



A Comparison of Manufacturing Processes

Advanced Processes & Materials
(M6X0414)

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2. Abstract

This report looks to compare two nonconventional manufacturing processes with the conventional process of CNC milling. Consideration is made with regards to the structural integrity of the product, quality, cost and weight. The report considers what obstacles a nonconventional process such as SLM requires to do in order to be used as a mainstream common process, the growth trend of this process is considered. Composite moulding may potentially be a suitable alternative to CNC milling, this is due to the material properties being both strong and incredibly light.

This is not however conclusive as it is not possible to determine that best process without fully understanding the product's requirement, but it does however determine what process is suited for a particular given application.

3. Introduction

The aerospace industry has specific regulatory/certification requirements that must be adhered to, in the UK these are governed by EASA. Certification will focus on the safety factors including weight, corrosion resistance and stress factors.

The task is to report on two possible alternatives to milling, the seven recognised requirements are: -

- (i) **Product size** = 580 x 330 x 25mm. Consider this as a standard required size that the process must be capable of producing.
- (ii) **Tolerance** = ± 0.127 mm. This does not however consider any significant characteristics of the product, therefore it is assumed that the tolerance is standard for all dimensions regardless of size.
- (iii) **Surface finish** should be better than that of milling.
- (iv) **Stress** factors, products such as cockpit floors must not only be tough enough to withstand impact from the passenger/pilot, but may also need to meet crash condition requirements.
- (v) **Weight**, there will be a target weight for aerospace components, as we do not have this data we should consider a process that is capable of producing the lightest possible products, whilst maintaining structural integrity.
- (vi) **Cost** will be greatly impacted by production quantities, if we are to consider a specialist process for manufacture, will; (a) The production quantities warrant the cost of the machinery? (b) The sale cost warrants the production material cost and cycle time to produce?
- (vii) **Post processing operations**. The process should be as such that the finished product can be produced without the need for secondary or tertiary operations such as machining or fabrication. This will eliminate the added cost associated with additional manufacturing processes.

4. Process selection

In order to select the two most suitable manufacturing processes for comparison, we should first consider several options. Here is a table summarising a range of available options, and how they compare to the abovementioned criteria.

	Water jet cutting	Laser cutting	Composite resin infusion moulding	EDM	Direct energy deposition	SLM
Product Size (mm)	14,000 x 4,000 [1]	4,000 x 2,000	Greater than the requirement	550 x 470 x 150 [2]	2,100 x 1,500 x 1,500 [1] [3]	600 x 360 x 280
Thickness	Thin & thick [1] [4] [5]	Thin & medium [1] [4]	Thin & thick	Thick & thin [4]	Thin & thick	Thin & thick
Tolerance (mm)	Up to 0.076 [4] [6]	Up to 0.025 [1] [4]	Up to 0.15 [7]	Up to 0.0025 [4]	Up to 0.0025 [3]	0.02mm
Surface finish	Good [1]	Good but may have burring [1]	Good – depending on process; e.g. ‘bag surface’ may be poor (if injection moulding process is not used)	Excellent [4]	Can be excellent but does depend on speed [8]	Good but may require a finishing process [9] [10]
Stress implications	Good – Aluminium or composites [1]	Edge hardening of material [1] could cause brittleness	Good	Edge hardening of material could cause brittleness	Ability to control grain structures therefore very good [8]	Good – Aluminium & Titanium [10]
Weight	Good – Aluminium and composites possible [1]	Good – Aluminium possible [4]	Excellent	Good – Aluminium possible [4]	Average - not Aluminium, but Titanium possible [3]	Very good – hollow structures possible with aluminium & titanium.
Cycle time	Medium cutting speed, fast set up [1] [4]	Fast cutting speed, fast set up [1] [4]	Slow	Medium speed – not as fast as water jet [4]	Very slow	Very slow
Cost	Medium to high cost machine [1] medium to low running cost [5]	Medium to high cost machine & medium running cost [1]	Low cost machinery & medium to low running cost	High cost machine and medium running cost	High cost machine and medium running cost	High cost machine and medium to low running cost
Post processes	Fabrication almost certain	Fabrication almost certain	Possibly CNC routing	No	Possibly some de-burring	Possibly surface finishing

The selected processes will be composite and SLM, mainly due to weight and stress, although all processes have their benefits, we could use any of the above to analyse.

