CHAPTER 5: PROPOSED PROCESS FOR MANUFACTURING COMPONENTS WITH A CLASS A FINISH

This Chapter provides the proposed process for the manufacturing of a Class A finished component based on the results from the literature survey, Chapter 2, the mould survey Chapter 3, and the experimental investigations of Chapter 4. It should be noted that any changes to the mould might also affect the plug. Thus, although the manufacturing processes occur in the sequence of plug, mould, part, the design process of all three takes place simultaneously.

It should further be noted that this process only provides solutions for the surface finish and factors that affect it directly. It does not provide solutions for other important mould manufacturing factors like:

- Allocation of the split surface
- Number of mould sections needed to form part of the manufacturing process
- Alignment methods of the moulds
- Bonding & trimming methods of the parts
- Demoulding assistance
- Structural back support of moulds
- Clamping methods of moulds
- Heating and vacuuming provisions to the moulds; or
- Any aspect inherent to parts, plugs and moulds which is not directly related to the surface finish.

These are factors which should also form part of the designing and manufacturing processes of the part, plug and mould, and further research on those factors is advised. The process described in this section, however, will assume that those factors have indeed been finalised. The process will thus only adhere to the direct influences of the manufacturing of the surfaces of the plug, mould and part.

5.1 MANUFACTURING OF A CLASS A FINISHED PLUG

The manufacturing of a Class A finished plug is divided into three sections, namely the:

- Modelling of the plug from the part with CAD
- Plug CNC programming and cutting, and
- Plug finishing.

These individual sections, as illustrated below, will now be described in full details.

5.1.1 PLUG CAD MODELLING

The plug modelling process starts with the outlines of the part model. Any outer surfaces or features that the part has will be needed on the plug. The following provisions should be made to the plug:

- A slot can be made directly next to the profile, as illustrated in Figure 5-1. The width of the slot is determined by the diameter of the smallest tool which can be used in the CNC process. If the tool diameter is, say, 10mm, then it is advised to make the slot slightly larger, say 10.2 mm or 10.5 mm. The depth of the slot does not matter that much, but in the tests a 10mm depth was sufficient.
- The split surface can be repositioned down to make provision for an acrylic split surface. This repositioning should be sum of the acrylic sheet thickness plus the fastening material of the sheet to the surface, as illustrated in Figure 5-1.

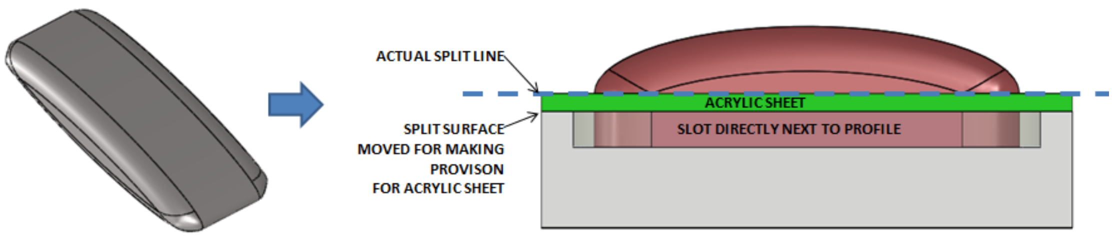

Figure 5-1: Surface finish provisions of the plug.

A clear method for creating the plug CAD model has not yet been devised, but there are a few guidelines which can be followed with a view to ensure that the CAD model is ready for CNC programming. These are:

- Ensure that there are no open surfaces. Always try to merge surfaced sections of the model into one united solid body. If a merged solid cannot be created, it means that there is an open surface somewhere on the model. Open surfaces may cause possible errors when programmed with the CAM software.

