

# A composite manufacturing process for producing Class A finished components

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## ABSTRACT

The purpose of this study was to develop a composite manufacturing process that would be able to deliver Class A surface finished products in the context of mould manufacturing methods. The problem required solving was to overcome the time needed to prepare Class A surfaces, by developing a composite manufacturing process that will deliver Class A surface finished products straight from the mould. The process was aimed at the entire development process, from mould and plug design up to the finished product.

A literature study and a factory mould survey were conducted with a view to obtain the necessary insights into surface finishing and composite manufacturing. These surveys were followed by seven constructional tests which determined the most appropriate solutions for the proposed manufacturing processes.

Test 1 was used to determine a quality finish standard for composites from the sanding grits used to finished composite surfaces versus surface roughness values used in other industries. The standard determined that a P800 finish has a roughness between 0.200 and 0.150  $\mu\text{m}$  and constitutes a Class A3 finish. P1000 to P1200 have a roughness between 0.150  $\mu\text{m}$  to 0.100  $\mu\text{m}$  and constitutes a Class A2 finish. Finally a P2000 and higher have a roughness of 0.100  $\mu\text{m}$  and lower and constitutes Class A1 surface finish. After the standard was set, the tests for finishing of the moulds, plugs and parts commenced.

Test 2 was conducted on the CNC manufacturing of plugs out of Nucoron651 tooling board. Tool path parameters were varied in a matrix. The samples with the best surface finish value were cut with a step-over of 0.5 and feed of 800 mm/min. These parameters were found to be the most influential. Test 2 and 4 revealed that the plug surface finishing should commence with conventional 2K paint finishing, with a possibility of acrylic split surface. This process produced projected mould surfaces between 0.150  $\mu\text{m}$  and 0.200  $\mu\text{m}$ , which can be categorised as Class A-3.

Test 5 and 6 determined methods for improving the mould surface quality and durability. It was established that the tooling gelcoat should be applied whilst being heated and backed with at least two layers of glass veil and a steady increase of GSM of structural glass fibres to prevent print-through. Test 3 determined that the mould corners could be strengthened with rovings pressed into the corner. It was also established that the moulds surfaces will require finishing after demoulding.

The final moulds were manufactured from a fibreglass composite structure with tooling gelcoat surface. A number of guidelines and a set process were developed in order to produce moulds with a surface finish of average 0.9  $\mu\text{m}$ , equivalent to Class A1. Release agents were tested in Test 7, and the Loctite Frekote 770-NC release system was deemed appropriate for use with In Mould Coating (IMC) of 2K Paint. These elements were all synthesised into plug, mould and part manufacturing processes.

The proposed processes were validated by the manufacturing of a JS instrument panel, which delivered a Class A2, 0.175  $\mu\text{m}$ , finish with IMC of 2K paint. With only a minor sanding of P3000 grit and polishing, the part was made into a Class A1 surface, measured at 0.63  $\mu\text{m}$ .

The study proved that it is possible to produce Class A finished part with IMC. This method can provide a solution aimed at the elimination of P600 and lower finishing of composite parts manufactured with IMC.

## OPSOMMING

Die doel van hierdie studie was om 'n saamgestelde vervaardigingsproses te ontwikkel wat 'n Klas A-afgewerkte oppervlak kan lewer in die konteks van benaderings tot gietvormvervaardiging. Die probleem wat onderneem moes word was om die tyd benodig vir die voorbereiding vir Klass A afgewerkte parte te verminder deur 'n saamgestelde materiaal vervaardigings proses daar te stel wat Klas A produkte sal kan lewer direk uit die gietvorm. Die proses was toegespits op die algehele ontwikkelingsprosesse - vanaf die model, die gietvorm self, en ook die finale produk.

'n Literatuurstudie, sowel as 'n ondersoek na fabriekgietvorms, is onderneem met die doel om die nodige insig te verkry met betrekking tot oppervlakafwerking en benaderings tot saamgestelde vervaardiging. Hierdie ondersoek is gevolg deur sewe konstruksiegedrewe toetsings wat die mees gepaste oplossings vir die voorgestelde vervaardigingsprosesse aan die hand gedoen het.

