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Nordic Innovation Centre

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Norrama Nordic Network of Rapid Manufacturing (RM)

- Design freedom in product development with RM
- Manufacturing assembly fixtures and jigs that eliminate or reduce process steps and obtain reduced cost and lead time
- Cost effective manufacture of low volume production of parts or even one off the kind



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NORRAMA

Nordic Network of

RAPID MANUFACTURING

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Abstract: The ability of Rapid Manufacturing, RM , to manufacture any design created in a 3D CAD system, without having to consider the geometrical limitations of production processes or expensive tooling, opens new possibilities for individual design of products and parts. Design freedom in product development is now a reality with RM. The potential of RM is significant. RM parts can be manufactured with highly complex internal and re-entrant features, complexities which are impossible to produce with conventional production methods. RM can be used to manufacture assembly fixtures and jigs that eliminate or reduce process steps and obtain reduced cost and lead time. RM allowing manufacture of low volume production of parts even one off the kind can be produced cost effectively. Rapid Manufacturing has the potential to introduce totally new and innovative products to the market, faster and cheaper than seen with the traditional methods. When used in the right way, RM will strengthen the competitiveness for the innovative industry and will be of special importance for the SMEs in the Nordic countries. Transfer of new knowledge is required to commence this development, i.e. knowledge of the RM technology and business development of "new innovative products" which are not available today. The Nordic industry must learn how to design, produce and make business with the new possibilities within RM.		
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Executive summary

Main objectives

The overall objective of the network was to initiate, support and speed up successful implementation of Rapid Manufacturing in the Nordic industry. To achieve this, the following specific objectives have been defined to be reached among the partners themselves as well as widely in the industrial and educational society.

Awareness objectives

1. Widespread awareness of the RM business areas and economic potentials today and tomorrow (e.g. through collections of RM business cases on the network webpage)
2. New thinking in new design possibilities (e.g. through collection of cases on entirely new products or product designs at the network webpage)

Synergy objectives

3. Exchanged experience (e.g. through visits to partners, seminars, conferences, workshops)
4. Collected and refined knowledge (e.g. guidelines for Manufacture for Design)
5. Transferred technology and knowledge (e.g. through information about material data and RM parts characteristics)

Educational objectives

6. Courses for the industry (e.g. in re-design of existing products for RM)
7. Courses for students (e.g. on design rules, material properties, and process capability data)

Norrama has achieved this aim by:

Awareness

- Webpage www.isv.hut.fi: business cases in technical magazines, and paper presentations at conferences, seminars and workshops.

Synergy objectives

- More than 20 conferences, seminars and workshop have taken place in the 4 countries with 50 to 100 participants at each arrangement.
- Report with guidelines
- Database of RM materials from an intensive development program in materials.

Educational objectives

- Courses materials have been developed, and several courses for industry have taken place
- Several courses for students have taken place
- Updated course materials for engineering high schools have been delivered.

Main results

Guidelines for:

- New business processes and possibilities with RM
- Design for RM
- When to use RM
- Materials for RM
- Re-design for RM
- New potential application with RM
- RM cases.

The Norrama webpage has been set up with a link to other European RM activities, network, platforms and RM service bureaus in the Nordic countries. Between 1500 and 2000 participants have taken part in the Norrama activities.

The Norrama network has grown continuously since the network started due to the good and relevant industrial contents of the conferences and seminars.

The Norrama RM network will be continued in all 4 countries.

A common initiative to a Nordic tooling network is also made.

Partners in the network have successfully made an application for the EU FP7 programme, theme 4 NMP, including RM technology. The title of the project is *Com-polight*.

The following conclusions can be drawn

Norrama has successfully transferred RM technology knowledge to the industry and to educational institutions by means of conferences, seminars, workshops and webpage.

The Norrama network has expanded its number of members over the project period, from about 25 companies to over 175.

RM report with guidelines is available for the industry.

Recommendations

There is a need for continuing the RM network in the Nordic countries, for transferring the latest RM technology to SME's, as well as R&D work in design is needed too. Still, there are not quite enough "really" RM products on the market. R&D work in RM materials and RM processes is needed as well.

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1 Introduction to Norrama

Background

The globalization and the continuous development of the Internet means that even small local Nordic companies are up against international competition. Important factors are: reduced product lifetime, increased number of variants and higher product complexity. Increased focus has been moved from Mass Production to Mass Customization, where the company must be able to deliver individually designed products, i.e. one-off production. This forces the industry to use new methods and technologies to maintain their competitiveness.

The new innovative concept Rapid Manufacturing, RM, is believed by many to be able to provide part of the solution to the problem above and a pre-project has been started to investigate the potential. Important milestones of the pre-project are to clarify the potential of RM, define industry needs and identify the technology platform.

Potential

The ability of RM to manufacture any design created in a 3D CAD system, without having to consider the geometrical limitations of the production processes or to produce expensive tooling, opens new possibilities for individual design of products and parts. FOC, Holland is the first design company in the world having used RM and they have created a totally new innovative lamp series. Their message is: "If you compare RM with traditional technologies you don't create anything new! Use RM as it is now!"

Low volume production technology

The potential of RM today is low volume production down to one-off such as direct metal parts of titanium for the space and medical industry, tooling inserts made in tool steel, stainless steel parts and indirect casting processes and plastic parts made in different materials.

New business concepts for RM

To benefit from RM in the future, companies have to review their strategy and business process. Possibilities such as design freedom, new material combinations, individual design and production on demand can lead to new innovative products and a new production philosophy. Among the RM pioneers who are offering truly customized products are the hearing aid industry and medical implant manufacturers.

Industry needs

One of the defined industrial needs is to describe potential business areas for RM today and tomorrow, to develop standards and test methods for RM parts and materials, to set up design guidelines for new products as well as the re-design of existing, to collect material and process data bases, to develop specifications for RM production machines, start education, transfer technology and to raise awareness.

Technology platform

Each of the Nordic countries has a comprehensive technology platform in Rapid Prototyping and Tooling, though with varying focus. By increasing Nordic cooperation and combining already existing research and application knowledge, an excellent knowledge base for initiating and implementing RM is created. In the consortium there are R&D partners developing and producing machines, processes, materials and software fit for RM. There are advanced end user companies some of which have already started to use RM as low volume production (the hearing aid industry in Denmark, the car industry in Sweden as well as foundries). The possible platform is quite outstanding in an international comparison.

The aim

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2 Introduction to RM

Rapid Manufacturing (RM) is a vision of the future production technology (Wohler's report 2003).

Rapid Manufacturing is defined as "*the direct production of final parts and products from a Rapid Prototyping (RP) machine*". The technique uses additive processes to deliver final parts directly from digital data, without any tooling (Wohler's report 2003).

Other definitions of Rapid Manufacturing:

E-Manufacturing (EOS GmbH).

Advanced Digital Manufacturing, ADM (3D SYSTEM).

Rapid Manufacturing is the production of parts for the end user, produced directly or indirectly from a RP machine (Olivier Jay, DTI).

Currently, there are no RM systems available on the market. RP systems are, however, being used successfully in RM applications for the production of end-used parts.

The existing RP machines become general-purpose systems that are not designed for manufacturing applications; therefore, these systems to be designed must be addressed specifically to RM in order to succeed. This applies for surface finish, repeatability, accuracy, speed, size, and material properties, among others.

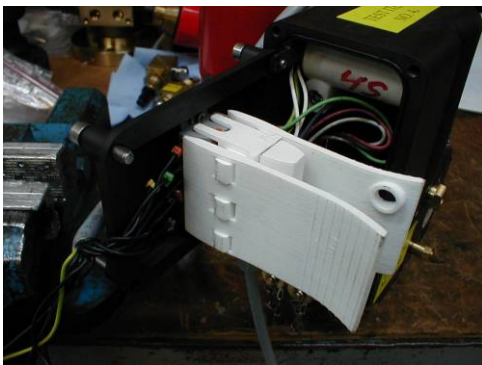
Industry is currently in a transitional phase where the RP systems, in spite of their limitations, produce low volume and customised parts. Rapid manufacturing systems, with the desired speed, cost, and quality, do not exist at present. They will be developed in the future.

3 RM Technical Platform in Norrama

3.1 RM Technical Platform in Denmark

In Denmark, Rapid Manufacturing is growing and the industry is looking towards metal as type of material.

The use of additive processes for producing end-use products directly or indirectly is growing. The Danish Hearing Aid industry is still leading the production of direct manufacturing. Other companies are also starting to use the technology but it is still on small projects. The education is still needed in the area of RM design. Danish Technological Institute has been helping companies to design parts for Rapid Manufacturing.



The picture is showing an example of a montage grip for programming and calibration. The grip has been designed for SLS technology and it has been produced for 40% of a traditional price. It has also got more functionality than the traditional due to the fact that it has been designed from the functionality and not from a production point of view.

Medical applications remain at a low level. Few RM applications in that area have been made, more precisely in heart-rings and pre-guided operations parts.

The companies have started to require more from their prototypes, and they are started to get more out of the technology. The Danish industry demands for stainless steel and metal have been growing fast during the last year, but the area is typically covered by indirect production as wax pattern from Thermojet machines or polystyrenes patterns.

2006 has also been a good year for Danish industry, and the number of machines is still growing towards the direction of 3D printers. Danish Technological Institute is investing in a Selective Laser Melting technology from the company MCP-HEK. The machine is making micro-fusion of metal as titanium and stainless steel. The machine was the first in in Denmark and was installed in 2007. .



Danish Technological Institute is still working on the pioneer job of promoting RM and will during the next few years work to implement the SLM metal technology in the area of conformal cooling and RM.

3.2 RM Technical Platform in Finland

Within the worldwide industry for additive systems, Finland is best known as the host and administrator of the rapid prototyping mailing list (rp-ml) that is a global mailing list for RP&M discussion. In 2007, an average of 1 to 2 messages per day was sent to the list. Following the discussion is possible either by subscribing to the list or by reading the messages from the www archive.

The mailing list was originally launched by Dr. André Dolenc, who was working in the Helsinki University of Technology (HUT). Currently, Mr. Hannu Kaikonen and Mr. Seppo Niemi are carrying on the work of the rp-ml. The mailing list is supported by The Finnish Rapid Prototyping Association (FIRPA).

The Finnish Rapid Prototyping Association (FIRPA) celebrates its 10th anniversary in 2008. A large national seminar will be organised in November 2008 to honour this important milestone.

Over the past decade, the electronics and telecom industries have been at the leading edge of these technologies in Finland. During the past few years, product development industries have grown rapidly. Success and growth have encouraged these companies to study new solutions based on rapid manufacturing technologies.

In 2006, Helsinki University Hospital (HUT), a group of Finnish companies and some international research partners started a cooperative program in the field of RP&M medical applications. The goal is to study additive medical applications in academic research and application-oriented projects. A software company called DeskArtes Oy, a biomaterial company called Inion, a DMLS materials development company called EOS Finland and a high-tech dental equipment company named Planmeca are also participating in the research program.

Sheet Metal Innovations SMI Oy (established in 2004) is one of the fastest-growing service providers in Finland. The company uses incremental sheet forming (ISF) technology from Amino Corp. of Japan. Most of their customers manufacture one-of-a-kind and short series products, such as paper and forest machinery, tractors, production machines and air ventilation products. This service provider company is a spin-off of a joint research project between HUT and Relicomp Oy.



Photo 3.1 Example of a Product which include Rapid Manufactured ISF components, courtesy of Sheet Metal Innovations and Sandvik Mining and Construction

EOS Finland Oy develops new applications and metal powder materials for the EOS Direct Metal Laser Sintering process. 2007 was a fruitful year for DMLS with increasing acceptance of the process. In 2006 the company launched new material, EOS MaragingSteel MS1. The material has two main application fields: production tooling and high-strength metal components. The material, coupled with conformal cooling, is gaining attention.