- Zoom into the model at all possible intersections of surfaces and ensure that there are no protruding or intruding surfaces smaller than the smallest tool available to cut at those sections. Sometimes an intersection appears as a line, but upon closer inspection small surfaces appear. These surfaces can cause errors with the CAM programming, as the software tries to cut a small surface, which is smaller than the smallest tool the machine can use.
- Draft angles are necessary, not only for demoulding purposes of the part, but also to ensure that the cutting tools do not chafe against the side wall to result in scuff marks on the side of the part, as illustrated in Figure 5-2.

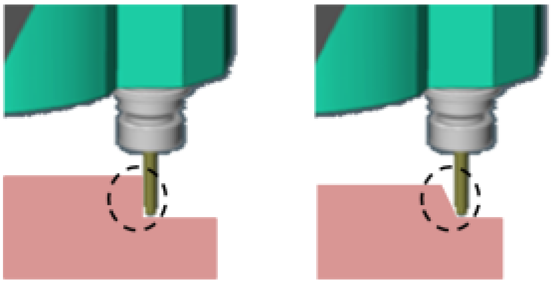

Figure 5-2: Draft angles on parts preventing scuff marks on side walls of plug

- Ensure that cut height and depth are sufficient for the CNC cutting tools available. This means that if, for example, an incision of 2 mm deep should be cut 80mm below the highest point and the cutting tool and the tool available is 85mm, it might appear possible to cut. If, however, the incision is directly next to a 90 degree protruding section, the head of the CNC machine might interfere. The solution is to redesign the protruded area with a draft or fillet, as illustrated in Figure 5-3.

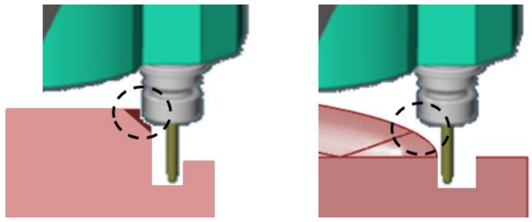

Figure 5-3: Provision for tool shanks versus depths of cuts.

- Ensure that the tolerances of the added features like alignment pins co-align with the tolerances of the CNC machine. For example, an alignment feature is exactly 10mm and the provisional hole on the plug is exactly 10 mm, the feature will not fit. Thus it would be necessary to either slightly decrease the alignment pin diameter or slightly increase the hole in the plug. It was found for example that a 10 mm diameter pin with a g6 tolerance fits correctly in a CNC manufactured hole with a tool path offset of 9.95 to 10 mm.

If the above guidelines are followed, the plug should be ready for the CNC programming.

5.1.2 PREPARATION OF THE PLUG MATERIALS

Preparation of the plug materials can commence as soon as it is clear what the outside diameters of the plug should be. As this study makes use of nuceron651 tooling board the preparation is as follow:

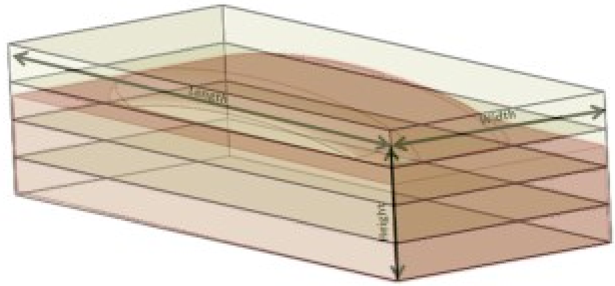

Figure 5-4: Plug Material preparation

1. Calculated the length, width and height of the plug.
2. Determine from the available sizes of tooling board a layout to fully cover the calculated area, as illustrated in Figure 5-4. It should be noted that one should try to have as few as possible bonding lines on the critical profile.
3. Prepare Axson F16 (or F19) Fast cast Polyurethane for the bonding of the materials. (A mixture of approximately 150 gram should cover about 1 square metre (Lion-Cachet, 2013).)
4. Ensure that the tooling board is properly cleaned and free of dust.
5. Spread the Axson F16 (or F19) fast cast polyurethane onto the tooling boards in a quick and even manner and position the top tooling board.
6. Allow the blocks to cure.
7. Skim the top of the block on the CNC machine to the exact size with which the plug cutting will start with.