5. Composite

5.1.1 Introduction

Composite manufacturing is not a new process, but it does however satisfy two of the aerospace industry's requirements for being both lightweight and strong [11] [12] [13]. There are several different composite processes available, the most common are pressure bag moulding, autoclave moulding and vacuum bag moulding [14]. The RIM (resin infusion moulding) process involves a mould tool, glass or carbon fibre sheets are layered within the tool, each sheet usually having the fibre direction at either 45 – 90 degrees to the last. Epoxy resin is pumped into the tool to completely cover the fibre sheets, then the mould is left to set [15].

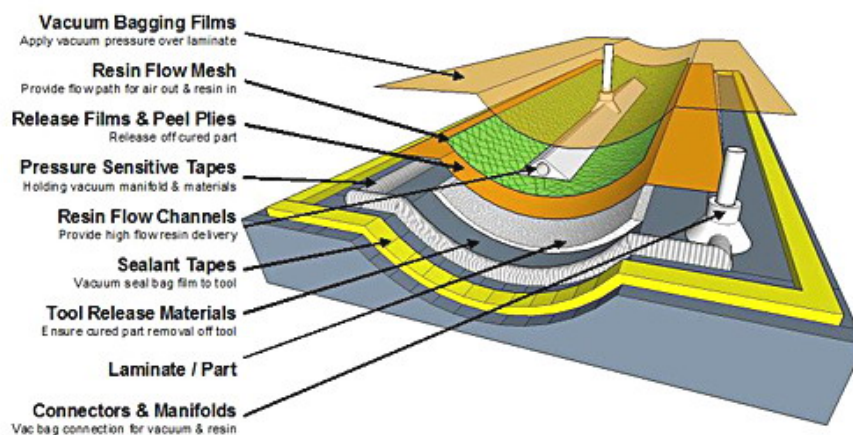


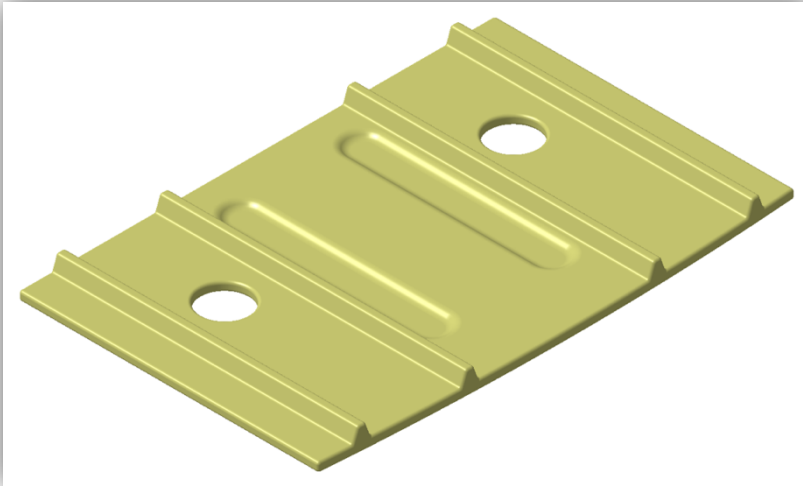
Fig. 1 [14]

5.2. Cost

The cost of RIM moulding is generally cheap, requiring low cost material and often simple tooling. The capital investment for the RIM moulding process is really cheap in comparison with buying an AM machine [13]. The use of composites within aerospace has increased in recent years due to a reduction in material cost of carbon fibre, currently costing £10/kg approximately [11]. Furthermore, the aerospace industry now only accounts for 20% of the market share for composite manufacture [11], which means the increase in demand should continue to drive down cost in future.