3.3 RM Technical Platform in Norway

The development of Rapid Manufacturing (RM) in Norway is still in its initial phase. However, there have been some activities in the area of Additive Manufacturing in Norway for over a decade – especially pioneering efforts in academic institutions such as NTNU in Trondheim, Høyskolen in Narvik and Arkitekt Høyskolen in Oslo – but still the concept of RM has not yet quite taken off to a wider acceptance within the Norwegian industry. Arkitekt Høyskolen in Oslo has besides its education and research program been running their Additive Manufacturing Lab as a service bureau since 1997, but ceased this activity two years ago. They do still accept commissions, however, only if it is suiting their own projects and activities.

Still, the definition of RM is vague and in some cases parts that originally may have been intended for end use have proven insufficient for that particular application, meaning that they rather have been examples of functional prototyping, or (perhaps more commonly) functional prototypes have proven very well satisfactory for end use purposes and thus rapidly transformed to RM. As an example of the latter NORSAP (Norske Sørlandets Aluminiumprodukter AS) and their experiences with FDM, should be mentioned. NORSAP, a manufacturer specializing in e.g. operator seats for maritime and the oil industry equipment, had invested in their own FDM Vantage SE to be used for the production of functional prototypes. However, while working towards a tight deadline, they found that their FDM prototypes did not only exceed the functional requirements for the final parts, the prototypes also looked so good, that there was no reason why they should not be used as functional parts in the final product. This has now become common practice, and today 70% of NORSAP's FDM produced parts are used for production purposes.



Photo 3.2 EOS tool made by Form-Tek.

For tooling purposes (if we would consider a tool as a single end use product), the ski-binding manufacturer Rottefella has, after initial investigation of the potential Additive Manufacturing processes (in cooperation with Arkitekt Høyskolen in Oslo) purchased an EOS M250 Xtended in collaboration with the local tool maker Form-Tek (see fig. 1). This machine is used primarily for Rottefella's purposes but is also available for other commissioned assignments.

Additive technologies have often been used for the realization of artistic parts and designs, and if this application in practice could be considered as RM, then the trophy awarded for the annual engineering achievement ("Årets Ingeniørbragd") in Norway is an excellent example. The complex geometry is designed by Marius Watz but produced by SLS (steel-bronze composite) at Arkitekt Høyskolen in Oslo (see Photo 3.2).



Photo 3.3 Brunvoll Inspection Technologies, proud winners of "Årets Ingeniør Bragd 2007" holding their SLS, RM-made trophy at the price ceremony (Teknisk Ukeblad/NTNUInfo).

In RM research, the perhaps most spectacular project in Norway is arguably the development of the MPP process at SINTEF Technology and Society in Trondheim. This new RM process for metallic and metallic matrix materials is based on a combination of layer fabrication by Xerography in combination with metallic consolidation by pressure and heat. This apparently complex approach to RM holds great promise for building speed and the capability of making combinations of materials that are "impossible" with the presently available RM process equipment. The project was initiated in 2001 and has recently been granted continued financial support from the research council of Norway until 2011. In addition to this, there has been a Ph.D. project running for the last few years at NTNU, with the purpose of investigating, among other things, the effects of integrating conformal cooling channels in

injection molding tools produced by Arcam's EBM method. A second Ph.D. project is in progress at Arkitekt Høyskolen in Oslo, addressing the issues of new design methodology needed in connection with RM. Furthermore, within tooling a new project will be launched in 2008 under the CRI NORMAN (Center for Research driven Innovation) program. This project will comprehend investigations in techniques for increased flexibility and adaptability in tooling, and among the technologies that will be investigated for this purpose are Additive Manufacturing technologies, if suitable in combination with more traditional technologies such as machining. The project will to a large extent be based on industrial cases and it is also quite possible that the direct manufacture of end use parts (more typical RM cases) will be included in the investigations. Historical Norwegian RM projects have been addressing polymer parts, but have met serious challenges based on limitations in the then present technologies. For example a type of measuring instrument for hip surgery by SLS was hampered by difficulties with rinsing the parts from un-sintered powder, and the customized sunglasses simply had too rough surface to be appealing.

In conclusion we can say that despite ongoing efforts for several years, Additive Manufacturing and RM have not yet reached, or gained acceptance from, Norwegian industry. However, with the upcoming initiatives, from academia as well as individual actors within the industry, there is a great potential for a positive development within the next few years.

3.4 RM Technical Platform in Sweden

The penetration of machines for additive fabrication in Sweden is relatively strong, with an estimated 223 systems installed in the country through the end of 2007. There are three additive processes developed in Sweden available to the market.

Service providers are experiencing a very strong market following a general industrial boom. Functional prototypes are now in higher demand than visual models. Rapid manufacture of components in small quantities is increasing in both plastic and metal.

2006 was a very successful year for Arcam. Orders were received to an extent that almost doubled the customer base. Machines were sold to high-end customers, also in new markets, e.g. Japan and China. The machines are intended for complex components in the aerospace industry, but even more in the implant sector where biocompatible titanium is a favourite. Q1 2006 agreement gives Stratasys the exclusive right to distribute Arcam's products to customers in North America. Arcam's proprietary additive process, called electron beam melting (EBM), uses an electron beam gun operating in a vacuum to melt metal powder.

The fcubic company has developed a powder-based, high-precision inkjet manufacturing process. Focus shifted in 2006 from ceramic to metal parts, primarily stainless steel. The target is to replace MIM parts in applications with not too high part numbers. Layer thickness is 40 μ (after sintering 35 μ). Layer completion time is 20 seconds and decreasing. The current machine has a build volume of 50 x 50 x 150 mm (2 x 2 x 6 inches). The properties of fcubic facilitate automation of the handling, making it a potential high volume process.

Speed Part of Sweden has developed a plastic powder-sintering process aimed at high-volume production. The company Particular AB has developed a very special application, sintering gold powder in the Direct Metal Laser Sintering machine from EOS. The business concept is individually shaped pieces of jewellery such as necklaces, designed in a way that is very difficult or impossible to fabricate with any other technology. The results to date have been impressive; the route to commercialization is being explored.

4 New Business Possibilities with RM

To understand how to benefit from RM in the future, companies have to review their strategy and business process.

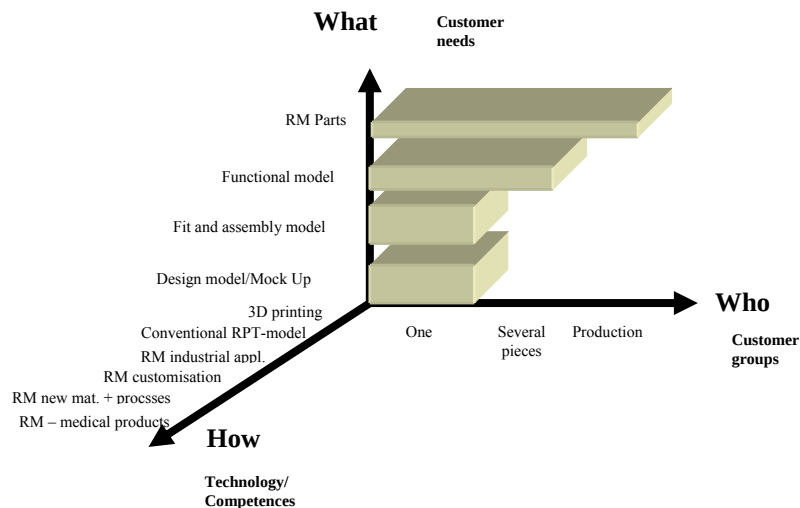


Figure 4.1 Defining the business

Figure 4.1 shows an example of how to define the RM business and Figure 4.2 shows examples of product portfolio.

	★	● Lamps ● Medical implants in metal * Low volume metal parts in titanium, stainless steel	?	● Medical implants with new materials * RM-micro with new machines * Tooling inserts with conformal cooling * Metal parts in graded materials
High				
Market growth rate				
Low	🐮	* Investment castings (indirect method) ● Jewels * Low volume plastic parts in PA (12% glass) and ABS ● Custom design, hearing aid devices ● Dental teeth alignment devices		🐴 * Polyurethane castings (indirect method)
		High	Relative market share	Low

Figure 4.2 Product portfolio: ● Products * RM Technologies

Figure 4.2 shows examples of RM products and technologies and an evaluation of their present placing on the market.

The most successful RM products are custom-designed hearing aid devices (e.g. Widex, Phonak, Siemens) and dental teeth alignment devices (Invisalign).

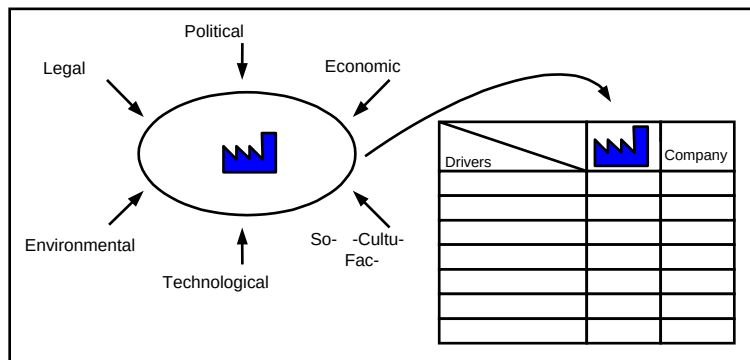


Figure 4.3 Macro environment gives a survey/picture of the external elements that companies have to consider.

Why is the RM technology so interesting for the industry? The following drivers imply that the production basis is 3D data.

Drivers:

Fast change of products
 Individualised products
 Global market
 Features
 Time to market
 Products in many variants
 Fast change of technology
 Product on-demand

The concept of RM offers a lot of benefits:

Without tooling the cost and time for producing moulds, and dies is eliminated
 Design freedom where any design can be produced
 New material combinations
 Customized products
 On-demand production/just-in-time production
 Decentralised production
 Low volumes down to one-off

Values for the companies using RM:

- In the R&D process, RP&M secure fewer mistakes, fewer changes, better and faster decision-making, more tests are made faster and cheaper, better quality of the end product, and shorter lead time.
- No tooling is needed to start production of a new product (Ramp Up) using RM technology or a new RM re-designed product. The market of the new product can be tested with low cost. When the product is successful on the market, the company can invest in tool-

ing if necessary.

- Optimized design by using FEM, CFD and other CAE tools means that less material will be used for the product.
- Any geometry that can be designed and produced means new product design possibilities.
- Internal geometries such as conformal cooling channels in tooling inserts can be produced. This will lead to better quality of the product and less cycle time or more capacity.
- Parts can be produced in many different materials such as metal, plastic, ceramic, sand, wax and starch.
- New material combinations are possible – Graded Materials – which in the future will provide us with new product design possibilities and material savings.
- No changing cost when the product is re-designed because production data are digital data and no tooling is needed.
- Custom designed products can be produced, home-made design.
- RM re-designs and new RM design will lead to less assembly operations because of fewer parts and more functions in RM parts.
- Assembly fixtures and drilling gauges are very easy to make, which saves a lot of cost and reduces the lead time.
- Spare parts can be made easily, also using scanning and reverse engineering.
- RM micro products have a big potential.
- Minimizing stock cost, production is possible locally.
- Industrial designers have to learn how to design with the RM possibilities.

Present weaknesses of RM:

- RP machines are still prototyping machines.
- No fully automatic RM process exists today where you go from a 3D CAD model to the final part without any manual operations.
- Materials properties depend on building parameters.
- Materials properties depending on building directions (x, y, z).
- Stair case steps on the surface.

- Surface cleaning and polishing are necessary.
- RP&M machines are very expensive.
- No big machines are available. Materialize has built its own – see page 37.
- No testing procedure for one-off RM part is developed.
- Material data of mechanical properties etc. is missing.
- Safety protection gloves etc. must be used for resin machines.
- Materials are not stable as regards UV light.
- Accuracy is not as good as CNC machining.
- Very small details are difficult to make, less than 0.5-0.3 mm.

