.8˚C (275±5˚F) based on lagging thermocouple for 30+10 /-0 minutes.
- Continue to heat at 1.7-2.8 ˚C/minute (3-5 ˚F/minute) to 191˚C (375˚F).
- Dwell at 191±2.8˚C (375±5˚F) based on lagging thermocouple for 240 +30 /-0 minutes.
- Cool at a maximum of 2.3 ˚C/minute (5 ˚F/minute) to 49˚C (120˚F) before releasing pressure.

HexTool® M61 Cure Cycle

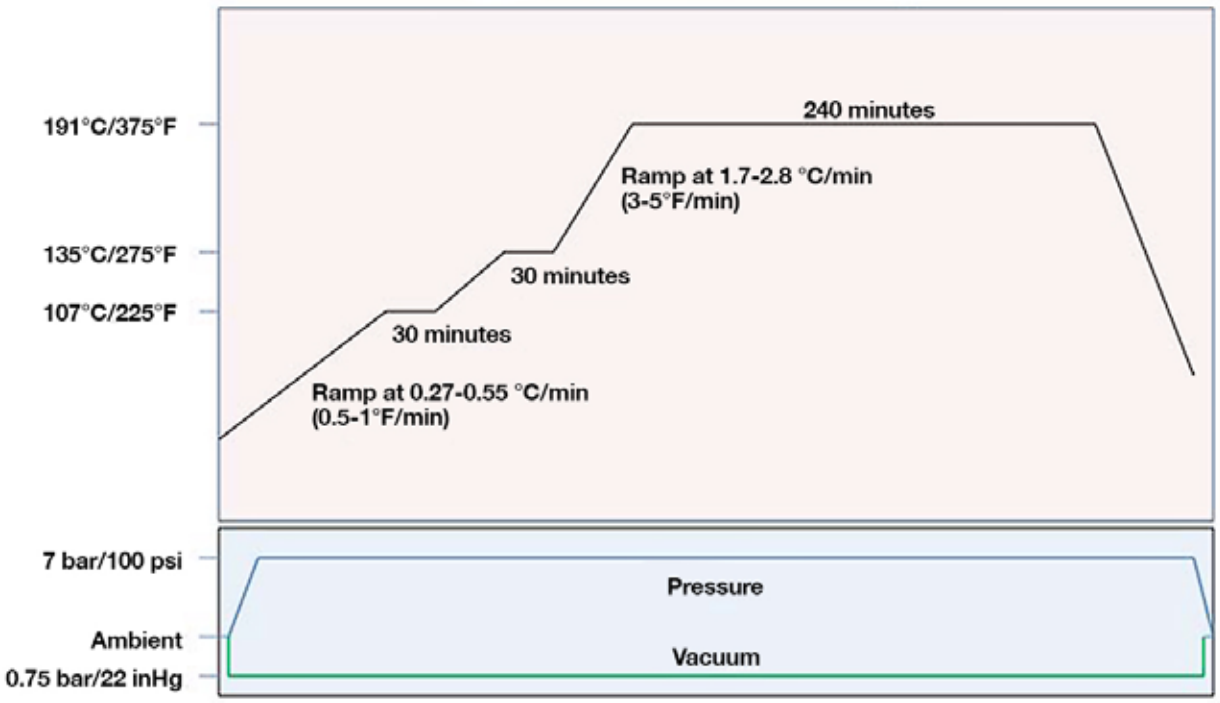

Figure 29

Abort Criteria

- At start of cure, vacuum shall be a minimum of 0.75 bar (22 inHg) after leak test confirms no more than 0.067 bar (2 inHg) loss in 5 minutes.
- It is considered a bag breach if the vacuum falls below 0.51 bar (15 inHg) anytime during the cure.
- If this occurs before the leading thermocouple has dwelled at 135˚C (275˚F) for no more than 10 minutes the cure can be aborted by cooling at the maximum rate of cooling. Vent pressure once the tool is below 49˚C (120˚F).
- After cooling the bag leak can be repaired and the cure cycle restarted.

Post Cure Cycle
Illustrated in Figure 30.

- Begin heating the tool at a maximum of 2.8 ˚C/minute (5 ˚F/minute) to 149˚C (300˚F).
- When leading thermocouple reaches 149˚C±2.8˚C (300˚F ±5˚F) reduce ramp rate to a maximum of 0.27 ˚C/minute (0.5 ˚F/minute) and continue heating to 218˚C (400˚F).
- Cool at a maximum rate of 2.8 ˚C/minute (5 ˚F/minute) to 65˚C (150˚F) before removing from the oven.
- Allowed to open door at 116˚C (240˚F) based on a lagging TC to assist with cool down.