5.3. Materials

Composite material is corrosion resistant [11], which means there is no requirement for a surface treatment as would be the case with metallic parts. Even though some metals may not require a corrosion resistant treatment individually, consideration must be taken to avoid galvanic corrosion between different material groups such as Titanium and Aluminium. The two main composite materials are carbon fibre and glass fibre [11] [16], these can be manufactured using both autoclave and RIM moulding processes [11]. The RIM moulding process achieves an excellent surface finish [13] and is widely used to produce highly aesthetic carbon fibre components.



This model was generated from the given information so that an approximate mass comparison can be carried out. The Volume of the component is 0.0017978m^3 , given this information, the mass can now be calculated using the formula:

$$m = \rho \times v$$

fig. 2

CNC milling

2024-T351AMS Aluminium; $\rho = 2,780\text{kg m}^3$ [17] [18]

$$\therefore 2,780 \times 0.0017978 = \underline{4.998\text{kg (3dp)}}$$

Composite moulding

Composite Carbon Fibre; $\rho = 287.871\text{kg m}^3$

$$\therefore 287.871 \times 0.0017978 = \underline{0.518\text{kg (3dp)}}$$

In this instance, the composite component's estimated mass is significantly lighter at approximately 4.5kg below that of a traditionally machined component. This is an argument in favour of composite [11].

(Please note that the density of the composite material was obtained from a CAD CATIA V5 materials database).

5.4. Process

RIM moulding consists of curing at room temperature and has a reasonably short cycle time [13]. Methods such as autoclave and vacuum bagging require heat to cure and generally require significantly longer cycle times [13]. Whereas the vacuum bagging method has a longer cycle time, although several components can be produced at once and placed in the oven to cure often without the requirement for complex mould tooling, therefore effectively reducing cycle time.

RIM moulding composite moulding can be made much tougher with the use of an alkaline treatment, Kumar et al studied the effects of this and discovered that the treatment could improve both hardness and impact strength by 9% approximately [15], this alone may not appear to be much, but it also could be significant if there was a specific stress certification standard to meet [12].

6. SLM – Selective Laser Melting

6.1. Introduction

SLM is widely used across many industries including aerospace, automotive and medical to name but a few [9] [19] [20]. Due to demand, the AM market has grown steadily, seeing an average increase in sales of machines at a constant rate of between 20.3% and 20.7% annually [10].

6.2. Cost

Additive manufacturing does not require time consuming setups such as product holding fixtures [10], programming, production planning [19], tool/cutter selection and reduces the possibility of human error [21]. The initial investment cost of additive manufacturing is high compared with conventional machines. Consider an individual component, there is little set up cost to additive manufacturing, and the cost comprises of the time taken to produce the component as well as the material cost. Further cost is effectively flat lined, it does not increase nor decrease regardless of quantity and is therefore a constant. In contrast, the cost of producing a component using CNC milling will initially be very high, this is due to the cost of programming and jigs and fixtures, but over time the cost is overcome by how cheap each part is to manufacture [10].

V. Sriram *et al* studied the business trends of additive manufacturing and reported that Siemens predict that additive manufacturing “*will be 50% cheaper and up to 400% faster in the next five years*” [9]. Furthermore, the aerospace sector currently accounts for approximately 50% of additive manufactured components worldwide [9].

6.3. Materials

Commonly used materials for SLM are Titanium (Ti-6Al-4V, ELI, CP & G-TA), Aluminium (6061 & Al-Si-Mg) and high carbon steel (316, 420, 347 & PH 17-4) [10] [21]. Additive manufacturing is used within the aerospace industry due to the high strength and lightweight materials it uses such as Aluminium and Titanium [10]. The material density and microstructure of SLM components will impact their strength, [22] they can be relatively hollow and supported using a simple internal skeleton such as a honeycomb structure. This is an advantage as it reduces weight, making it a big benefit in the aerospace industry [10]. Using the previous model (*fig. 2*) and by applying the formula to determine the mass:

SLM

Aluminium; $\rho = 2,680\text{kg m}^3$

$$\therefore 2,680 \times 0.0017978 = \underline{4.818\text{kg (3dp)}}$$

Making this very similar to CNC milling, if we consider the product to be a solid model.