After the tooling board material has been prepared, the CNC programming can commence.

5.1.3 PLUG CNC PROGRAMMING & CUTTING

If the plug model is clear of any of the problems describe in the previous section, the CNC programming should proceed without much difficulty. The cutting time and the surface finish are the two critical influences. No two CNC programs are the same, but there are guidelines to follow when creating the CNC tool paths.

Tool paths can be divided into roughing cuts and finishing cuts. One should always commence with a large roughing tool, then follow with smaller roughing tools and end with the finishing tools. The larger the tool diameter, the higher the input values. For example, a 40 mm diameter end mill tool will use a step-over of 20, and a speed of 17100 rpm, feed of

8000 mm/min. Where a smaller diameter end mill such as a 12mm diameter is used, one must make use of a 6-8 step-over, a speed of 17100 rpm and a feed of 8000 mm/min. Table 5-1 provides guidelines that one can follow for the settings of these types of cutting methods:

Table 5-1: CNC tool path settings

	Roughing	Finishing	
Types of cuts	Roughing spiral In / out, Milling	Constant step-over, steep/shallows, rest area	Face mill zig zag, planar faces
Tools used	End mill, slot mill	Ball nose	End mill, slot mill
Cut mode	Rough	Finishing	Finishing
Step-over	6 – 20	0.5	4 - 20
Speed [rpm]	16000 – 17500	17000	17000
Feed [mm/min]	7000-8000	800	800-2000
Resolution	0.1	0.1	0.1
Facets	120	120	120

Depending on the final cutting times, one might decide to split the cutting to be cut on separate days. When this is necessary, the splitting should be done between operations. It is always good to try and finish an entire operation before splitting it. The reason for splitting between operations and on edges of tool paths is that when the machine is switched off, it makes a small indent in the material where the tool comes to rest. It is thus better to ensure that these indents are on edges rather than on critical profiles.

For instance, one might group the roughing and slot mill operations then split the program at the beginning of the finishing operations. If more than one finishing operation is required, one might split it further between those operations as well. One should, however, always ensure that a split occurs where a tool path ends on edge or area of non-significance. This is determined by the plunging and step-over methods. By setting the step-over and plunging methods a tool path can either commence from the inside to the outside or vice versa. Depending on where the tool path ends, one can determine where the stop indents will be.

After the plug has been cut, the acrylic split surface could also be cut using the laser cutter (if an acrylic split surface is required). The laser cutter intensity and speed will be determined by the thickness of the acrylic sheet. It was found that the laser cutter accuracy decrease away from the zero position in

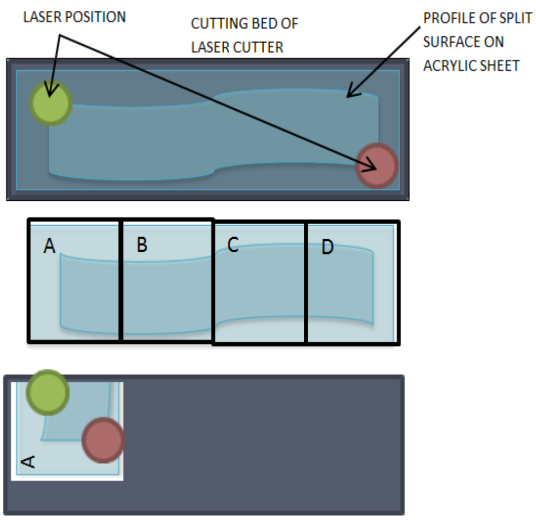

Figure 5-5: Improved cutting method for laser cutting of plug split surfaces.

the upper left corner as shown in Figure 5-5. The highest accuracy was measured in the upper left hand corner and the worst accuracy in the lower right hand corner. It is therefore advisable to try and use the upper left hand corner of the cutting area and stay away from the lower right hand side. To achieve this, the split surface can be divided into sections, as shown in Figure 5-5. Each section can then be cut in the upper left corner, to ensure better accuracy.