Die eerste toets het 'n kwaliteits standaard gestel vir saamgestelde materiale. Die standaard is bepaal deur die skuur papier grade te vergelyk met oppervlak grofthede wat verkry is vanaf ander industrië. Die standaard het bepaal dat 'n P800 graad 'n grofheid tussen 0.200 en 0.150 um het en vergelykbaar is met 'n Klas A3 afwerking. So ook het 'n P1000 tot P1200 graad 'n grofheid tussen 0.150 en 0.100 um het en vergelykbaar is met 'n Klas A2 afwerking. Om af te sluit het 'n graad van P2000 en hoër, 'n grofheid van laer as 0.100 um en is vergelykbaar met 'n Klas A1 afwerking. Nadat die standaard vir oppervlak kwaliteit gestel was, is die res van die toetse onderneem.

Toets 2 is onderneem na die Rekenaarnumeriese beheer-vervaardiging van modelle deur van die sogenaamde Nuceron651 gietvormbord gebruik te maak. Die bestek van die instrumentpadmoontlikhede is deur 'n matriksvariasie vasgestel. Die voorbeelde met die beste oppervlakafwerkingswaardes is met 'n oorhang van 0.5 teen 800 mm/min gesny. Hierdie bestekmetings het die sterkste invloed uitgeoefen. Toets 2 en 4 het getoon dat die modelle se oppervlakke eers afgewerk moet word met konvensionele 2K-verfafwerking, met die moontlikheid van akrielloppervlaksplitsing. Die proses het geprojekteerde gietvormoppervlakke van tussen 0.150 um en 0.200 um gelewer, en kan daarom as Klas A-3 gekategoriseer word. Die oppervlakke van die gietvorms kon daarna verder gepoleer word met die oog daarop om 'n Klas A-oppervlak te verkry.

Toets 5 en is is onderneem om die gietvorm se oppervlak kwaliteit en duursaamheid te verbeter. Dit was bepaal dat die jelgebaseerde oppervlakbedekking aangewend moet word terwyl dit verhit word en versterk moet word met 2 lae van glas sluiers en 'n bestendige vermeerdering in die gram per kubieke meter van die strukturele glasvesel lae. Toets 3 het bepaal dat die gietvorm hoeke versterk kan word deur glasvesel rovings. Dit was onderneem dat die gietvorm oppervlakke steeds afwerking sal benodig nadat dit verwyder is van die modelle.

Die finale gietvorms is vervaardig deur van 'n saamgestelde veselglasstruktuur met 'n sogenaamde Axon GC1150 gietvorm jelgebaseerde oppervlakbedekking, gebruik te maak. Sodoende is 'n aantal riglyne sowel as 'n vasgestelde proses daargestel wat gebruik kan word om gietvorms te vervaardig waarvan die oppervlakafwerking gemiddeld 0.9 um is – ekwivalent aan dié van 'n Klas A1. Loslaatmiddels is daarna getoets, en die sogenaamde Loctite Frekote 770-NC-loslaattelsel is bevind om toepaslik te wees vir die in-gietvormbedekking van 2K-Verf. Hierdie elemente was almal deel van die oorhoofse vervaardigingsprosesse van modelle, gietvorms en onderdele.

Die voorgestelde proses is getoets deur die vervaardiging van 'n JS1-instrumentpaneel, wat 'n Klas A2, 0.175 um afwerking gelewer het met 'n in-gietvormbedekking van 2K verf. Deur die oppervlak slegs liggies te skuur met P3000-grofheid en dit te poleer, is die onderdeel se oppervlak verbeter na dié van 'n A1 oppervlak wat 0.63 um gemeet het.

Die studie het getoon dat dit moontlik is om Klas A-afwerking te verkry deur in-gietvormbedekking indien 'n toepaslike benadering gevolg word tot die vervaardiging van hoë gehalte model en gietvorms. Hierdie metode kan help om 'n oplossing te wees op weg na die bekamping van P600 en verminderde afwerking van onderdele wat deur in-gietvormingsprosesse vervaardig word.