HexTool® M61 Post Cure Cycle

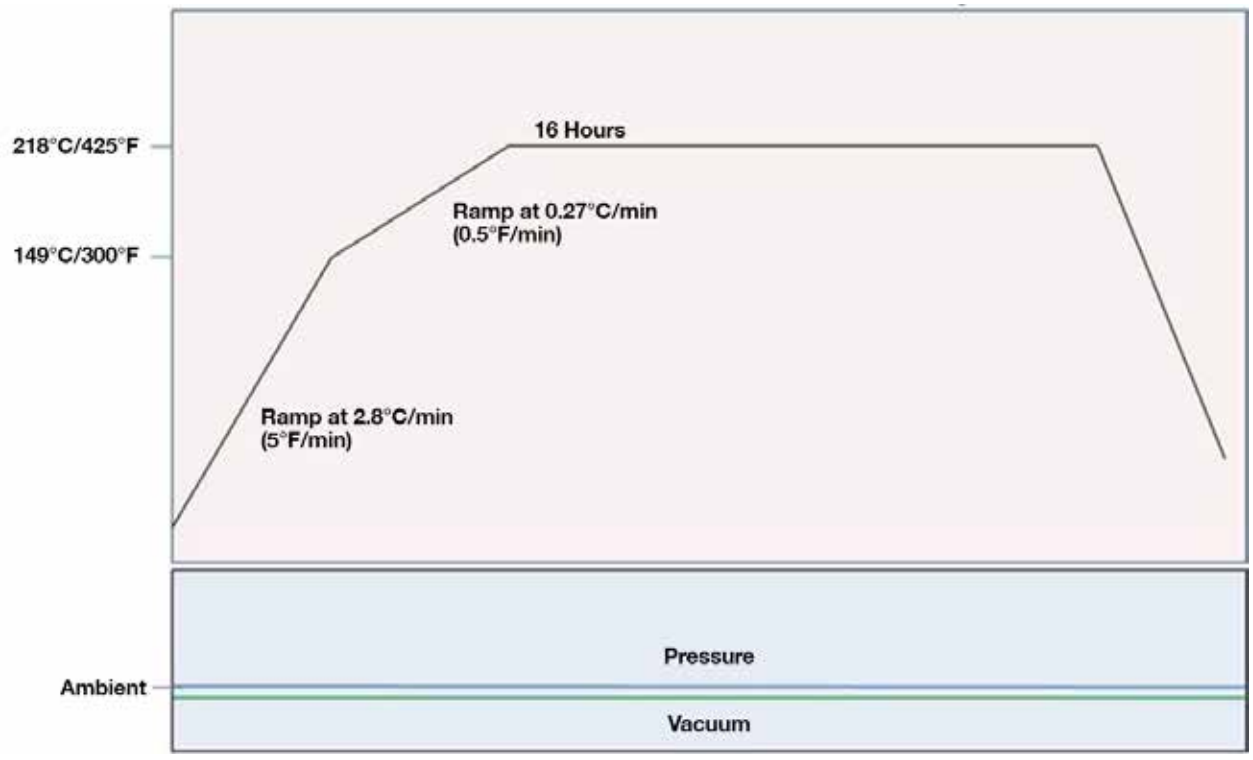

Figure 30

M81 HexTool® (Epoxy Version)

Material Information

Product Format & Definition

- 2000 g/m² (0.41lbs/ft²) carbon fiber reinforced mat
- Composed of 8 x 50 mm (0.315 in x 1.97 in) prepreg bundles presented in a quasi-isotropic orientation
- High strength carbon fiber with a nominal fiber volume of 55%
- Epoxy matrix at 38% resin content (by weight)
- Storage life:
  - 12 months at -18°C (0°F) or below
  - 14 days at room temperature
- Autoclave cured at 125°C (260°F) under 7 bar (100 psi) pressure
- Out-of-autoclave post-cure at 205°C (400°F)
- Average cured-ply thickness:
  - 2000 g/m² : 1.25mm (0.05 in)
- Machined cured-ply thickness:
  - 2000 g/m² : 0.97 mm (0.038 in)

Mechanical & Physical Properties

Table 4: M81 HexTool® Physical Properties

Property	Units	Condition	Method	Value
Rockwell B Hardness			ASTM D785-08	81
Glass Transition Temperature	˚C (˚F)	Dry	DMA	220 (430)
Coefficient of Thermal Expansion	Expansion x 10^{-6}/˚C	X-Y Bias Plane	ASTM E289-90	5 (0.72)

Table 5: M81 HexTool® Mechanical Properties

Property	Units	Condition	Temperature C˚(F˚)	Method	Value
Tensile Strength	MPa (ksi)	Dry	RT (73)	ASTM D3039	175 (25.37)
			120 (250)		170 (24.65)
Tensile Modulus	GPa (msi)	Dry	RT (73)	ASTM D3039	43 (6.23)
			120 (250)		40 (5.80)
Open Hole Compression Strength	MPa (ksi)	Dry	RT (73)	ASTM D6484	250 (36.25)
			120 (250)		250 (36.25)
Compression Modulus	GPa (msi)	Dry	RT (73)	ASTM D695	32 (4.64)
			120 (250)		30 (4.35)
Short Beam Shear Strength	MPa (ksi)	Dry	RT (73)	EN 2563	45 (6.52)
			120 (250)		35 (5.07)

Lay-up Instructions

See M61 Lay-up Instructions above.

Thermocouple Placement
See M61 Thermocouple Placement Instructions above.

Hot Vacuum Debulk
See M61 Hot Vacuum Debulk Instructions above.

Hot Pressure Debulk
See M61 Hot Pressure Debulk Instructions above.

Bagging for Final Cure

- The following bagging materials are required:
  - Sealant tape to withstand autoclave temperatures of 177˚C (350˚F)
  - Porous PTFE glass peel ply fabric
  - Non-perforate FEP release film
  - Breather material
  - Epoxy resistant vacuum bag
- A typical bagging assembly for M81 HexTool® is outlined in Figure 31.
- If you are using materials not shown in table below please contact your local Technical Support representative.

Table 6: Recommended bagging materials for use with M61 HexTool® and requirements for suitable alternatives.

Material	Recommended Material	Generic Requirements
Nylon Vacuum Bag	WL7400 WL 5400 HS 800 HS 9171	Epoxy resistant
		177˚C (350˚F)+ service
		Suitable for long duration temperature and pressure
Solid Release Film	Wrightlon 5200 HT-7000	0.05 mm (0.002 in) thick
		204˚C (400˚F) service
Breather	Ultraweave 1332 RC-3000-20 Super 18	204˚C (400˚F)/ 7 bar (100 psi) service
		Suitable for long duration temperature and pressure
Peel Ply	Release ply A or F	80-110 g/2 (2.35-2.95 oz/yd2)
		Nylon or Polyester suitable for temperature up to 191˚C (375˚F)
Glass Breather String	ECG 37 1/4 dry glass tow	Glass tow of equivalent size

- For a successful cure, and to improve the breathing, strips of PTFE glass fabric should be added to connect the M81 HexTool® and peel ply inside the solid FEP release film inner bag to the breather and vacuum supply outside of the inner bag. This concept is similar to the addition of glass breather strings outlined in the M61 HexTool® bagging guide above.