When will RM not be successful?

- When we continue to think traditionally, materials are the limitation for substituting old design with new RM design.
- To develop real RM automated production machinery will be costly.
- The process will stay at a high level.
- No testing method is approved for RP materials.
- Responsibility of custom-/home-made designed products (legislation).

Example of new business concept is "Housing on-line":

A business concept that is built on an extensive application of IT-integration and Rapid Manufacturing.

Background

Throughout the world, developed products need to have box for electronics or electricity in one or more places. It would typically be a question of control of or communication to the product. It is, however, just as often a matter of "simple" boxes, which gather the electric connections in an orderly and safe manner.

For products that are not produced in large numbers, the engineer would typically choose a box made of plastics or metal, which is more suitable for the purpose. It may not necessarily have all the required features such as input/output, sealing and dimensions, etc. or it may have more features than required. In the first case, a reworking is necessary in order to provide the required features and in the latter one would have "bought" more features than one needs.

Purpose

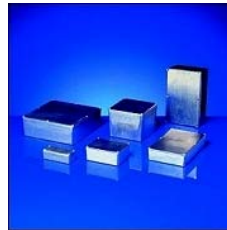
“Housing on-line” offers a service that produces and delivers the exact box one needs - not more, not less.

Content

By connecting a web-based product configuration to a well-working 3D CAD-system and Rapid Manufacturing technologies, the required services and functions are provided.

Step 1:

The user logs on to the web service and choose a product family:



The features are then specified:

Materials

Dimensions

Cover, degree of sealing, sealing and assembly method

Number of outlet/inlet, size, location, design

Attachment principle and location, etc.

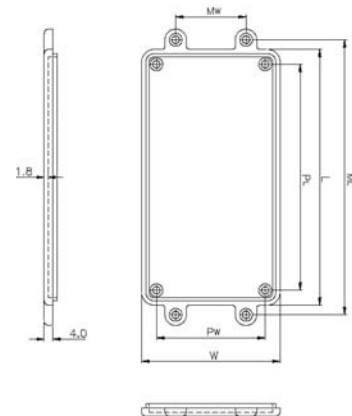


Figure 4.4

Step 2:

The chosen parameters are related to the product configuration and forwarded to the CAD-system, which automatically creates the product with corresponding 2D and 3D documentation.

The created documentation is returned to the user on the website and is shown to him both in 2D and 3D. The user may now choose to verify the product on the website or to download CAD-files for his/her own use so that he/she may incorporate the geometry in his/her own CAD-model of the product, which is being developed. If necessary, the specification is modified after the web verification or after the user's own CAD-verification. Alternatively, the product is ordered (as a prototype, if necessary). In both cases this is done by giving an order number of this exact box.

Step 3:

As mentioned, ordering of a physical product is done by giving a unique number, which is issued along with the previous configuration of the product. When the number is given one may choose between the following:

- 1) Ordering of a part (rapidly delivered model for check of dimensions, assembly and other features). Price and time of delivery of the part may be calculated online instantly.

After physical verification.

- 2) Ordering of a number of metal products (boxes are produced in almost any thinkable metal by means of casting based on masters made by means of a RP&M technology). Price and time of delivery of the part may be calculated online instantly.
- 3) Ordering of a number of plastic products (boxes produced in for instance polyamide, polyamide with glass, ABS, PC, etc. by means of a Rapid Prototyping technology). Price and time of delivery of the prototype may be calculated online instantly.

Additional orders are also made by giving the number, cf. the above-mentioned.

5 Design Freedom with RM

The advantage of RM is that it is possible to design and construct any complexity without any limitation such as tooling, because tooling is not needed. When RM is applied to manufacturing processes, the possibilities for new innovative product design and manufacturing will be immense.



Photo 5.1 New lamp design from Freedom of Creation in Holland

The ability to manufacture any shape that is created in a 3D CAD-system is leading us into a new era of Manufacturing for Design (MFD) instead of in conventional design and production where the restriction was Design for Manufacture (DFM), see photos Photo 5.1, Photo 5.2.

This design freedom will be one of the most significant elements of RM. Parts with complex shapes and features are delivered in less time and at a lower overall manufacturing cost.

The elimination of tooling also has the benefit that the need of producing thousands of parts to spread the burden of amortised cost of tooling is eliminated. Thus, the opportunity of cost-effective, custom-manufacturing becomes an attractive option. When a single part can be produced with no tooling costs, widespread customization is feasible, creating greater customer satisfaction.



Photo 5.2 Laser-sintered fabrics, design of Freedom of Creation, Holland

6 Criteria for products suitable for RM (when to use RM)

Rapid Manufacturing is no doubt of increasing interest as an alternative to conventional technologies, but - how is the designer to know if RM is a feasible alternative in a certain case? Or is it the production planner who should have the knowledge and make the decision?

As RM technologies are still quite un-known and include many new features and properties, there should be careful considerations before decisions are taken. Designers, production planners, material specialists and others should be involved. There are no simple rules of thumb as to whether RM is the right choice for a certain part, but there are indications which should trigger a deeper investigation.

In principle there are three main reasons for considering RM:

1. Improved properties or entirely new features are possible for a component, which open up for new or better design solutions. Most likely the part is designed differently than it would have been without RM. Low cost of the component is less important than its performance.
2. A faster, more direct, tool-less process chain leads to lower cost of component than with conventional methods. RM is simply the most economical manufacturing method at hand. This case includes series production of low numbers up to, if they are small, maybe thousands of parts.
3. Individual design - short series, for some products only one, of highly individualized parts but still economically feasible due to RM. The key-words in this case are Low Volume + High Value. The RM based individualization is part of what is since long called Mass Customization, but RM brings with it an enhancement of this concept.

These three main reasons will be discussed in this chapter.

6.1 Improved properties/new features of parts

Change the mentality

Design For Manufacturing has been an important concept for improving the producibility of parts, and it has taken a lot of effort to bring about a reasonably wide-spread use. Nevertheless it is time now to introduce new concepts to serve as alternative targets for designers. Design For Function, without many of the restrictions imposed by producibility demands, should be a leading star!

With RM as the manufacturing method, a number of present restrictions simply don't rule anymore, e.g.:

- Complexity is not to be avoided – it is OK and may give a competitive edge!
- Radii that are not functionally required but had to be introduced for manufacturing process reasons can be removed.
- Draft angles, nearly constant wall-thickness, split line location and other restrictions enforced by injection moulding may be abolished.

Still – some restrictions, but others

However there are some new rules that have to be taken into consideration, e.g.:

- In general, it is desirable to keep the part height low as this a very decisive factor for the manufacturing time and thus the part cost.
- It is also important to reduce the part volume, i.e. the amount of material in a part, for the same reason. Luckily the opportunity for material reduction through creation of internal cavities without complicating things is excellent.
- To minimize postprocessing, minimal supports should be aimed for. For example one should try to choose such angles for overhangs that they may be built without supports.

Aim for improvements!

“What if....?” is a question which should be used a lot when contemplating whether RM is a path to take. Below are listed some factors where each one increases the probability of RM being worth looking at as a manufacturing alternative, and that is for functional reasons:

- What if a certain functional problem had no geometrical restrictions – which solution would then be preferable? Can we combine five parts into one complex, leading to no extra cost and with an improved material flow? Can we include joints and flexible areas in this one part to save manufacturing time and costs? Can we reach a better or more attractive solution through utilizing really freeform geometry? In Photo 6.1 Many parts have been integrated in this vacuum-gripper for removing fresh parts from an injection moulding machine. This patented solution from Acron is an example. is an example of a very efficient - without being advanced – solution which this way of thinking may lead to in practice.
- What if a really lightweight design could be obtained? RM offers new ways of reducing the material in a part. A good start is to look at the part as a connection between the important functions of the part and then in principle add material just where it is needed to provide the required strength. To reduce the material, internal cavities and channels can be distributed freely (as long as there is some way of getting the unprocessed material out of the part). Thin walled parts may thus meet the loads and stresses and provide the required rigidity with little material and optimal shape. Would this lead to a functionally superior solution?
- What if it were possible to have different material properties in different sections of a part? So called functionally graded materials are ideal candidates for applications involving e.g. strong thermal gradients or a need for a protective surface through impact or wear-resistant outer layers. Products, e.g. indexable tool inserts, are manufactured today by special heat treatment of the surface, but then with the grading possible only perpendicular to the surface. RM however holds the promise of enabling changing properties in any direction and thus make possible a “free” integration of material and structural considerations in the component design. Early applications are likely to be high-value components such as turbine blades, armor protection for military applications, fusion energy devices and aircraft and aerospace parts.



Många fördelar med Acrons
patenterade Gripsystem

- Lägre vikt
- Integrerade vakuumkanaler
- Inga slangar
- Korta ställtider
- Reducerade cykeltider

Photo 6.1 Many parts have been integrated in this vacuum-gripper for removing fresh parts from an injection moulding machine. This patented solution from Acron is an example.

6.2 Faster, tool-less process chain

Volume production

When is RM a purely economically competitive manufacturing method for series of parts, i.e. not only a few but hundreds, maybe thousands? The competition that RM is up against is mostly different forming manufacturing methods. Figure 6.1 shows a simplified calculation of the cost of parts made by injection moulding and RM (in this case laser sintering) respectively. Disregarding the figures on the axes, the diagram can be seen as a principal and general description of the relation between RM and manufacturing with forming methods. So, simply put RM is competitive when the number of parts to be made is lower than what is needed to justify the cost of an injection moulding, forging or some other kind of tool.

Influencing the development is also the general market trend for more product variants being demanded and offered, leading to shorter product lifetimes. This in turn leads to smaller numbers of those components that are connected with the forming of variants, which means that there are smaller numbers of components to form the economical basis for the production of tools.

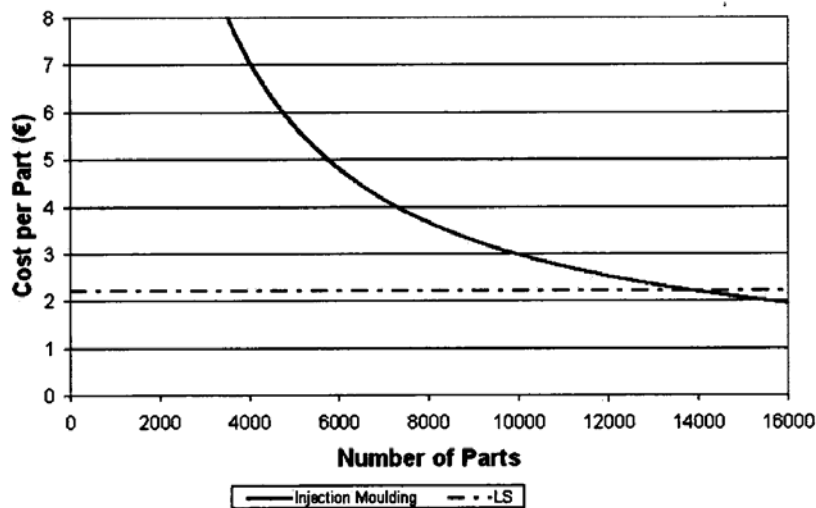


Figure 6.1 Break-even analysis comparing laser sintering with injection moulding.
Source: Hopkinson and Dickens (2003)

Another factor changing the break-even point is the fact that the rate of improvement of the RM technologies is higher than that for more traditional manufacturing methods. Only a few years ago, the probability for RM competitiveness was quite low and fulfilled only in a very limited number of cases. The chances for profitable RM use would then have required that the parts in question

- have a complex geometry
- be small
- be of polymeric material
- have low demands on surface finish and preferably be hidden and not visible during use
- have modest requirements on strength.