6.4. Process

The process involves spreading a thin layer of metallic powder across the machine bed [9], each layer is generally between a 0.01mm – 0.10mm thick [21], a series of heat intensified lasers are then used to melt the powder at the desired areas [22] [9]. When the lasers have melted the powder to create a thin layer of solid metal, a further layer of powder is deposited on top of the previous layer, and the process is repeated until the complete solid component is created [9]. The number of lasers depend upon the machine itself, the more lasers operating simultaneously the faster the cycle time, therefore the number of lasers on a machine is a major consideration if time is a factor for the company.

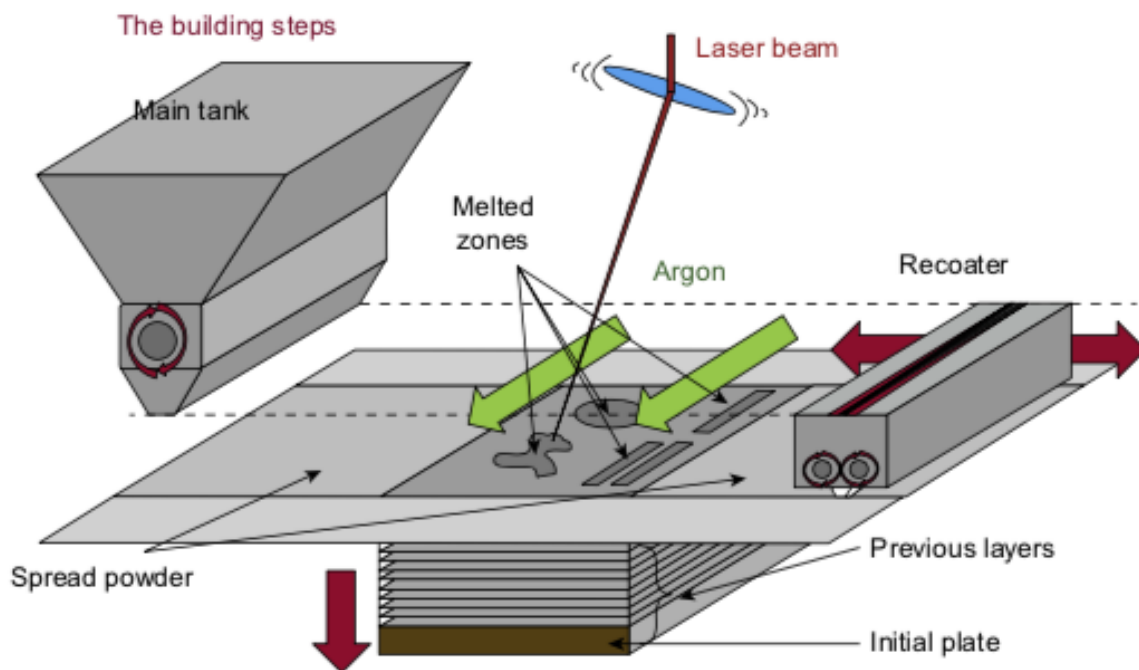


Fig. 3 [22]

SLM is excellent for limiting material waste when compared to CNC milling, the unused material can easily be reused with minimum effort or processes [10]. As the world becomes increasingly aware of resource, SLM can be considered a favourable manufacturing method [23]. SLM has the ability to create shapes that conventional milling cannot [10], it is also regarded as one of the leading AM techniques due to its ability [20]. Although component size can be a negative factor with additive manufacturing [10].