5.1.4 PLUG FINISHING

The plug finishing process is a long process, but if not done properly it could mean the difference between a Class A demoulded mould surface or a mould surface which requires intensive rework. Because the materials used for the plug finishing are softer than those used on the surface of the mould, it is advised that one should rather put more effort into the plug finishing as it would be easier to achieve a perfect surface than to trying to fix the mould surface afterwards. The following steps should be followed:

1. Ensure that the mould is wiped clean of any dust.
2. Wrap the plug, with painting protection wrapping material, so that only the profile and slot next to the profile is visible (it was cut to be used with an acrylic split surface)
3. Prepare a 1K primer paint, enough to cover the surface of the plug.
4. Spray the plug profile with a mist coat layer or 1K primer paint. (Note: Do not sand the plug before spraying the first layer. This layer serves as a detection coat and enables the sander to maintain the designed profile.)
5. Wait five minutes before applying a full layer of 1K primer paint. Ensure that all the surfaces are covered and whilst spraying, and ensure that the nozzle is at the same distance parallel to all the sections of the surface.
6. Let this layer cure for about two hours.
7. This layer will now be sanded starting with a P600 sanding paper.
8. Sanding can then commence up to a grit of P800 (if the plug will only be used once, it can be sanded to a P3000 and polished.)
9. The surface is then be sprayed with a 2K paint mist layer, with five minutes' interval between the two full layers of 2K paint.
10. Leave the surface to cure according to the paint datasheet.
11. After the painted surface has cured, sanding commences starting with a P800 and working all the way up to a P3000.
12. If any pinholes, orange peel, or any other discrepancies are noted, these should be properly repaired as described in Appendix E.

13. After the surface has been sanded up to a P3000, the surface is machine polished to provide a glossy, shiny, Class A surface.
14. Whilst the surface is still in the dust-free area, the wrapping is removed and the acrylic sheets can be bonded to the split surfaces (if acrylic split surfaces are to be used.)
15. After a perfectly smooth plug surface has been attained, it is advised that one should prepare the surface with the release agent and then cover the plug with a dust-free bag. The plug should then only be opened once one is ready to manufacture the mould (if a 2K paint was used, Frekote can be used, but if the plug only has 1K paint surface, Mequiars Mirror glaze 87 wax can be used.)

5.2 MANUFACTURING OF THE MOULD

The manufacturing of the mould should start with the preparations of all the material needed for the mould. The following guidelines should be followed:

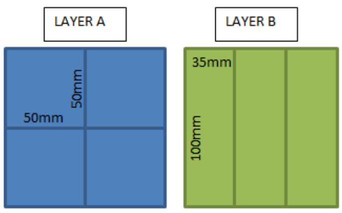

Figure 5-6: Brick layer illustration

- All fibres needed should be cut into bricks. The shape of the mould will determine the brick sizes and layout. Usually two types of brick layers would be sufficient, as illustrated in Figure 5-6.
- Pre-cut the fibres, which would be situated around inserts, with the necessary holes.
- Stack the fibre bricks in the sequence of application and in the direction it will be applied.
- Prepare the tooling gelcoat brushes or application gun. If a brush is used, it should be cut to two-thirds of the length, as illustrated in Figure 5-7.

Figure 5-7: Brush cut shorter for gelcoat

- Prepare the working area to be clean and dust free, with an ambient temperature of about 20-25°C, and cover the working area with plastic.
- Have ample clean rags, acetone, mixing sticks, scissors, clamps, all accessories, scale, heat gun, etc. ready.
- Pre-weigh the fibres and calculate the resin to be used. (Hand layup fibre to resin ratio is 100:60.)
- Calculate the tooling gelcoat to be used as described in datasheet of the tooling gelcoat to be used (Appendix G).