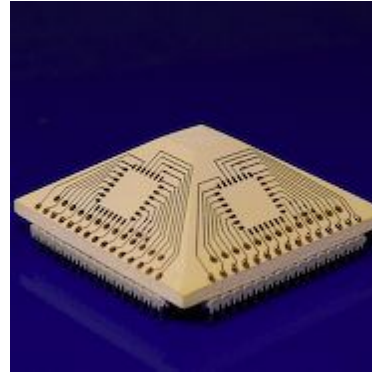
Already today the situation has improved a lot. While the first factor is still valid, it is now possible that the material is steel or some other metal, that the resulting surface is quite good and that the part strength is enough for rather demanding applications. Regarding size, see below.

As an example, the company **fcubic** offers the following manufacturing service in its present proprietary equipment: Parts made in stainless steel (316L), titanium or tool steels at a speed of 1000-2000 parts per day for a part size of 10 mm maximum dimension. The process has a resolution of 35 microns and the surface finish is typically around 4 microns (Ra). Typical parts suitable for this kind of RM are shown in Photo 6.2.



Microwave filter

Parts made in the fcubic process.



Gyro holder with printed silver lines

Photo 6.2

So, how big is “small”? In the fcubic case, the parts should be maximum 10-20 mm in size for optimal quality. This restriction is due to present process limitations. With most other RM processes, such as laser sintering, parts can be much bigger with an obvious limitation being the size of the build chamber. However, the bigger the part, the likelihood of RM being the most economical method decreases unless there are high demands on the part, which is treated in the next section.

Now the build chamber is not only the absolute geometrical restriction, but the relation between the volume of the build chamber and the part geometry also controls the economy of RM in a certain case. The packing ratio, i.e. how efficient parts can be fitted into the build chamber is of big importance for the cost of the manufacture. In fact, this is a restriction which should be taken into account when designing a part for RM. Obviously, the bigger the parts, the more critical is the nesting of the parts to be made and the higher is the risk that a part is just a little too big or too “bushy” to allow efficient utilization of the available volume. In Figure 6.2 it is shown how for a certain part the cost is fluctuating when one more part is to be made than what there is room for in a line, a layer or a bed (build chamber).

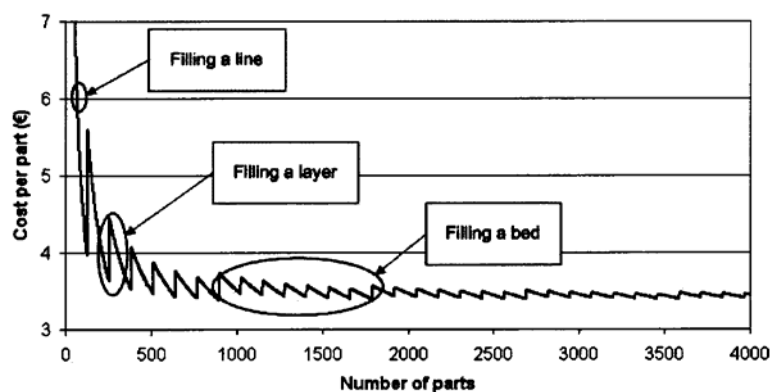


Figure 6.2 Production curve for a RM manufactured part.

Source: Ruffo, Tuck, Hague (2006)

An interesting question when it comes to filling the build chamber in an optimal way: Is it always best to keep the part height down and position parts as horizontal as possible? A comparison for some simple box type parts is shown in Figure 6.3. What is evident is that

the optimal positioning varies with the number of parts to be made. When planning the manufacture, it is almost certainly of value to take this issue into account.

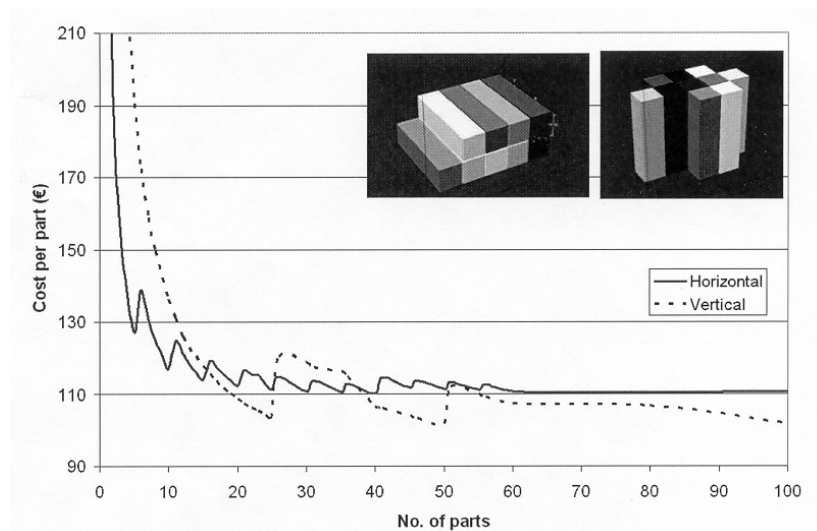


Figure 6.3 Effect of different orientations on the cost.

Source: Ruffo, Tuck, Hague (2006)

High performance components

So far we have discussed RM for parts in rather large numbers, but RM may also be the most economical method for single-part production if the requirements on the parts are high and they are made from expensive materials like e.g. titanium. Such components are time consuming and expensive to produce using subtractive methods as for aircraft and aerospace parts there can be a ratio as high as 15:1 between blank and finished part. Near-net shape, possible to make with RM, must be highly desirable in such cases where the volume/weight ratio is high. Figure 6.4 shows in principle how a RM system, in this case LENS, has a clear niche for those parts where conventionally a lot of material is converted into chips.

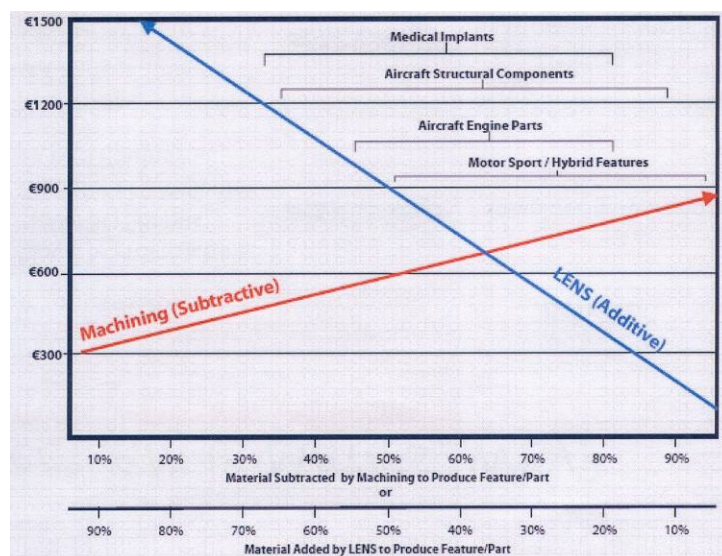


Figure 6.4 An additive method is preferable when otherwise most material is removed.

Source: LENS

Some metallic RM processes like the Arcam EBM process have the capability of producing functional components in materials such as titanium and cobalt-chrome. Material proper-

ties are comparable to bar stock material with corresponding performance for static strength, fatigue strength, fracture toughness, notch sensitivity, corrosion resistance and other properties. Some data for a certain titanium grade are given in Figure 6.5.

	Arcam Ti6Al4V ELI	Ti6Al4V ELI Required*
Yield Strength (Rp 0,2)	910–940 MPa	795 MPa
Ultimate Tensile Strength (Rm)	950–990 MPa	860 MPa
Rockwell Hardness	30–35 HRC	30–35 HRC
Elongation	14–16%	10%
Fatigue strength@600 MPa	>10,000,000 cycles	>1,000,000 cycles
Modulus of Elasticity	120 GPa	114 GPa

* ASTM F136

Figure 6.5 Comparison of data for a certain titanium grade, Arcam and cast.

Source: Arcam.

Of course these rather exclusive materials, where RM has a clear edge, have a limited application range, but important fields of use are a.o. biomedical implants, aircraft components and cryogenic and marine applications.

Two examples of successful application are shown below.



Photo 6.3 Drill-bit and impeller, made using the Arcam EBM process.

6.3 Individual design - Low Volume, High Value

The area of individual design is probably where, on a short term, the main business opportunities for RM application are. Today there are many people wealthy enough to be able to buy products with an extra touch of “very special”. Leaving aside the very important area of medical parts, fields of increasing interest are leisure and luxury items of varying kinds but also others.

Today general Mass Customization, in the form of built to order with individual additions is already happening . However, current forms of customization are quite limited most often to selecting from a predetermined list of options. The next stage of customization that RM may bring about is about letting the customer enjoy much more creative design freedom. The general idea is to make products convincingly attractive to the customer, to increase the product value through higher functionality and/or attractive design and reduced delivery times. The attraction may increase the more the customer gets involved in the design of his or hers future purchase and gets the chance to transfer ideas into concrete objects.

An example is an Austrian ski manufacturer whose skis in the upper quality segment can have their topsheet interactively designed by the customer and thus look perfectly personal, at no extra cost.

Much more advanced individualization is underway. A lot of research is carried out in the automotive field to pave the way towards custom seats, steering wheels, gear knobs and hand brakes built to individual requirements, for comfort as well as safety reasons. The vision is to have the customer design the interior of the car the same way he or she decides about the interior of the new kitchen.

A research project of high interest is Custom-Fit which is a European project to develop a new knowledge based design and manufacturing process for customized products which integrates Rapid Manufacturing, 3D Body Scanning, information technology and material science. The aim of Custom-Fit is to create a fully integrated system for the design, production and supply of individualized products. These products are customized to fit the requirements of the consumers, both geometrically and functionally. The parts or components will be produced directly from CAD data using Rapid Manufacturing.

Products that will be individualized as a result of ongoing activities include helmets, footwear, bats, clubs, rackets, archery handles, grips and much more. Personal Protective Equipment, both for sports and for e.g. police officers is also of interest.

Summing up

To sum up, RM technology will not replace the traditional, tooling-based methods of manufacture for a long time and probably never. The role of RM, which will increase steadily for many years is as a compliment, to be used where from a holistic perspective it is the most economical solution. It may be the result of a pure calculation, it may be the result of a trade-off between functionality-leadtime-part cost or it may be new business opportunities that lie behind the final decision. In a steadily, maybe even rapidly, increasing number of cases, RM will be the choice.

7 Process Chains for Plastic and Metal Parts

7.1 Design for RM of Plastic Parts

Loughborough University, Richard Hague, has made a design study comparing traditional design for injection moulding with design for RM, see Figure 7.1.

The RM design study demonstrates clearly design freedom in style and shape and the possibility for material reduction.

Figure 7.2 and Photo 7.1 show the process chain for making plastic parts with RM, RM mould insert and traditional CNC and EDM method.

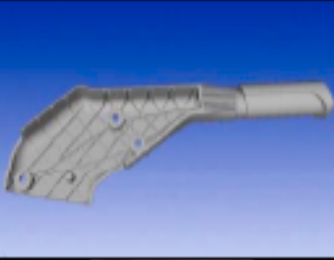
Design for Injection Moulding		Design for Rapid Manufacture	
Disadvantage	Sample Picture	Advantage	Sample Picture
Mainly flat surface		Attractive and stylish shape	
Constant wall thickness		Non uniform wall thickness	
A bulky design due no optimisation		12% reduction in weight despite double sided nature of design	
Heavily ribbed to comply with DFM criteria		Selectively reinforced to comply with design specifications	

Figure 7.1 Comparison between design for injection moulding and RM. RM design study. Courtesy of Richard Hague, Loughborough University, UK.