HexTool® M81 Final Cure Bagging Scheme

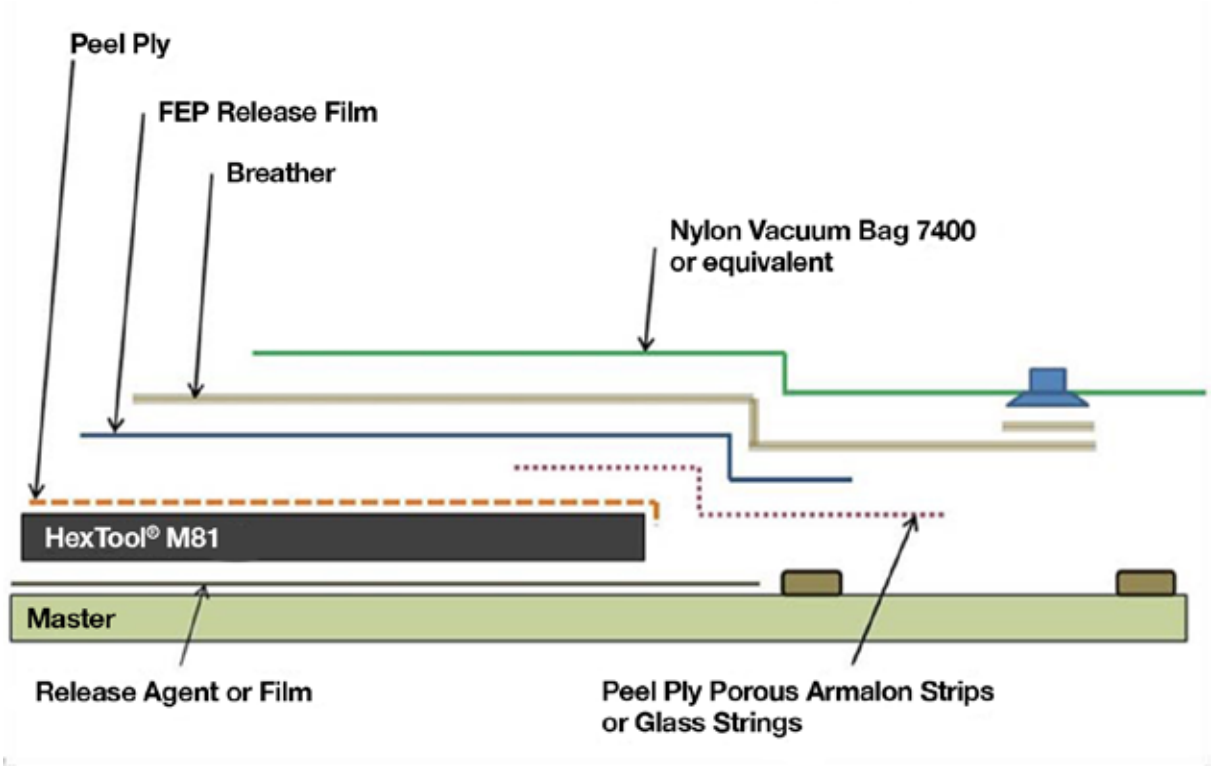

Figure 31

Curing

M81 HexTool® can be cured in two ways:

1. Low temperature cure cycle combined with post cure
2. Standard/high temperature cure cycle (no post cure)

Low Temperature Autoclave Cycle

- Apply full vacuum 0.7 bar (22 inHg).
- Ramp to 127˚C (260˚F) using a ramp between 0.55-1.1 ˚C/minute (1-2 ˚F/minute).
- Apply 7 bar (100psi) gauge pressure when temperature reaches 50˚C (120˚F).
- Hold at 127˚C (260˚F) for 360 minutes.
- Cool down using a 0.55 ˚C/minute (1 ˚F/minute) ramp to 60˚C (140˚F).
- At 60˚C (140˚F) release pressure and vacuum.