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## KEYWORDS

Class A surface finish

Composite

Mould

Plug

Surface Roughness

Wet layup

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“I will instruct you and teach you in the way you should go; I will counsel you with my eye upon you.”

*Psalm 32:8*

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## DECLARATION

I, Zelldra Lombard (Identity Number: 881124 0012 080), hereby declare that the work contained in this dissertation is my own work. Some of the information contained in this dissertation has been gained from various journal articles; text books, sources etc., and has been referenced accordingly.



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Z. Lombard

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## NOTE TO THE TEXT: DOCUMENT LAYOUT

Although the Table of Content provides an overview of the layout of the document, this textual note aims to clarify the various elements of the dissertation text together with the appendices and their functions.

A list of Figures, Tables, Abbreviations and Symbols is provided in the content pages.

A glossary of terms used in the study is also provided in the content pages, before Chapter 1 commences.

Appendix A provides information of the data compiled during the JS Mould survey. This data was used to provide the results for Chapter 3.

Appendix C provides the data used in the CNC tests of Chapter 4, test 2.

Appendix D provides information on the manufacturing of the JS1 instrument panel, which was used as validation in Chapter 6 of the process described in Chapter 5.

Appendix E provides extra information on finishing processes that were not directly related to the literature study but which were considered as valuable information during the testing phases.

A list of materials, equipment, consumables and software used in this study is provided in Appendix F.

Appendix G is a compilation of the most important datasheets used in this study.

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## LIST OF ABBREVIATIONS

CAD	Computer-aided design
CAM	Computer-aided manufacturing
CNC	Computer numerical control
FRP	Fibreglass reinforced plastics
IMC	In mould coating
JS	Jonker Sailplanes
PPF	Paint protection films
VOC	Volatile Organic Compounds
PU	Polyurethane
SPI	Society of Plastic Industries
SWP	Standard workshop practises
TIA	Technology innovation association
WBS	Work breakdown structure

## LIST OF SYMBOLS

Symbol	Unit	Description
Ra	um	Average surface roughness
T	°C	Degrees Celsius, temperature
Rz	um	Average surface roughness at 10 points measured in micrometres.
Pxxx	grit	Sanding paper grit size
x , //	Degrees	Degrees, fibre orientation
GSM	g/m <sup>2</sup>	Fibre weight measured in grams per square meter
	rpm	Revolutions per minute
	sqm	Square meter
	mm/min	Millimetres per minute

## GLOSSARY OF TERMS USED

- 1K paint / coating - A 1K coating is said to be a single component coating that does not require a hardener or second component in order to cure. A 1K use solvents and air dries. 1K most commonly found in lacquer finishes, but may also be found in epoxies, enamels, and urethanes depending on the blending (The Eastwood Company, 2013).
- 2K paint / coating - A 2K coating is a double component polyurethane coating that requires a hardener catalyst or activator to cure the coating (The Eastwood Company, 2013).
- acetone - A flammable colourless liquid ketone made by oxidizing isopropanol, used as an synthetic reagent and organic solvent, used mostly in nail polish remover or general paint solvent (LLC, 2013).
- Acrylic sheets - Acrylic sheets are a cell cast high molecular mass. It has a general high gloss and a hard finish, and can be compared to clear glass (Pilkington, 2009).
- Aviation - The science or art of flying aircraft, including the design, production, and maintenance of aircrafts (Farlex, 2012).
- Balanced laminate - "Any laminate that contains one ply of minus theta orientation, with respect to the principle axis of the laminate, for every identical ply with a plus theta orientation (e.g. a laminate with a principal axis of 0° combined with an equal number of plies that have -45° and +45° orientations)" (TIA 6, 2011).
- Brick style - The layup of fibre lamina in a style representing the layup of bricks in a wall. The fibres are cut into smaller pieces, bricks, the top layer bricks is laid upon the intersectioning area of the previous layer's bricks. (TIA 5, 2011)
- Class A surface finish - Class A surfaces are aesthetic/free form visible surfaces (interior/exterior). It has a high surface quality and an optimal aesthetic shape. Mathematically a Class A surface is curvature continuous, while providing the simplest mathematical representation needed for the desired shape/form. Class A surfaces do not have any undesirable waviness (Catia, 2012).
- Composite - It is a three-dimensional mixture of two or more materials differing in form or composition, with a distinct interface splitting the components. Composite materials are artificial. It is created to obtain properties that cannot be attained by any of the components acting on its own (TIA 6, 2011).
- Curvature continuity - Curvature continuity is continuity of sharing boundary surfaces. It means that every point of each surface, along the shared boundary, has the same curvature radius (Catia, 2012).