Process Chain - plastic parts

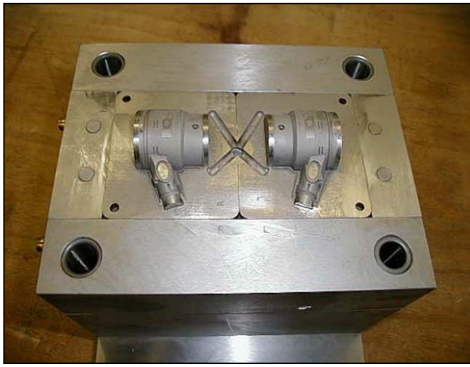


Photo 7.1 RM plastic injection mould inserts

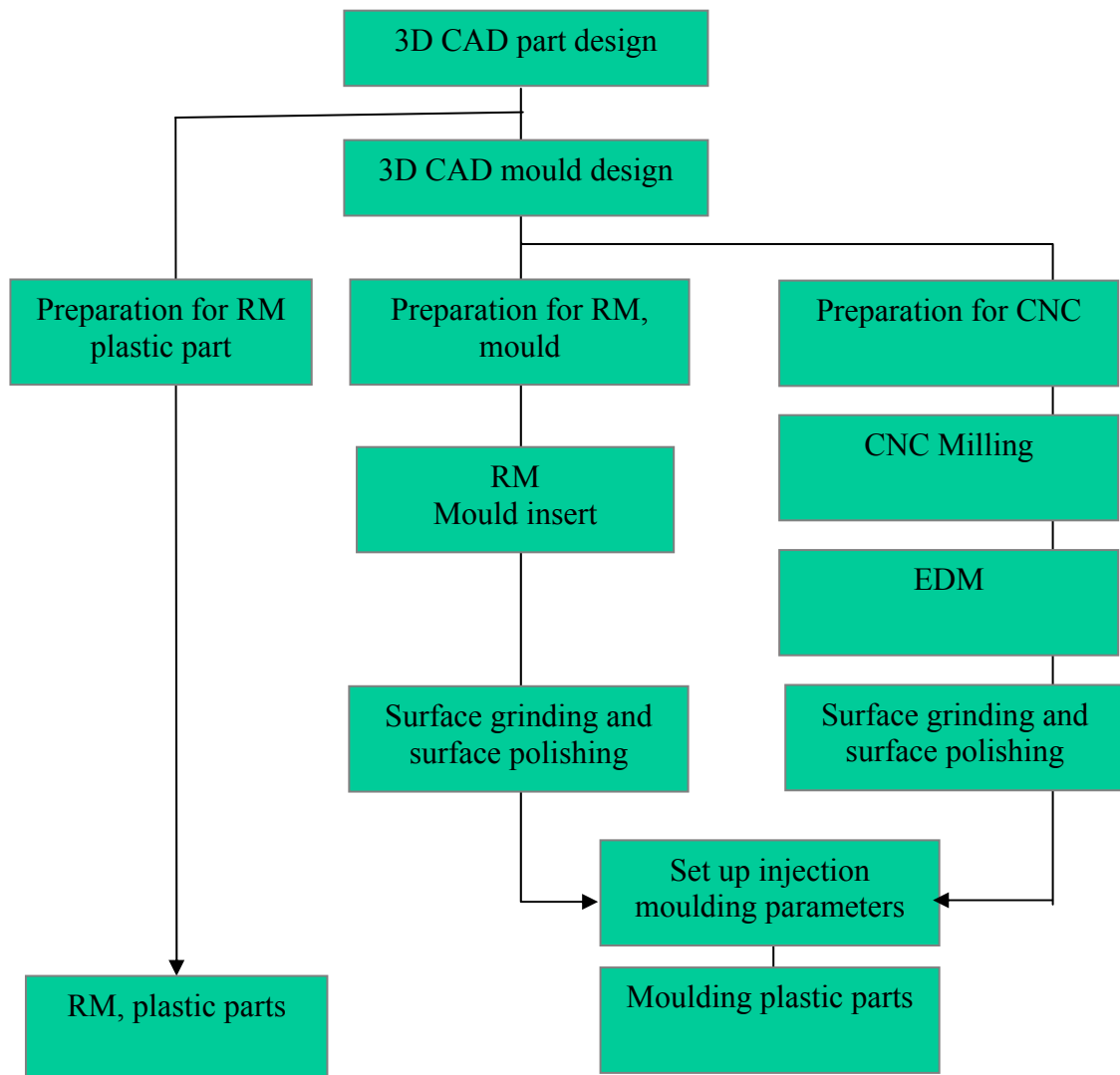


Figure 7.2 Process chain – making plastic part using RM. RM for making tooling insert and traditional CNC milling.

7.2 Design for RM metal parts

To determine if RM is suitable for a given part, it is important to consider the following main factors: part, shape, size, production volume, part quality, tolerances.

When it makes sense to use RM

Examples of application are illustrated as follows:

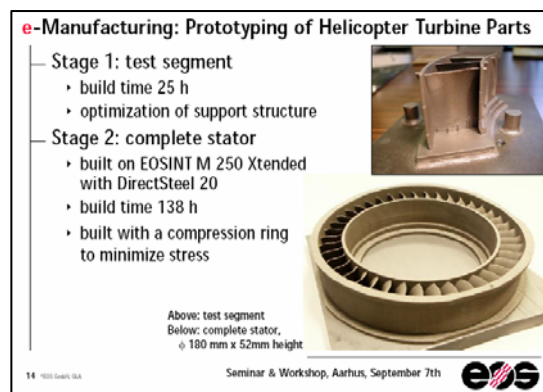
RM of metal parts.
RM of metal tooling inserts.
RM of metal casting parts (indirect method)
Re-design of metal casting parts
Re-design of plastic parts.

RM of metal parts

Metal parts from Arcam and EOS for the aerospace industry:



Figure 7.3 RM of metal parts – titanium



RM metal part – DS 20 (EOS)

RM of metal tooling inserts

Tooling of inject moulding:

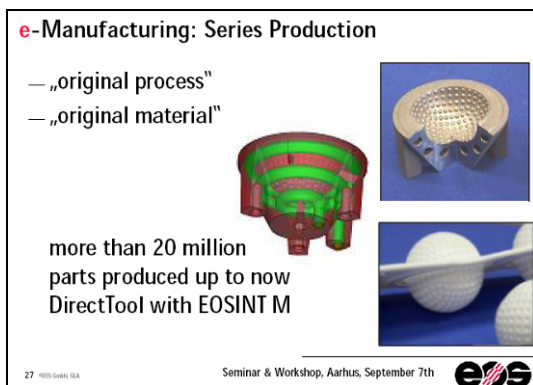
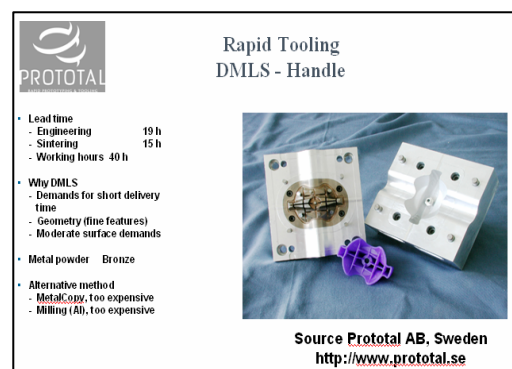


Figure 7.4 Tooling part (EOS) with conformed cooling



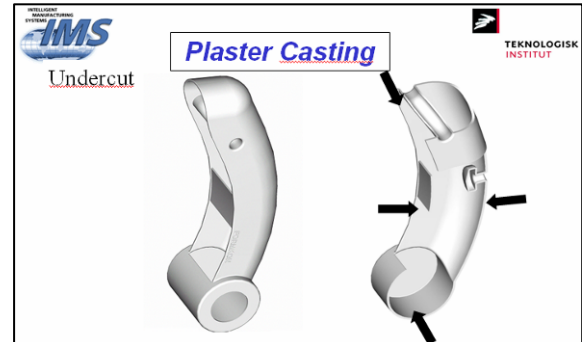
Protototal part with a metal copy insert

Metal Casting Parts

Aluminium plaster cast part from a polystyrene model (Formkon):



Figure 7.5 Plaster cast parts made of aluminium (Formkon)



Re-design of metal casting parts

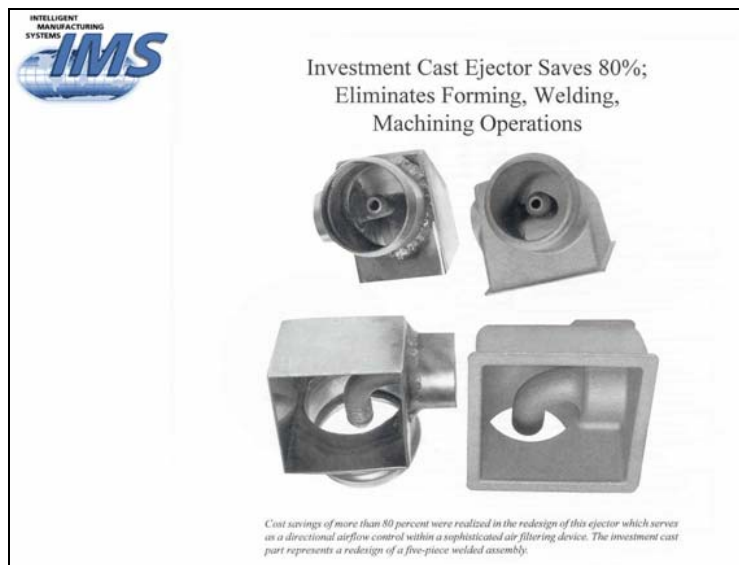


Figure 7.6 Redesign from 5 parts to 1 made by investment casting

The investment cast ejector is a prime example of the advantages of the process. Multiple part assembly is eliminated and additional labour intensive machining and welding operations are unnecessary. Cost savings of more than 80% due to the elimination of expensive forming, welding, and machining operations.

The investment cast part represents a redesign of a five-piece welded assembly consisting of a custom-formed sheet metal box, a bulge-formed, thin-walled tube, a custom bent, thick-wall tube, and two machined components in 304 L stainless. The centre nozzle section of this casting contains two undercut features, requiring some innovative casting techniques. Water soluble cores were employed to achieve the undercuts. This is a very cost-effective means of producing complex internal configurations.

Figure 7.7 shows the process chain for investment casting parts.

Process chain – metal casting parts



Photo 7.2 shows the wax part and the metal part.