HexTool® M81 Low Temperature Cure Cycle

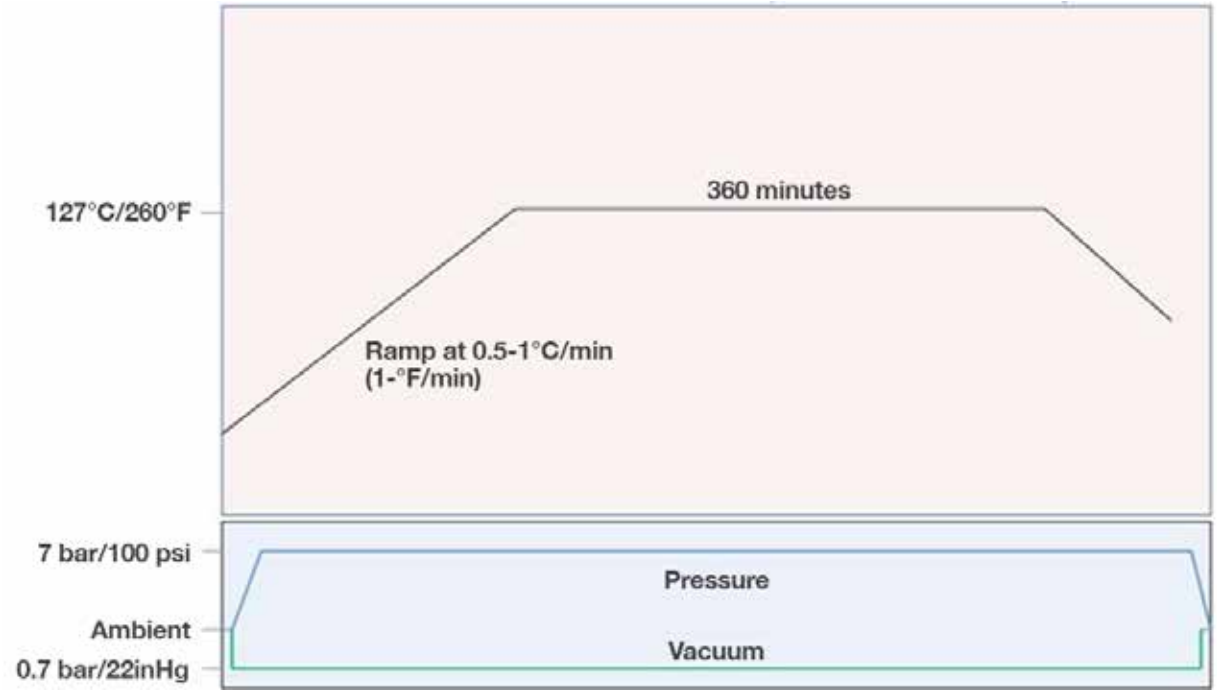

Figure 32

Post Cure Cycle

- Heat up to 138˚C (280˚F) using a ramp between 0.55-2.2 ˚C/minute (1-4 ˚F/minute).
- Heat up to 204˚C (400°F) using a ramp between 0.27-1.1 ˚C/minute (0.5-2 ˚F/minute).
- Hold at 204˚C (400˚F) for 2 hours.
- Cool down using a 0.55 ˚C/minute (1 ˚F/minute) ramp to 150˚C (300˚F).
- Cool down using a 1.1 ˚C/minute (2 ˚F/minute) ramp to 60˚C (140˚F).

HexTool® M81 Post Cure Cycle

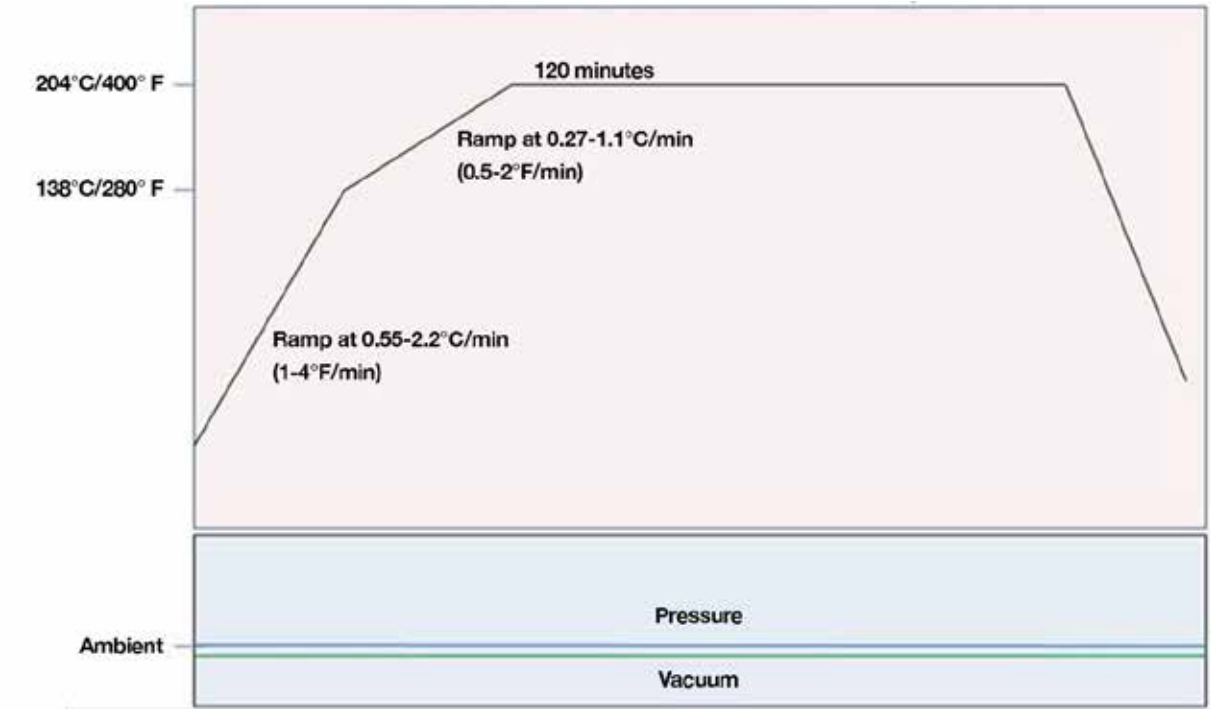

Figure 33

Standard/High Temperature Cure Cycle

- Apply full vacuum 0.7 bar/22 inHg.
- Ramp to 121˚C (250˚F) using a ramp between 1.1-2.2 ˚C/minute (2-4 ˚F/minute).
- Apply 7 bar (100psi) gauge pressure when temperature reaches 50°C (120°F).
- Hold at 121˚C (250˚F) for 60 minutes.
- Ramp to 177˚C (350˚F) using a ramp between 1.1-2.2 ˚C/minute (2-4 ˚F/minute).
- Hold at 177˚C (350°F) for 240 minutes.
- Cool down using a 0.55 ˚C/minute (1 ˚F/minute) ramp to 60˚C (140˚F).
- At 60°C (140˚F) release pressure and vacuum.