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- Demould - To remove a part from a mould or tool after it has cured (TIA 6 2011).
  - Filler - A component, usually inert, added to a resin and hardener to modify a composite's properties to increase viscosity (TIA 6, 2011).
  - Gelcoat - "An un-reinforced, clear or pigmented coating resin applied to the surface of a mould or part to provide a smooth, impervious finish on the part exterior" (TIA 6, 2011).
  - Glass veil - A very thin cobweb-like glass fibre mat (Wanberg, 2009).
  - Glider - A very light aircraft that can be lifted by an upward current of air after being launched or towed aloft (Farlex, 2012).
  - Hardener - A substance added to a resin to promote the curing process. The substance is consumed by the cure reaction (TIA 6, 2011).
  - Heat gun - A device that emits a stream of hot air between 60°C and 100°C. Heat guns usually have the form of an elongated body and 'n handle fixed with a trigger (Farlex, 2012).
  - IMC - In mould coating. Refers to a process where the surface layers / coatings are applied directly into an open mould (Sunbelt Materials, 1998).
  - Laminate - The uniting or bonding of more than two layers or laminate (often with the aid of pressure and/or heat) of a fibre- or fabric-reinforced composite. The laminate can have one or more fibre orientations with respect to a reference plane (TIA 6, 2011).
  - Matrix - The fluidly part of the composite material in which the reinforcing fibre is embedded. Matrix materials include thermosetting and thermoplastic polymers (TIA 6, 2011).
  - MEKP - Methyl ethyl ketone peroxide is an organic peroxide. It is used as a hardener for gelcoats, vinyl ester resins or polyester resins. When MEKP is mixed with the resin, the resulting chemical reaction causes heat to build up and cure or harden the resin (James Town Distributers, 2008).
  - Model - The original piece/part that will be replicated, which may include an extended split surface (TIA 6, 2011). (see also: plug)
  - Mould - "An enclosed cavity or open form from which a composite component takes its shape, size and exterior surface appearance (also known as a tool)" (TIA 6, 2011) (see also: tool).
  - Plug - The original piece/part that will be replicated, which may include an extended split surface (TIA 6, 2011). (see also: model)
  - Polishing - Refers to a process whereby a substance, containing chemical agents or abrasive particles, is rubbed onto a surface to smoothen it, producing a glossy and shiny appearance (Farlex, 2012).
  - Polyester - A thermosetting resin produced by dissolving unsaturated, generally linear, alkyd resins in a vinyl-type active monomer, such as styrene. It is usually furnished in a dilution form, but powdered solids are also available (TIA 6, 2011).