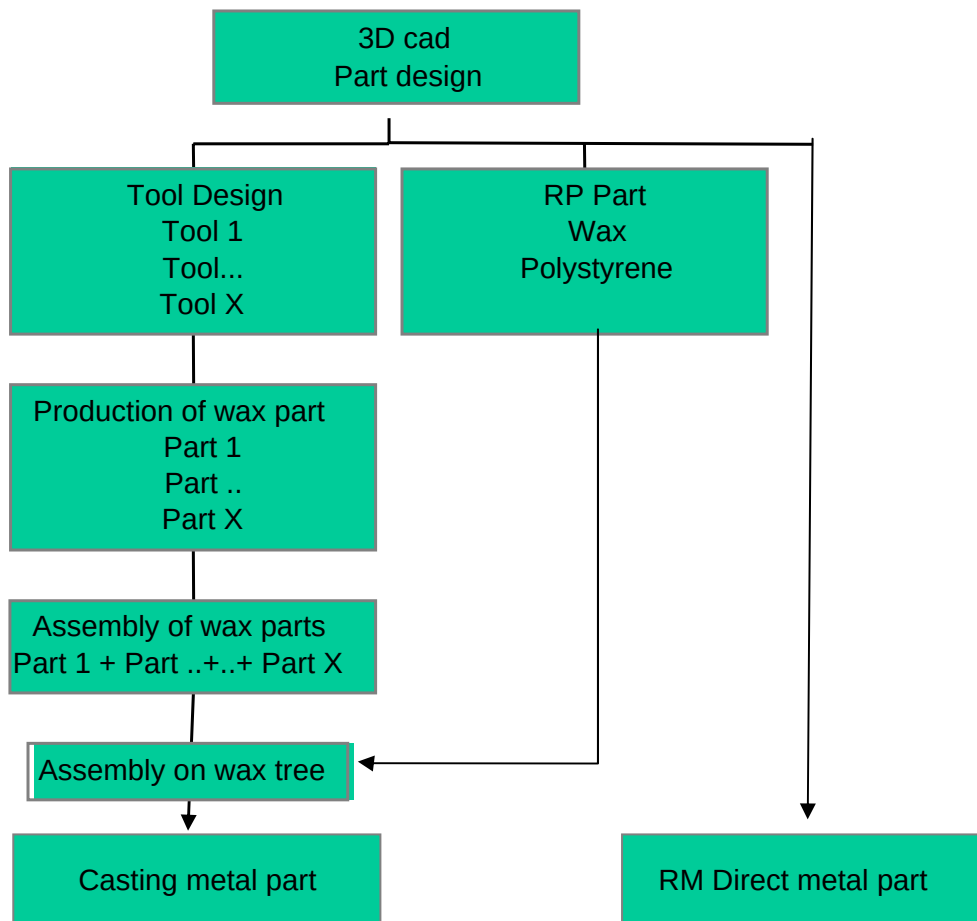


Figure 7.7 Shows the savings of process steps when using RP/RM of a wax or polystyrene part. RM direct metal parts are limited in size and choice of materials.

8 New potential application areas

Looking at the future of Rapid Manufacturing, there is a general trend towards improvement from three very important aspects:

- The list of available materials is constantly prolonged for all processes and vendors as new materials are being introduced. These new materials are improved in one or more of many aspects: stronger, more flexible, more rubber-like, more transparent, more heat resistant, finer grain-size, in new colours etc.
- The accuracy and surface finish which the different processes deliver is higher for each year.
- The manufacturing speed of the processes is increased through different measures which are partly hardware changes, partly process enhancements realized in software. More of this will come as system developers are trying to automate the process steps that follow the core process to a higher degree.

All these improvements combined with other benefits of RM such as the accelerated route from design to manufacture open up possibilities for stronger or new applications and new opportunities to add value. In this chapter, we will look at some examples of such new areas where utilization is in an early phase or is expected to happen soon.

8.1 Manufacturing aids

Manufacturing aids like jigs, fixtures and assembly guides are made in short series, often one, but in total in large numbers, of course in companies like car manufacturers but also (relatively speaking) in injection moulding companies and many others. Traditionally it is a very manual type of manufacturing where little use is made of the fact that the CAD data of the product are what directly should be used for designing and manufacturing the fixtures etc that will be needed for the final production.

Some have started. BMW have used FDM for making many fixtures and assembly guides for manual production. One aim has been to make the tools ergonomical which has been easy with RM techniques. A bonus has been savings in both weight and money. Another example is Boeing that has used RM to produce composite tooling and manufacturing aids such as drill plates.

A very nice example is the Swedish service bureau Acron Formservice that have introduced a patented gripper system to be used for extracting hot and soft fresh parts from injection moulding machines. Apart from having a very short design and manufacturing time, the grippers are functionally better as the vacuum channels are integrated in the grippers which makes them much slimmer with a better reach, see example below.

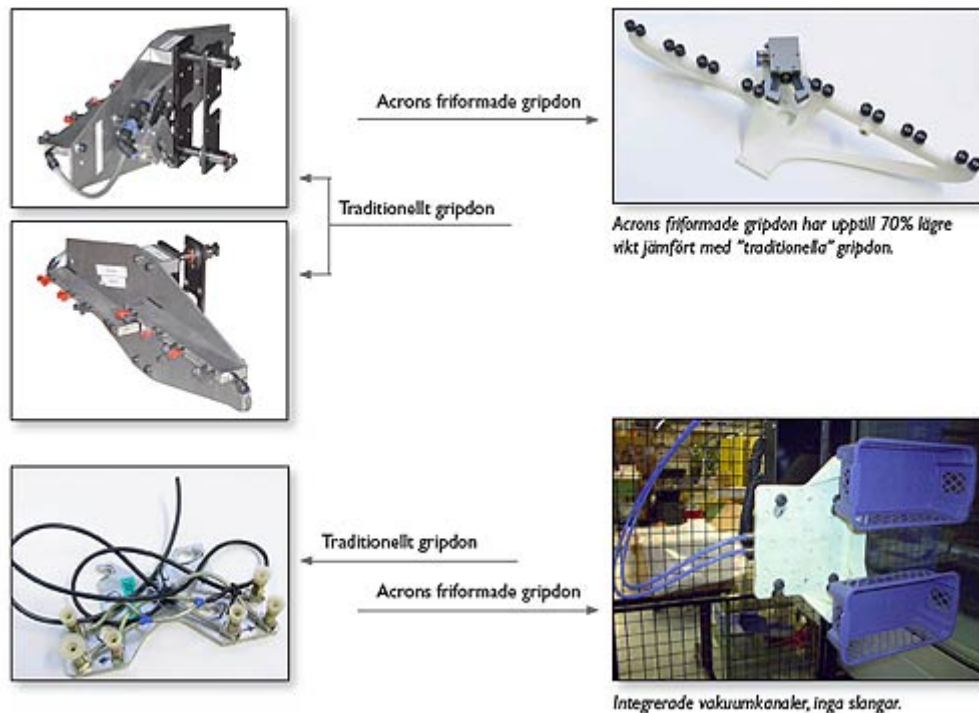


Figure 8.1 Example from Acron Formservice

8.2 New functionality

The possibility of RM to provide parts with graded and mixed materials as well as the ability to combine different materials such as metals and ceramics means that new functionality is within reach. The properties of metal-matrix composites allow designers of e.g. combustion engines to work towards enhancing the performance to new levels. We will hear a lot more about developments of this kind.

8.3 Optimal utilization of the material

Complex metal parts in low volumes are typically manufactured by casting and machined, however this takes a lot of machine time and man-time, with a very long lead-time. RM means that a near-net shape part can be built in days with very little final machining.

Also the geometrical freedom offers new possibilities. An especially interesting possibility is for lightweight design as it is possible to optimize the balance between material and part strength through freedom in localization of material and introduction of lattice structures and internal cavities. Obviously this is of particular interest in applications where weight is a major concern such as racing cars or aircraft.

8.4 Making use of porosity

Several RM processes are powder-based and produce parts which are not fully dense but somewhat porous. Most often this is unwanted in the final part and infiltration or other action is used to get rid of the porosity. However for some types of products, porosity is required and RM is beginning to be considered an efficient way to produce such parts.

One such product type is filters for gases and liquids for which a porosity whose properties are possible to control is vital. Often the geometrical complexity of these filters is high which makes this an even more suitable RM application. Another, rather similar, application is gas storage cells. The big potential here is storage of hydrogen for fuelcell-powered cars and other vehicles. Still another interesting field is batteries. They are layered in shape which fits well with RM techniques, and if the porosity is controlled, it is possible in principle to increase the power density.

8.5 Small, smaller...

The Swedish company fcubic has developed a process to produce metal parts using ink-jet technology. The process is developed with the goal to transfer layered manufacturing from prototyping to a high volume production process for small parts, up to 10mm in size. Today 1000-2000 parts per day can be made but development of a faster process is underway. The parts are made from a fine stainless steel powder (316L) and are sintered to full density. Other steels and metals such as silver and titanium are possible to manufacture. The resolution of the parts are approximately 35 microns and the surface finish approximately 4 microns (Ra). With this accuracy, both decorative and technical parts are well within the scope for real RM.



Figure 8.2 Chess pieces



Figure 8.3 Small turbine wheel in stainless steel

Even smaller parts have long been made by microstereolithography in polymers by the German company microTEC and in real mass production – up to 150.000 parts per hour. Also this process develops and e.g. parts in ceramic-polymer composites can now be made. Such microparts have interesting properties for microrobotic or microfluidic applications.

8.6 Body shape adapted parts

Custom design of medical and dental products

The medical area is not a new application for RM, on the contrary it is one of the first and most successful with custom-fitting hearing aids and dental devices being probably the most well-known. When it comes to actually having implants inside the human body for many years of remaining life, the demands from different aspects get very high to ensure safety. Although titanium, cobalt-chrome and other metals have been proven acceptable to the body, it is not evident that the properties of RM made implants are fully comparable to conventionally made:

- Necessary requirements are that the surfaces of the objects result completely solid and smooth so that they can be completely cleaned.
- RM parts made from powder may remain somewhat porous which could be too good a place for bacteria, leading to infections.
- Powder-based processes may also have an inherent risk of particles getting on the loose inside the body which would be hazardous.

Nevertheless, as the understanding of these important remaining problems gets deeper, many more applications than the present will be possible in the medical field. The advantages of individualization are so obvious for implants for knee or hip joints, for repairs of bone fractures from accidents or congenital deformities, for critical devices etc.



Figure 8.4 Individual boneplate made in Arcam EBM process

Sportswear

In the upper prize segment of sports wear, there are many applications for individualized RM parts. Football shoes with perfect adaption for the individual may be expensive but using RM not impossibly so. There are many possibilities for making golf or tennis clubs more comfortable and efficient through adaption to the individual's hands.

Personalized awards and gifts

The design company Freedom of Creation (FOC) has shown the way to a wide variety of decorative objects with a purpose. They have designed and produced many examples from exclusive give-away products such as paperknives or paperclips with a twist of impossible shape to very exquisite packaging for luxury cosmetics.

8.7 Art, craft

Architectural Models

There is a large application area for RM in the architectural field - there is almost always a need for a physical model in planning and construction projects and they are expensive and time-consuming to build with present, mostly manual, methods. Still this application has not quite taken off and one main reason is that the requirements of such models are quite different from the mechanical and medical models which have so far dominated the RM scene. The main difference is that architectural models are usually built in 1/100 or 1/1000 of real size leading to many elements such as roofs resulting absurdly thin if built in scale. Also the database of a full object usually contains many details without interest for the purpose of building but complicating the build procedure. So, the obstacle for using RM widely for architectural purposes is not the available RM processes but rather the CAD software where development is needed (and underway). When this situation is improved, the built volume of architectural models is expected to become very high.

Architectural Components

RM offers at least two new possibilities when it comes to architectural components: They may be produced in new aesthetic shapes and be made stronger with less material. External shape freedom may be combined with components having high strength-to-weight ratio, e.g. through optimized lattice structures. Just think about the well-known un-finished church Sagrada Família in Barcelona: If RM had been within reach for the architect Gaudí, probably the cathedral would have been finished long ago – and even higher!

Sculpture

A growing number of sculptors are using RM technology as a means to express their artistic intentions. An interactive example of this has been realized by the Swedish artist and designer Jens Evaldsson, "Visual poetry", who at the exhibition "From Reality and Back" populated a virtual universe where the visitors were taking part – they were scanned and, down-scaled, manufactured by RM techniques. Other examples are to be expected from this very creative category of RM users.

Jewellery

Jewellery is a growing field for RM. So far, most work has been carried out by the use of secondary processes, i.e. making a model in a soft material and then using investment casting. More direct RM however is on the verge of being economically justified – especially as the result is so beautiful: The process fcubic described above has been used by

the creative designer Janne Kyttänen of Freedom of Creation to take new steps in jewellery design, making use of the very fine detail of the system.



Figure 8.5 Decoration, FOC, Spinn 10, Janne Kyttänen



Figure 8.6 Decoration with Gold coating, FOC, Heart, Janne Kyttänen

8.8 To sum up

The possibilities for new applications are continuously improving. Although the use of RM is continuously increasing, the potential is such that it could be used much more already today. The main obstacle for a wider use of RM potential lies in the mindset of mechanical designers, production planners, artists etc. which in general has not yet been opened to this widening array of opportunities.