HexTool® M81 Standard/High Temperature Cure Cycle

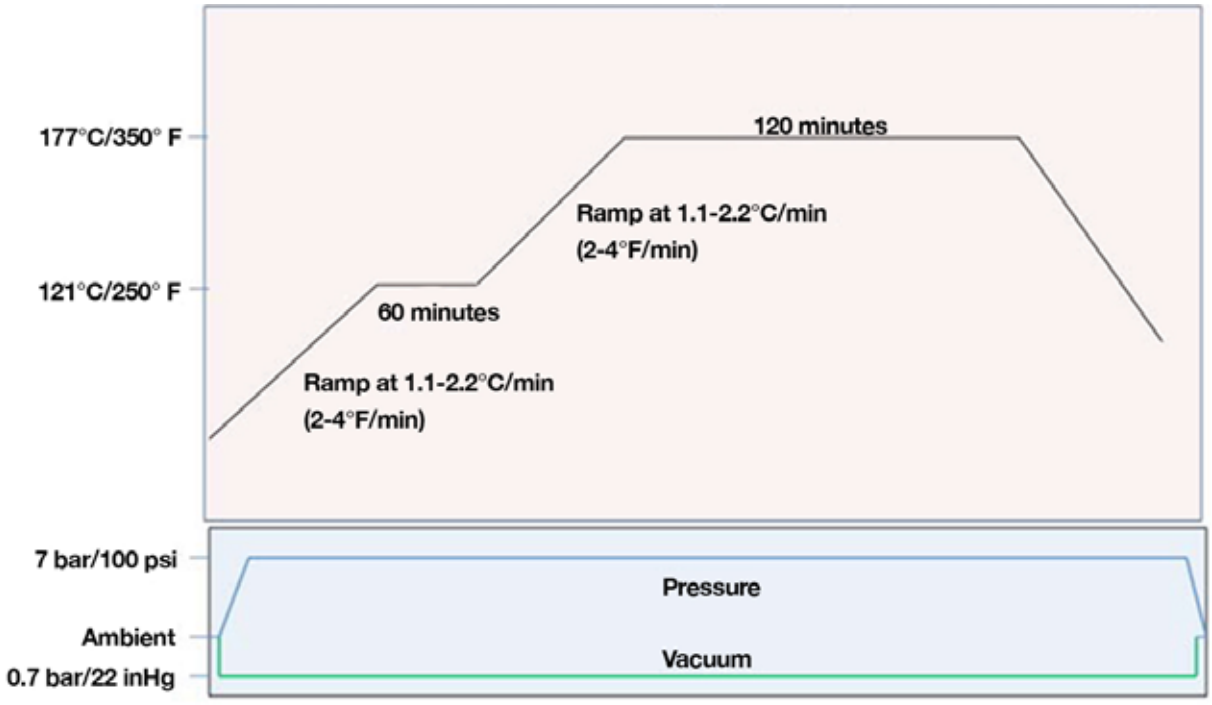

Figure 34

Abort Criteria

- At start of cure, vacuum shall be a minimum of 0.7 bar (22 inHg) after leak test confirms no more than 0.067 bar (2 inHg) loss in 5 minutes.
- It is considered a bag breach if the vacuum falls below 0.51 bar (15 inHg) anytime during the cure.
- If this occurs before the leading thermocouple has dwelled at 121˚C (250˚F) for no more than 10 minutes the cure can be aborted by cooling at the maximum rate of cooling. Vent pressure once the tool is below 49˚C (120˚F).
- After cooling the bag leak can be repaired and the cure cycle restarted.

The following sections apply to both M61 and M81 HexTool® materials

Machining and Finishing of HexTool® Tools

Rough Machining

- Rough machining of the tools surface contours are accomplished using a 1.27-2.54 cm (0.50-1.0 in) diameter 40/60 diamond abrasive cutter and the following machine parameters:
  - Rough machining cutter velocity should be maintained in the range of 396-457 m/min (1,300-1,500 ft/min).
- Use table below to achieve this cutter velocity with varied tool bit diameter.
  - Feed rate of 2.03-3.8 m/min (80 to 150 in/min)
  - Cut depth of 1.27-5.08 mm/pass (0.05 to 0.20 in/pass)

Tool Bit Diameter	RPM Range
1.27 cm/0.50 in	10,000 – 12,000
1.92 cm/0.75 in	6,500 – 7,500
2.54 cm/1.00 in	5,000 – 6,000

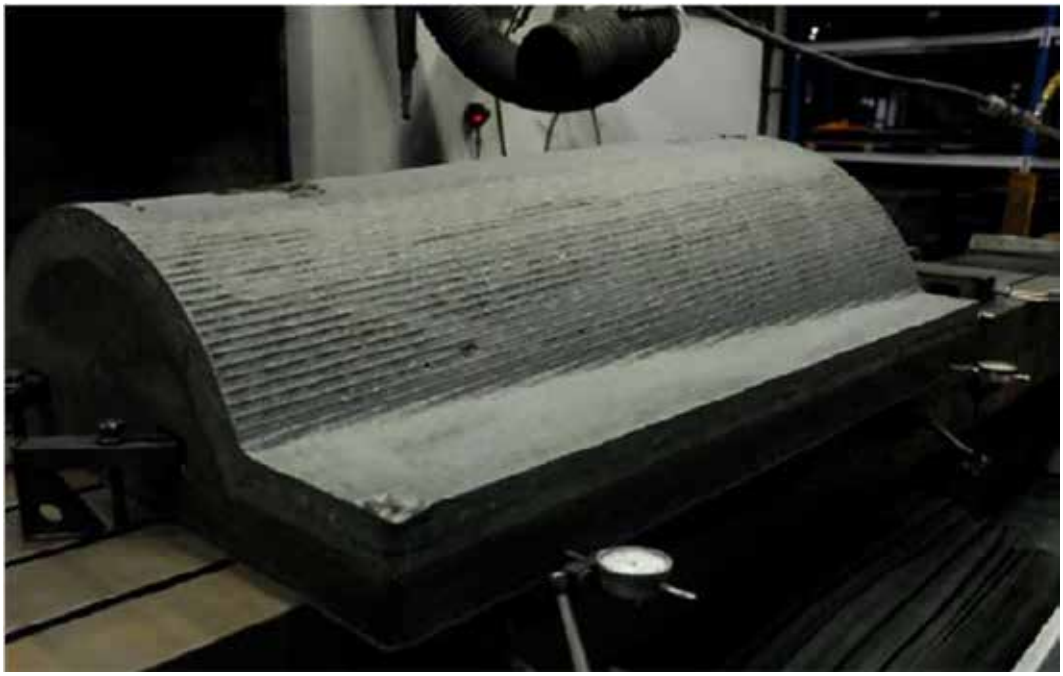

Figure 35: Rough machined surface of HexTool® tool.