- Polyurethane (PU) - A class of synthetic materials made by copolymerizing an Isocyanate and a polyhydric alcohol and commonly used as foam (polyurethane foam) for insulation and packing, as fibres and hard inert coatings, and in a flexible form (polyurethane rubber) for diaphragms and seals. Extremely tough composite which have rapid manufacturing possibilities” (TIA 6, 2011).
- Post cure - The application of external heat to enhance the curing of a resin enabling a stable state of cure in the shortest possible time (NGCC, 2013).
- Post mould - Refers to a process where the surface layers are applied onto the part after the part has been demoulded (Sunbelt Materials, 1998).
- PPF - Paint protection films. Layers of stretchable, clear polyurethane wrapping used in automotive industry to protect surfaces from road depresses (Argotec, 2008-2013).
- Print barrier - A layer added between the surface layers and structural layers of a laminate to prevent print through of the structural layers (Morena, 1994).
- Print-through - Print-through occurs when a laminate is heated and cooled and the fibres and resin within the laminate expands and contract slightly. This result in a faint image of the fibre weaves in the surface of the laminate (Wanberg, 2009).
- Profilometer - Gauge used to measure surface roughness. A profilometer uses a conical diamond stylus to measure the roughness with traces which are typically done perpendicular to the “lay”(Degarmo *et al.*, 2003).
- Pxxx grit - The ISO / FEPA sanding paper grit designation. The higher “P” number, the finer the grit, providing smoother surface finishes (TIA, 2012).
- Release agent - A particularly formulated material applied onto the mould surface to prevent permanent bonding between the mould and layup during cure. It also facilitates demoulding after cure (TIA 5, 2011).
- Resin - “A solid or pseudo-solid polymeric material, often of high molecular weight, which exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally. As composite matrices, resins bind together reinforcement fibres and work with them to produce specified performance properties” (TIA 6, 2011)
- Rovings - “Endless glass fibre bundles; a collection of parallel strands (assembled roving) or parallel filaments (direct roving) assembled without intentional twist” (NGCC,2013).
- Sailplane - A very light glider that can be lifted by an upward current of air (Farlex, 2012).
- Sanding - Sanding occurs when a surface is rubbed with an abrasive paper / cloth in order to remove any discrepancies on a surface. It has a direct influence on the surface roughness (TIA 3, 2011).
- Scallop - A small cusp of material remaining from the tool step-over between adjacent cuts.

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- Shear strength - "The maximum shear stress that a material is capable of sustaining" (TIA 6, 2011).
  - Split surface - The extended flange areas around the mould.
  - Stepover - The offset distance parameter between adjacent CNC tool paths (Julie *et. al.*, 2006).
  - Stiffness - "Stiffness or flexibility is the pliability or rigidity of an object — the extent to which it resists bending. They are complementary concepts so the more flexible an object is, the less stiff it is" (TIA 6, 2011).
  - Surface finish - The spraying, sanding and polishing of a surface to obtain a better quality and improve the surface roughness (TIA 3, 2011).
  - Surface layer - "The outside layer on a part. Designed to fulfil a specific purpose. Example, UV resistance, chemical resistance, etc." (TIA 3, 2011)
  - Surface roughness - The surface roughness is a measure of the finely spaced surface irregularities. In engineering, this is what is usually meant by "surface finish". (Mike *et al.*, 1998-1999).
  - Symmetric laminate - "Laminate in which the stacking sequence for the plies located on one side of the geometric mid plane are the mirror image of the stacking sequence on the other side of the mid plane" (TIA 6, 2011).
  - Thermoset - A class of plastics that, when cured by thermal and/or other means, becomes substantially infusible and insoluble. Once cured, a thermoset cannot be returned to the uncured state (TIA 6, 2011).
  - Tool - The mould, either one- or two-sided or either open or closed, in or upon which composite material is placed in order to make a part (TIA 7, 2011) (see also: mould).
  - Tooling gelcoat - Tooling gelcoat is harder, more abrasive and resistant, and less flexible than general purpose gelcoat. It is used where no movement is required, such as for moulds and countertops (Fibreglass Warehouse, 2013).
  - Toolingboard - "Also known as modelling boards and machinable slabs, these are typically made from filled polyurethane. Tooling boards exhibit very high dimensional stability and low density. Tooling boards take the place of wood and metal in master models, prototype tooling, patterns, moulds, jigs and fixtures" (AMT composites, 2013).
  - Trim - The manual removal of unwanted material from a composite part with a blade (TIA 7, 2011).
  - UV - "Ultra violet. UV light is found in sunlight and is also emitted by specialised light (e.g. black lights). It can be used to help cure certain varnishes and coatings. Coatings protect certain surfaces from UV rays" (TIA 6, 2011).
  - Vinyl wrap - Tough flexible, shiny plastic wrapping material used in the advertising business to wrap cars (Farlex, 2012).
  - Weave - "To interlace fibres in a pattern, often based on a 0°/90°grid, the fabric pattern

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- Wet layup - formed by interlacing yarns” (TIA 6, 2011).  
- “Application of a resin to dry reinforcement materials in the mould.” (TIA 6, 2011).