9 Materials for RM - Guide for selection of Materials

Introduction

Rapid Manufacturing, (RM) has been defined as the manufacturing of end use parts by an Additive Manufacturing process. In principle this means that any application of Additive Manufacturing for end use purposes potentially could be considered as RM, it is simply up to the user. This materials selection guide takes an open approach to this and has included a wide array of materials from different suppliers, unless the clearly declares that their system or material primarily is intended for visualization or prototyping purposes. This has meant that some mayor systems (such as Z-Corp) are not represented in this guide, since their technology traditionally is used for prototyping and visualisation purposes as is clearly stated on the company's home page.

The data presented in this guide has been gathered from what has been made available on the Internet and through other channels. Since there is an intimate coupling between materials and process in an Additive Manufacturing process, they are not intended to be seen as absolute but rather as typical values published for the purpose of comparison. Many properties are highly influenced by process parameters during building which makes any prediction of material properties rather uncertain unless it is coupled to fixed process conditions. Several suppliers do this, but not all, so for those that have a particular interest in the properties of specific materials in a certain process it is recommended that they contact the suppliers of systems and materials. Furthermore, in a layered approach to Additive Manufacturing, which most commercial systems indeed are based on, there may occur anisotropic material properties, which means that the material can be stronger perpendicular than parallel to the building direction. Again this effect can be dependent on the build parameters.

For a liquid phase (melting) based Additive Manufacturing process in metallic materials, it is in principle possible to use any weldable material, which also is a part of the business strategy of some systems. For this reason are not systems such as MCP-HEK Realizer, DMD, Phenix Systems and 3DMicroMac represented in this guide, but this does not mean that these processes in any way should be less suited for RM purposes, only that the vendors have not made the material properties data available. It can however be assumed that the material properties produced by these systems are similar to those produced by similar systems. Again this guide is intended for the purpose of comparison, and to make the present capability for the manufacturing of functional end-use parts of the modern Additive Manufacturing systems and materials visible to the reader. And perhaps give a more realistic picture of the technology's present status and thus make the step to start exploiting the many possibilities of Additive Manufacturing for functional purposes seem less like a jeopardy. However, there is rapid progress in the development of new materials and processes, so it is very possible that new materials have been launched since this guide was completed and that some older, but still available materials have been overlooked. This, and all other possible mistakes, is entirely unintentional, and provided that time and funding will permit, this guide will be updated over time.

ABS and ABS-like Materials; FDM system

Property	ABS, moulded <i>www.matweb.com</i>	ABS Strata- <i>sys</i>	ABSplus <i>Stratasys</i>	ABSi Strata- <i>sys</i>	ABS-M30 <i>Stratasys</i>	PC-ABS Strata- <i>sys</i>
Tensile Strength	20.0 – 65.0 MPa	22 MPa	36 MPa	37 MPa	36 MPa	34.8 MPa
Tensile Modulus	1520 – 6100 MPa	1627 MPa	2265 MPa	1915 MPa	2413 MPa	1827 MPa
Tensile Elongation	1.70 – 6.00 %	6 %	4 %	3.1 %	4 %	4.3 %
Flexural Strength	40.0 – 95.1 MPa	41 MPa	52 MPa	61 MPa	61 MPa	50 MPa
Flexural Modulus	1500 – 25000 MPa	1834 MPa	2198 MPa	1820 MPa	2317 MPa	1863 MPa
IZOD Impact, notched	5.00 – 14.0 kJ/m ²	106.78 J/a	96 J/m	101.4 J/a	139 J/m	123 J/a
IZOD Impact, un-notched	3.46 J/cm	213.56 J/a		218.9 J/a	283 J/m	326 J/a
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	90° C	96° C	87° C	96°C	110° C
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	76° C	82° C	73° C	82°C	96° C
Glass Transition Temperature (Tg)	105 -115 °C	104° C		116° C	108°C	125° C
Coefficient of Thermal Expansion	0.80 -139 µm/m°C			12.1*10 ⁻⁵ mm/mm/C	8.82E-05 mm/mm/°C	
Melt Point	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Specific Gravity	1.05 g/cc	1.05	1.04	1.08	1.04	1.20
Rockwell Hardness	R90.0 – 119	R105		R108	R109.5	R110
Flame Classification	HB	HB		HB	HB	HB
Dielectric Strength kV/mm	15.7 -53.0	32			28.0	35
Dielectric Constant @60Mhz	2.00 -3.20	2.4				3.1 (@100Mhz)
Manufacturing Process or Machine	Inj. Moulding	Vantage, Titan, Maxum	FDM 200mc	Vantage, Titan, Maxum	FDM 400mc	Vantage, Titan, FDM 400mc

ABS and ABS-like Materials; SLS system

Property	ABS, moulded <i>www.matweb.com</i>	DuraFormEX 3DSystems	WindformFX ^{CRP} Technology			
Tensile Strength	20.0 – 65.0 MPa	37 MPa	48.96 MPa			
Tensile Modulus	1520 – 6100 MPa	1517 MPa	1357 MPa			
Tensile Elongation	1.70 – 6.00 %	5%				
Flexural Strength	40.0 – 95.1 MPa	42 MPa	45 MPa			
Flexural Modulus	1500 – 25000 MPa	1310 MPa	952 MPa			
IZOD Impact, notched	5.00 – 14.0 kJ/m ²	74 J/m	32.72 KJ/m ² (Charpy)			
IZOD Impact, un-notched	3.46 J/cm	1486 J/m	3.25 KJ/m ² (Charpy)			
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	188 °C				
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	48 °C	47.10 °C			
Glass Transition Temperature (T _g)	105 -115 °C					
Coefficient of Thermal Expansion	0.80 -139 µm/m°C	120 µm/m-°C				
Melt Point	Not Applicable	Not Applicable	190.70 °C			
Specific Gravity	1.05 g/cc	1.01 g/cm ³	1.027 g/cm ³			
Rockwell Hardness	R90.0 – 119	L69				
Flame Classification	HB	HB				
Dielectric Strength kV/mm	15.7 -53.0	18.5 kV/mm				
Dielectric Constant @60Mhz	2.00 -3.20	4.5				
Manufacturing Process or Machine	Inj. Moulding	Sinterstation Pro Sinterstation HiQ	Various SLS systems			

ABS and ABS-like Materials; SLA system, solid state (355nm) laser

Property	ABS, moulded <i>www.matweb.com</i>	14120 White DSM Somos	WaterShed 11120 DSM Somos	WaterShed XC 11122 DSM Somos	
Tensile Strength	20.0 – 65.0 MPa	45.7 MPa	47.1 -53.6 MPa	47.1 -53.6 MPa	
Tensile Modulus	1520 – 6100 MPa	2460 MPa	2650 – 2880 MPa	2650 – 2880 MPa	
Tensile Elongation	1.70 – 6.00 %	3.5%	3.3 – 3.5 %	3.3 – 3.5 %	
Flexural Strength	40.0 – 95.1 MPa	68.9 MPa	63.1 – 74.16 MPa	63.1 – 74.2 MPa	
Flexural Modulus	1500 – 25000 MPa	2250 MPa	2040 – 2370 MPa	2040 – 2370 MPa	
IZOD Impact, notched	5.00 – 14.0 kJ/m ²	23.5 J/m	20 – 30 J/m	20 – 30 J/m	
IZOD Impact, un-notched	3.46 J/cm				
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	53 °C	45.9 – 54.5 °C	45.9 – 54.5 °C	
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	48 °C	49.0 – 49.7 °C	49.0 – 49.7 °C	
Glass Transition Temperature (T _g)	105 -115 °C	44 °C	39 – 46 °C	39 – 46 °C	
Coefficient of Thermal Expansion	0.80 -139 µm/m°C	93 µm/m°C	90 – 96 µm/m°C	90 – 96 µm/m°C	
Water Absorption	0.05 – 2.30 %	0.24 %	0.35 %	0.35 %	
Specific Gravity	1.05 g/cc	1.10 g/cc	1.12 g/cc	1.12 g/cc	
Rockwell Hardness	R90.0 – 119	(Shore D 81)			
Flame Classification	HB				
Dielectric Strength kV/mm	15.7 -53.0	14.6	15.4 – 16.3	15.4 – 16.3	
Dielectric Constant @60Mhz	2.00 -3.20	3.5	3.4 – 3.5	3.4 – 3.5	
Manufacturing Process or Machine	Inj. Moulding	Various SLA (solid state laser)	Various SLA (solid state laser)	Various SLA (solid state laser)	

ABS and ABS-like Materials; SLA system, solid state (355nm) laser

Property	ABS, moulded <i>www.matweb.com</i>	WaterClear 10120 DSM Somos	WaterClear 10122 DSM Somos	HI-REZZ A1850CL SLAMa- terials	HI-REZZ ICE SLAMaterials
Tensile Strength	20.0 – 65.0 MPa	35 MPa	55-56 MPa	54.2 MPa	54.2 MPa
Tensile Modulus	1520 – 6100 MPa	1960 MPa	2860–2900 MPa	2380 MPa	2380 MPa
Tensile Elongation	1.70 – 6.00 %	4.1 %	4%	----(14.7 % break)	----(14.7 % break)
Flexural Strength	40.0 – 95.1 MPa	39.5 MPa	82 – 85 MPa	75.8 MPa	75.8 MPa
Flexural Modulus	1500 – 25000 MPa	2250 MPa	2410–2570 MPa	2000 MPa	2000 MPa
IZOD Impact, notched	5.00 – 14.0 kJ/m ²	48 J/m	24 – 26 J/m	22 J/m	22 J/m
IZOD Impact, un-notched	3.46 J/cm				
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	52.9 °C	46 – 47 °C	50 °C	50 °C
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	45.7 °C	42 – 43 °C	44 °C	44 °C
Glass Transition Temperature (Tg)	105 -115 °C	28 °C	42 – 46 °C	58 °C	58 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	0.80 -139 $\mu\text{m}/\text{m}^{\circ}\text{C}$	101	87.8 – 93.0		
Water Absorption	0.05 – 2.30 %	0.85 %	1.1 %	<0.10%	<0.10%
Specific Gravity	1.05 g/cc	1.12 g/cc	1.13 g/cc		
Rockwell Hardness	R90.0 – 119	(Shore D 81)	(Shore D86 – 87)	(Shore D78)	(Shore D78)
Flame Classification	HB				
Dielectric Strength kV/mm	15.7 -53.0	15.4	14.5 – 15.5		
Dielectric Constant @60Mhz	2.00 -3.20	3.6	3.0 – 3.2		
Manufacturing Process or Machine	Inj. Moulding	Various SLA (solid state laser)	Various SLA (solid state laser)	Various SLA (solid state laser)	Various SLA (solid state laser)