- Rough machining continues until surface offset is +2.54 mm (0.10 inches) from finish profile, this allows 2.54 mm (0.10 inches) for finish machining.

Finish Machining

- Finish machining is accomplished using 1.27-2.54 cm (0.5-1 in) diameter 80/120 grit diamond abrasive cutter and the following machine parameters:
  - Finish machining cutter velocity should be maintained in the range of 457-548 m/min (1,500-1,800 ft/ min).
- Use table below to achieve this cutter velocity with varied tool bit diameter.
  - Feed rate of 2.03-2.54 m/min (80 to 100 in/min)
  - Cut depth of 0.381-0.635 mm/pass (0.015-0.025 in/pass)

Tool Bit Diameter	RPM Range
1.27 cm/0.50 in	12,000 – 14,000
1.91 cm/0.75 in	8,000 – 9,500
2.54 cm/1.00 in	6,000 – 7,000

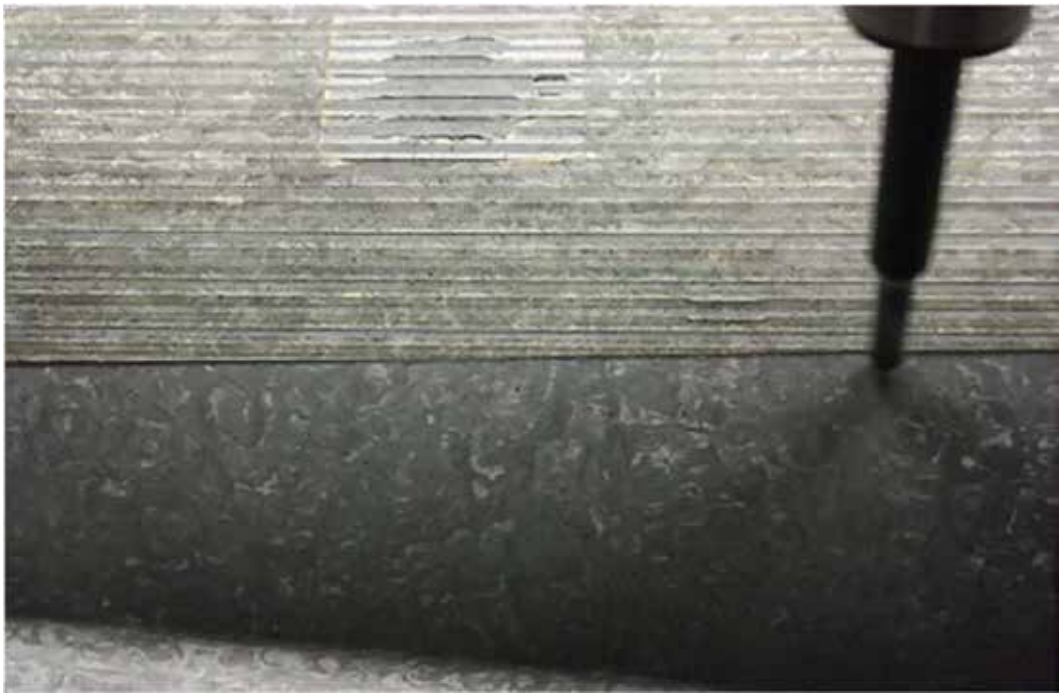

Figure 36: Finish machining of HexTool® tool.

Benching of HexTool® Tools

Materials

- 3M Diamond Micro Finishing Sandpaper
  - 20, 30, 45, 74
- Standard Wet/Dry Sandpaper with grit equivalents may also be used.
  - M 74 – 240 Grit
  - M 40 – 320 Grit
  - M 20 – 1000 Grit
  - M 10 – 1200 Grit
- Hutchins Waterbug Air Sander (HUT7004W) – or equivalent
- Clean Wipes
- Acetone
- Squeegee

Surface Sanding

- After finish machining the surface should be clean wiped with acetone to remove any remaining debris.
- The surface can then be wet sanded to remove any remaining scallop marks or imperfections left over from final machining using either a self-flushing vibrating sander such as the Hutchins Waterbug or manual wet/dry sanding on flat surfaces. Contoured surfaces can be sanded manually with running water.
- Begin wet sanding with 74 micron paper. Water lightly washing over the surface will allow you to visualize flow across the surface.
- Once the desired surface roughness is achieved, the tool is ready for sealer.

Sealing and Release of HexTool®

Rough Machining

This section will provide guidance on the application and maintenance of sealers and release agents on carbon tools manufactured with M61 and M81 HexTool®.

Sealing

Materials

- Sealers
  - Chemlease MPP117 (MPP712 in EU)
  - Chemlease MPP 2180
  - Zyvax MPP – 1006W
  - Mono-Coat E308
  - Frekote B-15
  - Solvent (acetone, MEK, MIBK or IPA)
  - Clean soft applicators
  - Scotch Brite pad or 1000 grit sandpaper
  - Steel wool or orbital polisher

Surface Preparation

First-use tools should be cleaned and dried prior to application of sealers and release agents. Drying is not required on tools that have been previously sealed.

- Clean surface using acetone, MEK, MIBK or isopropyl alcohol and a clean cloth.
- Wipe surface with soft cloth or cheese cloth, changing wipe until its free of residue.
- Dry tool in air circulating oven at 121˚C (250˚F) for 60 minutes to remove moisture.
- Apply sealer within six hours of drying cycle.