Additive manufacturing is excellent to produce new products quickly, from screen/CAD to manufacturing almost instantly, the CAD model can be saved in STL format when complete, then transferred to the machine [9] [19]. The machine will then slice the model into thin layers and then print one layer on top of another [9]. SLM is not currently regarded as a high-volume manufacturing process, simply due to its slow speed, although this has increased in recent years from 5mm³/s to 21mm³/s [23], if this trend continues then SLM could become a normal manufacturing process.

AM often creates an undesirable surface finish, such as a rough surface or a rib-like effect [10]. This means that in areas requiring a good surface finish such as highly aesthetic or visible surfaces, a post machining operation may be required such as a process known as 'Powerblast' or 'High Pressure Water Cleaner' [9]. SLA has a R_a (surface roughness) of 2–40 μm , followed by SLM at 5–35 μm [24], making SLM the best AM method for surface finish of metallic components. CNC milling can achieve a surface finish from 0.2–25 μm [25], therefore CNC milling is superior for surface finish.

There are several techniques used for improving R_a of SLM components, these techniques can be separated into two categories: Conventional & Non-Conventional [24]. Conventional processes include CNC finishing, hot cutter machining, micro-machining, optical polishing, vibratory bowl and even filling gaps with epoxy resin or painting/powder coating [24]. Non-conventional finishing techniques include electroplating, electrochemical polishing, laser micro-machining and ultrasonic abrasion [24] [26].

Vibratory bowl = 74% in R_a [24]

Hot cutter machining = 87% in R_a [27] (*although this is limited to flat surfaces*) [24]

Micro-machining = 84% in R_a [24] [28]

Laser micro-machining = 80% in R_a [24] [29]

7. Conclusion

Considering the helicopter floor sample, it is recommended that this be to manufactured using a composite RIM moulding method, the reasoning is thus: -

- (i) **Product size:** Whereas the desired size could be manufactured using SLM, we are pushing the machine to the limit, it is not ideal for a product of this size. Composite does not have an issue and neither does CNC milling.
- (ii) **Tolerance:** The composite processes will struggle to achieve the desired tolerance of $\pm 0.127\text{mm}$ without a post processing operation such as machining, with SLM achieving this without problem and machining will be better.
- (iii) **Surface finish:** Composite RIM can achieve the best surface finish, followed by machining and then SLM.
- (iv) **Stress:** All processes are good in this field, from the strongest being CNC milling to SLM being weakest, although stress analysis would need to be conducted on a component level basis depending on its application.
- (v) **Weight:** Composites are far superior when it comes to weight, being much lighter than both SLM and CNC milling.
- (vi) **Cost:** Initial capital investment is incomparable between the two alternative processes, with composites RIM moulding being far cheaper than SLM. The cycle time for a component will also be quicker with composites RIM moulding compared with SLM, but CNC milling is the best for cycle time. Although milling produces a lot of waste material.
- (vii) **Post processing operations:** There is no post processing required on the composite component unless there is any complex geometry or tight tolerance features, based on the example image this is not a concern. Applying the requirement for a smooth surface finish, SLM may require some post processing whereas milling falls between both composite and SLM.

There is one significant point to be made, there is a manufacturing process suited for each application depending on the component's requirements. For instance, if we require a product of a small batch quantity with complex and irregular geometry, SLM may be the best option. Furthermore, SLM would be excellent for taking a simple vision from an individual's mind through to a finished product very quickly, simply by creating a model and sending it to the SLM machine for printing. CNC milling continues to be used widely as it is reliable and relatively cheap, whereas composites are growing along with SLM. To conclude, without analysing a product and its individual requirements, it is not possible to say outright that one process is better than the other, although based on the information provided it is recommended that composite, milling or even a general fabrication of sheet/plate aluminium would all work well for this particular product. Composite would be preferred as it meets the weight, finish, cost

requirement and produces less waste, but the stress factor may be a concern and without that data it is not possible to conclude sufficiently. SLM undoubtedly has a place in the future, but improvements on its speed must be made in order for it to become a mainstream manufacturing process, therefore it is not recommended for this particular application.

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