The following process should be followed for creating the mould:

1. Ensure that the plug is treated with a wax release agent (Mequiars Mirror Glaze 87 Wax is used in this study).
2. Ensure that all the necessary inserts, like alignment pins, are also treated with the release agent and are placed in position on the mould.
3. Mix the first batch of the tooling gelcoat as calculated.
4. Apply the tooling gelcoat in long even strokes with the prepared brush. The tooling gelcoat viscosity is very high and thus it should be applied with a heat gun set at 60°C and held at about 20-30cm from the tool and brush. The heat gun should be moved to cover the entire area whilst applying.
5. Let the tooling gelcoat cure for about 20-30 minutes, as the heat applied during application decreased the curing time. Never let the gelcoat cure overnight or longer than 3-4 hours, as this could cause the gelcoat to shrink and cause wrinkles. The gelcoat should be tacky, Figure 5-8, but should not stick to one's finger upon touching.

Figure 5-8: Tacky Gelcoat test (Wanberg, 2009).

6. Mix the first batch of epoxy.
7. After the tooling gelcoat has become tacky, the bonding layers (print barrier layers) can be applied. When applying this layer, ensure that there are no air bubbles, as bubbles might cause irregularities in the gelcoat layer. This layer is the most important one.
8. After the bonding layers have been applied, the rest of the structural layers can be applied in brick format according to the layup schedule.
9. When applying the sandwich / core layer, one must ensure that these inserts are bonded correctly and have sufficient bonding area. It is always good to punch holes in the core layers to enhance bonding. The core layers must be bonded with a bonding mix. (Core layers should also be designed with large enough chamfered edges to smoothen the structural layers applied afterwards).
10. After the final structural layers have been applied, the layup can be left to cure according to the curing cycle of the resin system (usually 2-3 days is required)
11. Before the tool is demoulded, one can attach support structures if necessary.
12. If a support structure was applied, the structure bonding should be left to cure as well before demoulding.

13. After demoulding the tool, the surface can be inspected for any discrepancies and should be repaired according to Appendix E, if necessary.
14. After the surface has been repaired, one can start with the finishing of the tool surface. Depending on how the surface demoulded, and what the overall surface roughness measured, one can either simply polish the surface or sand it with a P1000 to a P3000.
15. After the surface has been polished, the release system can be applied to the surface according to the release agent datasheet. The chosen release system in this study is Loctite Frekote 770-NC release system.
16. After the Loctite Frekote 770-NC release system has been applied, the first part can be manufactured.

5.3 MANUFACTURING OF A CLASS A FINISHED PART

After the tool has been finished, it is important the break-in the mould with a first part. The first part will reveal any discrepancies on the mould surface. These discrepancies can then be repaired before the mould goes into production.

The process for producing the first part differs from part to part and thus this study will only attend to the basics of the surface finish. The following process can be followed:

1. Ensure that all the materials are prepared according to the drawings and manufacturing sheets.
2. Ensure that the mould is treated with release agent; in this study the Loctite Frekote 770-NC release system is used.
3. Mix the correct amount of 2K paint.
4. Spray the mould surface with 2K paint and let it cure for about 20 minutes.
5. Roughen the surface slightly to break the tension, with an 80 grit sanding paper.
6. Apply the bonding layer (print barrier) layers (1 or 2 layers would be sufficient)
7. Apply the rest of the structural layers.
8. Let the part cure according to the curing cycle.
9. Demould the part.
10. If any discrepancies are noted, these can now be fixed.
11. After the part has been demoulded, the mould should be cleaned and stored either face on face, or covered with plastic sheets to ensure that it does not contaminate or damage before the next production cycle.

5.4 CONCLUSION

The entire process of producing a Class A surface finished part begins with the careful design of the plug. The plug requires appropriate cutting methods that will ensure that excessive sanding is not required. Normal spraying and sanding methods can be used to finish the surface before release agent is applied. The mould layup should be designed prior to manufacturing and the given manufacturing guidelines should be followed to ensure that an optimum surface is obtained. If the mould surface is smooth and has no damage, this surface will be transferred onto the product and the desired Class A finished part will be created.