Sealer Application

- Apply a minimum of 3 coats of sealer allowing air drying between coats (follow manufacturers recommendations).
- Sealer shall be applied using soft cloth or cheese cloth.
- Apply liberal amounts removing excess with dry cloth, surface should appear uniformly wet but without runs or pooling.
- After final coat, oven cure as per the manufacturers recommendations.
- Light abrading between coats with fine Scotch Brite pad or 1000 grit sandpaper may be used to remove localized build-up or runs.
- Wipe abraded surface clean with dry clean cloth before next application.
- After final coat, sealer may be buffed using wool pad and orbital polisher.

Figure 37

Release Agent Application

Once sealed and cured, tool surface is resistant to moisture absorption, keep covered until release agent is applied to prevent dirt and dust from contaminating surface.

- If necessary, sealed surface may be cleaned with a ketone or alcohol wipe to remove dust or dirt.
- Allow surface to air dry before release application.
- Apply a minimum of three coats of release agent.
- Follow manufacturers recommendations for drying and curing release agent. In general the final coat of release agent should be cured at 25˚F above tool use temperature.

Release Agents

- Frekote 700 NC
- Frekote 770
- Zyvax Composite Shield
- Zyvax Departure

Preventative Maintenance – Re-sealing HexTool® Surface

After 25-50 cure cycles it will be necessary to re-seal the tool surface to maintain easy release and prevent excessive release agent build-up.

- The frequency of re-sealing is dependent on the release agent, cure temperature and the species of thermoset resin used on the tool.
- Indicators such as hard release, resin transfer or release build-up are indicative of re-sealing requirement.

Re-sealing Steps

- Strip the surface of resin or release agent residue.
  - Using fine Scotch Brite pad 7448 or 1000 grit sanding paper remove all resin and release residue from the surface.
  - Power equipment may be used with proper care to prevent damage or change of surface contours.
  - Frequent change of abrasive media will be required at first due to residue build-up on abrasive media.
  - Continue surface preparation until resin/release agent residue is completely removed from the surface.
  - Clean surface with cloth wipes and ketone or alcohol wash.
- Keep changing cloth wipe until it is free of residue.
- Air dry surface before application of new sealer.
- Follow directions above for sealer application.

Small Area Repair

- Small area repairs are defined as surface scratches or gouges that are less than 0.32 cm (0.125 in) deep and less than 58 cm^2 (9 in^2) surface area but larger than 0.1 cm^2 (0.016 in^2) surface area.
- Smaller defects will be addressed below as chip repair.
- These repairs may be accomplished using standard vacuum bag techniques and typically will not require autoclave or post cure. These repairs may also be hand finished so that re-machining is not required.
- For defects deeper than 0.32 cm (0.123 in) please contact a Hexcel technical support representative.

Surface Preparation

The importance of good surface preparation cannot be overstated. The quality and durability of the repair will be dependent on the quality of surface preparation.

- Using a die grinder or small rotary grinder and small abrasive drum remove approximately 0.05 inch material in the damaged area. More material removal (up to 2 mm (0.08 in)) may be required based on the age and condition of tool.
- Blend the damage area into surrounding surface with a 30 degree chamfer.
- Thoroughly scrub the repair and surrounding area with ketone or alcohol and a Scotch Brite pad.
- Air dry.

Repair Material Preparation

- Using shears or vibratory saw cut 0.635 cm (0.25 in) strips of HexTool® from a defrosted sheet of material.
- Heat material with hot air gun or oven at 71˚C (160˚F) until it can be pulled apart into smaller pieces.
- Collect small pieces on a clean surface for use in next steps.

Repair Material Application

- Pack the area for repair with the small fiber mat that was prepared in the previous step, use small chips as the size and depth allows.
- Use heat gun to gently warm the area to facilitate packing of the defect.
- Continue to add material with heat and moderate hand pressure until the repair patch is higher than the surrounding area.

Bagging Scheme for the Repair Patch Cure

- Assemble a vacuum bag surrounding the repair patch as follows (with recommended product examples found in prior tables):
  - One ply perforated FEP film
  - Peel Ply
  - Glass string connecting inner bag to Ultraweave
  - One ply solid FEP film
  - One ply Ultraweave
  - Vacuum bag film

HexTool® Repair Patch Bagging Scheme

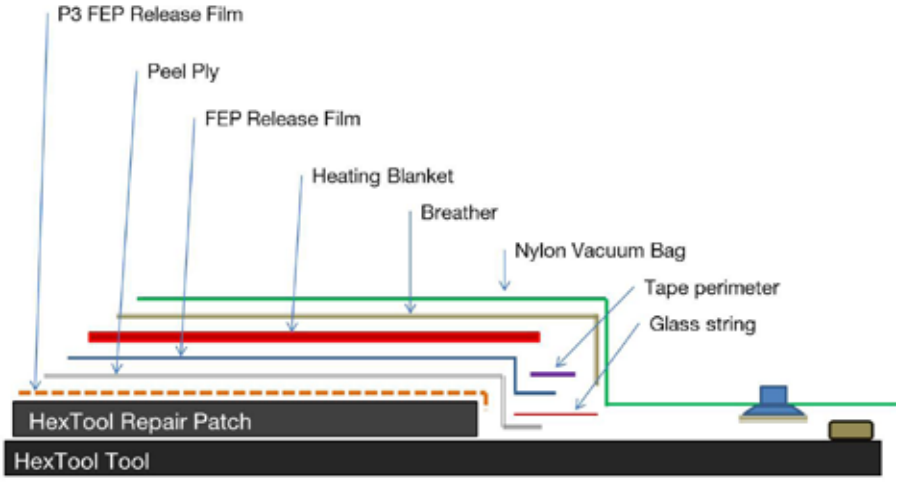

Figure 38

Cure the Repair Patch

- Cure repair as illustrated below, use surface thermocouple to monitor cure progress.

HexTool® M61 Repair Patch Cure Cycle

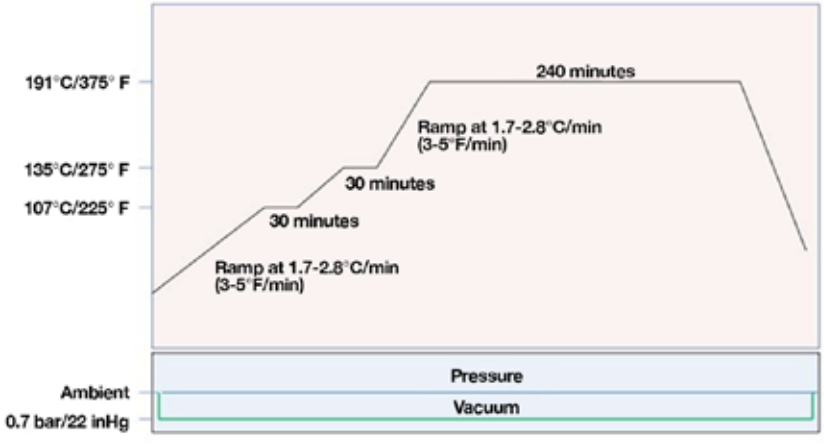

Figure 39

Surface Finishing

- Hand-block the repaired area using abrasive diamond grit paper, start with 320 grit and finish with 600 grit.
- Seal the area and apply release agent to the repair and surrounding areas as per instructions above.

Chip Repair

Chip repair is applicable to small nicks or scratches that are less than 0.254 mm (0.1 in) deep and less than 0.1 cm^2 (0.016 in^2) in surface area. These repairs do not require an oven or autoclave and can be performed in the field.

Recommended Product

- Ad Tech ESG 215

Surface Preparation and Application

- Clean with solvent and fine Scotch Brite pad.
- Sweep in AdTech surface fill using polypropylene sweep.
- Deep blemishes should be built-up using multiple applications allowing tack free drying in between layers.
- Follow manufacturers recommendations for applications and curing.

Surface Finishing

- Hand-block the repaired area using abrasive diamond grit paper, start with 400 grit and finish with 600 grit.
- Seal and release the repair area and surrounding areas as described in above.

Care and Maintenance of Tools Made With HexTool® M61 and M81

While a machined HexTool® surface has the same surface hardness as Invar and properly maintained will offer equal durability, certain differences do exist relative to the use and maintenance of carbon tools. The following will address general rules and guidelines for the use and maintenance of HexTool® carbon tools.

Always insure that the entire working surface is sealed and released as specified in page 39 of the HexTool® User Guide. The number one rule in working with carbon tools is to make sure no metal tools are used on the tool; this includes razor knives, chisels and scrappers.

Several tips may help facilitate the de-bagging process. If possible de-bag the tool while it is still warm; vacuum tape adhesion is less aggressive while it is warm easing release and resulting in less residue being left on the tool surface. Vacuum tape residue may be removed with plastic scrappers or cloth wipes containing cleaning solvents such as ketones, alcohols or D-limonene.

Inspect the surface for resin flash if any is found remove with cloth and solvent or if necessary solvent and a fine Scotch Brite abrasive pad. Re apply release agent as per manufacturers recommendations, bake tool if necessary. Keep the tool covered until next use to minimize contamination.

Periodic Tool Face Maintenance

Many factors such as type of resin system, release agent used and cure temperature will influence the number of cure cycles obtained before periodic maintenance is required. In general you can expect 25-50 cure cycles before the following periodic maintenance is required.

Stripping the tool surface
When release agent and residual matrix resin builds up to an extent that negatively impacts the part release or the surface quality of the part, the tool face must be stripped of all release and resin flash and re-sealed. HexTool® may be safely stripped and resealed as follows:

- Using Scotch-Brite 7447 or finer grade cleaning pad and a ketone, alcohol or D-limonene solvent, remove all residual sealer and cured resin flash
- The resulting surface will be stripped down to parent HexTool® exhibiting a matte black surface
- Remove remaining chemicals using clean cheesecloth wipes and solvent such as IPA
- Allow to air dry for 2 hours or place tool in air circulating oven at 200°F for 30 minutes

Inspection and Re-Sealing the Tool Surface
Thoroughly inspect the surface for minor defects, repair as necessary using procedure described on page 41 of the HexTool® User Guide.

Inspection and Re-Sealing the Tool Surface
- Chemlease MPP117
- Chemlease MPP2180
- Zyvax MPP 1006W

Regardless of which sealer is selected, always follow the manufactures directions. In general, liquid sealers are applied using clean cheesecloth or other natural fiber cloth. Liberally apply sealer to the cloth; working in small 4-6 square foot areas, continuously wipe the sealer onto the working area using a circular motion until the solvent flashes off and the area appears dry. Do not wipe on wet and allow to dry, sealer will have a tendency to pool leaving streaks and build up which will adversely impact the quality of your part. Continue application in small quadrants always overlapping previously applied area. Hexcel recommends 2 -3 coats of sealer be re-applied to insure maximum tool and release agent performance.

Release Application

Re-apply release agent following manufacturers recommendations; Hexcel recommends at least three coats of release agent be re applied after tool has been stripped and re-sealed.

Hexcel is a leading worldwide supplier of composite materials to aerospace and industrial markets. Our comprehensive range includes:

- HexTow® carbon fibers
- HexForce® reinforcements
- HiMax™ non-crimp fabrics
- HexPly® prepregs
- HexMC® molding compounds
- HexFlow® RTM resins
- Redux® adhesives
- HexTool® tooling materials
- HexWeb® honeycombs
- Acousti-Cap® sound attenuating honeycomb
- Engineered core
- Engineered products

HTU 367 AG16b