ABS and ABS-like Materials; SLA system, solid state (355nm) laser

Property	ABS, moulded <i>www.matweb.com</i>	ProtoGen O-XT 18120 DSM Somos			ProtoGen O-XT 18420 DSM Somos		
Tensile Strength MPa	20.0 – 65.0 MPa	51.7-57.1	56.9-57.1	68.8-69.2	42.2-43.8	56.9-57.1	66.1-68.1
Tensile Modulus MPa	1520 – 6100 MPa	2620-2740	2540-2620	2910-2990	2180-2310	2540-2620	2880-2960
Elongation at break	2.40 -110 %	6 – 12 %	8 – 12 %	7 -8 %	8 – 16 %	8 – 12 %	6 -9 %
Flexural Strength MPa	40.0 – 95.1 MPa	81.8 -83.8	83.8 – 86.7	88.5 – 91.5	66.7-70.5	83.8-86.7	84.9-87.7
Flexural Modulus MPa	1500 – 25000 MPa	2360-2480	2400-2450	2330-2490	1990-2130	2400-2450	2280-2340
IZOD Impact, notched	5.00 – 14.0 kJ/m ²	14-26 J/m		13-25 J/m	20-22 J/m		9 – 21 J/m
IZOD Impact, un-notched	3.46 J/cm						
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	55 -58 °C	56 -70 °C	95 -97 °C	53 -56 °C	65 – 70 °C	93 -98 °C
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	48 -50 °C	53 -54 °C	79 -82 °C	46 -47 °C	53 -54 °C	74 -78 °C
Glass Transition Temperature (Tg)	105 -115 °C	71 – 86 °C		76 – 94 °C	57 – 59 °C		78 – 96 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	0.80 -139 $\mu\text{m}/\text{m}^{\circ}\text{C}$	84.7 -95.3		75.0 -107.5	101.2-110.3		82.2 -86.4
Water Absorption	0.05 – 2.30 %	0.77 %		0.75 %	0.68 %		0.61 %
Specific Gravity	1.05 g/cc	1.16 g/cc	1.16 g/cc	1.16 g/cc	1.16 g/cc	1.16 g/cc	1.16 g/cc
Rockwell Hardness	R90.0 – 119	(Shore D84 – 85)		(Shore D87 – 88)	(ShoreD 86 – 88)		(ShoreD 86 – 87)
Flame Classification	HB						
Dielectric Strength kV/mm	15.7 -53.0	14.4-15.3		15.2-15.7	13.2 – 14.2		13.8-14.1
Dielectric Constant @60Mhz	2.00 -3.20	3.1 – 3.2		3.2 – 3.3	3.1 – 3.3		2.9 – 3.0
Manufacturing Process or Machine	Inj. Moulding	UV Postcure HOC-2	UV Postcure HOC+3	UV & Thermal Postcure	UV Postcure HOC-2	UV Postcure HOC+3	UV & Thermal Postcure
		Various SLA (solid state laser)			Various SLA (solid state laser)		

ABS and ABS-like Materials; SLA system, solid state (355nm) laser

Property	ABS, moulded <i>www.matweb.com</i>	RenShape SL 7560 <i>Huntsman</i>	RenShape SL 7580 <i>Huntsman</i>	RenShape SL 7585 <i>Huntsman</i>	SCR710 D- MEC	SCR735 D- MEC NPC PC	
Tensile Strength MPa	20.0 – 65.0 MPa	52 MPa	53.1 MPa	40 MPa	66 MPa	45	67
Tensile Modulus MPa	1520 – 6100 MPa				2700 MPa	2510	2720
Elongation at break	2.40 -110 %	11 %	11%	11 %	10 %	6.8 %	6.0 %
Flexural Strength MPa	40.0 – 95.1 MPa	94 MPa	82.8 MPa	57.5 MPa	85 MPa	83	97
Flexural Modulus	1500 – 25000 MPa				2700 MPa	2530	2570
IZOD Impact notched J/m		36 J/m	32 J/m	34 J/m	32 – 38 J/m	29-33	34-39
IZOD Impact, un-notched	3.46 J/cm						
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	58	63	61			
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C		52		49 °C	48 °C	85 °C
Glass Transition Temperature (Tg)	105 -115 °C				78 °C	90 °C	110 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^\circ\text{C}$	0.80 -139 $\mu\text{m}/\text{m}^\circ\text{C}$						
Water Absorption	0.05 – 2.30 %						
Specific Gravity	1.05 g/cc				1.19 g/cc	1.13 g/cc	
Rockwell Hardness	R90.0 – 119				(Shore D: 81)		
Flame Classification	HB						
Dielectric Strength kV/mm	15.7 -53.0						
Dielectric Constant @60Mhz	2.00 -3.20						
Manufacturing Process or Machine	Inj. Moulding	SLA Viper si2, 3500/5000/7000 (solid state laser)	Various SLA (solid state laser)	Various SLA (solid state laser)	SCS-2000, Various SLA (Ar/solid state laser)	SCS-8000, Various SLA (solid state laser)	

ABS and ABS-like Materials; SLA system, solid state (355nm) laser

Property	ABS, moulded <i>www.matweb.com</i>	Accura si 50 3DSystems	Accura 55 3DSystems	Accura Xtreme 3DSystems		
Tensile Strength MPa	20.0 – 65.0 MPa	48 -50 MPa	63 – 68 MPa	38 – 44 MPa		
Tensile Modulus MPa	1520 – 6100 MPa	2480-2690 MPa	3200-3380 MPa	1790-1980 MPa		
Elongation at break	2.40 -110 %	5.3 – 15.0 %	5 – 8 %	14-22 %		
Flexural Strength MPa	40.0 – 95.1 MPa	72 – 77 MPa	88 – 110 MPa	52 – 71 MPa		
Flexural Modulus	1500 – 25000 MPa	2210-2340 MPa	2690-3240 MPa	1520-2070 MPa		
IZOD Impact notched J/m		16.5 – 28.1 J/m	12 – 22 J/m	35 – 52 J/m		
IZOD Impact, un-notched	3.46 J/cm					
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	49 – 53 °C	55 – 58 °C	62 °C		
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	43 – 46 °C	51 – 53 °C	54 °C		
Glass Transition Temperature (Tg)	105 -115 °C	62 °C	56 °C			
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	0.80 -139 $\mu\text{m}/\text{m}^{\circ}\text{C}$	73 $\mu\text{m}/\text{m}^{\circ}\text{C}$	61 $\mu\text{m}/\text{m}^{\circ}\text{C}$			
Water Absorption	0.05 – 2.30 %					
Specific Gravity	1.05 g/cc	1.21 g/cc	1.20 g/cc	1.19 g/cc		
Rockwell Hardness	R90.0 – 119	(shore D 86)	(shore D 85)			
Flame Classification	HB					
Dielectric Strength kV/mm	15.7 -53.0					
Dielectric Constant @60Mhz	2.00 -3.20					
Manufacturing Process or Machine	Inj. Moulding	SLA Viper si2, 3500/5000/7000 (solid state laser)	Various SLA (solid state laser)	Various SLA (solid state laser)		

ABS and ABS-like Materials; SLA system, He -Cd (325nm) laser

Property	ABS, moulded <i>www.matweb.com</i>	RenShape SL 5260 Huntsman	WaterClear 10110 DSM Somos	WaterShed 11110 DSM Somos	
Tensile Strength MPa	20.0 – 65.0 MPa	58 MPa	43.4 MPa	48.3 MPa	
Tensile Modulus MPa	1520 – 6100 MPa		2040 MPa	2640 MPa	
Elongation at break	2.40 -110 %	12 %	37 %	25 %	
Flexural Strength MPa	40.0 – 95.1 MPa	81 MPa	57.7 MPa	63.7 MPa	
Flexural Modulus	1500 – 25000 MPa		1720 MPa	2140 MPa	
IZOD Impact notched J/m		40 J/m	45 J/m	19.3 J/m	
IZOD Impact, un-notched	3.46 J/cm				
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C	58 °C	51.2 °C	49.6 °C	
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	61 °C	44.9 °C	46.2 °C	
Glass Transition Temperature (Tg)	105 -115 °C		41 °C	41 °C	
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	0.80 -139 $\mu\text{m}/\text{m}^{\circ}\text{C}$		109.2	103.9 $\mu\text{m}/\text{m}^{\circ}\text{C}$	
Water Absorption	0.05 – 2.30 %		0.98 %	0.35 %	
Specific Gravity	1.05 g/cc		1.12 g/cc	1.12 g/cc	
Rockwell Hardness	R90.0 – 119		(Shore D 83)		
Flame Classification	HB				
Dielectric Strength kV/mm	15.7 -53.0		15.3	2995	
Dielectric Constant @60Mhz	2.00 -3.20		3.5	3.2	
Manufacturing Process or Machine	Inj. Moulding	SLA 250 (He-Cd laser)	Various SLA (He-Cd laser)	Various SLA (He-Cd laser)	

ABS and ABS-like Materials; SLA system, LD laser

Property	ABS, moulded <i>www.matweb.com</i>	HS-690 CMET	HS-696 CMET		
Tensile Strength MPa	20.0 – 65.0 MPa	70 MPa	64 MPa		
Tensile Modulus MPa	1520 – 6100 MPa	2000-2100 MPa	2300 MPa		
Elongation at break	2.40 -110 %	8 -10 %	6 -7 %		
Flexural Strength MPa	40.0 – 95.1 MPa	90 MPa	84 MPa		
Flexural Modulus	1500 – 25000 MPa	2200-2500 MPa	2500 MPa		
IZOD Impact notched J/m		35 -50 J/m	51 J/m		
IZOD Impact, un-notched	3.46 J/cm				
Heat Deflection Temperature @ 0.46 MPa	68.0 -140 °C				
Heat Deflection Temperature @ 1.82 MPa	65.0 -220 °C	55 -61 °C	52 -57 °C		
Glass Transition Temperature (Tg)	105 -115 °C				
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	0.80 -139 $\mu\text{m}/\text{m}^{\circ}\text{C}$				
Water Absorption	0.05 – 2.30 %				
Specific Gravity	1.05 g/cc	1.15 g/cc	1.15 g/cc		
Rockwell Hardness	R90.0 – 119	(Shore D 82 – 85)	(Shore D 83 -86)		
Flame Classification	HB				
Dielectric Strength kV/mm	15.7 -53.0				
Dielectric Constant @60Mhz	2.00 -3.20				
Manufacturing Process or Machine	Inj. Moulding	Various SLA (LD laser)	Various SLA (LD laser)		

Polypropylene-like Materials; SLA system, solid state (355nm) laser

Property	PP, moulded <i>www.matweb.com</i>	Somos 9920 DSM Somos	Somos 9120 DSM Somos	Somos 9420 DSM Somos	SCR9100 D- MEC	SCR9120 D- MEC
Tensile Strength MPa	12.0 – 369 MPa	31 – 39 MPa	30 – 32 MPa	17 – 20 MPa	28 – 32 MPa	30 – 32 MPa
Tensile Modulus MPa	8.0 – 8250 MPa	1345–1810 MPa	1227-1462MPa	553 – 850 MPa	1100-1400 MPa	1200-1500 MPa
Elongation at break	2.5 – 900 %	13 – 29 %	15-25 % (Yield)	25 – 30 %	14 – 17 %	15 – 25 %
Flexural Strength MPa	20.0 – 180 MPa	40 – 45 MPa	41 – 46 MPa	24 – 30 MPa	42 – 62 MPa	41 – 46 MPa
Flexural Modulus	26 – 6890 MPa	1190–1383 MPa	1310-1455MPa	768 – 900 MPa	1200-1500 MPa	1300-1500 MPa
IZOD Impact notched	10.9 J/cm (avg)	0.27 – 0.50 J/cm	0.48–0.53 J/cm	0.44–0.48 J/cm	0.32–0.43 J/cm	0.48–0.53 J/cm
IZOD Impact, un-notched	0.196 J/cm					
Heat Deflection Temperature @ 0.46 MPa	13.0 – 238 °C	54.5 – 61.6 °C	52 -61 °C	47 – 50 °C		
Heat Deflection Temperature @ 1.82 MPa	37.0 – 149 °C	45.4 – 48.0 °C		36 – 38 °C	60 – 65 °C	52 – 61 °C
Glass Transition Temperature (Tg)		37 – 52 °C		57 – 60 °C		
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	18.0 – 185 $\mu\text{m}/\text{m}^{\circ}\text{C}$	90 – 96 $\mu\text{m}/\text{m}^{\circ}\text{C}$		149.5 $\mu\text{m}/\text{m}^{\circ}\text{C}$		
Water Absorption	0.00 – 1.00 %	0.84 %		0.93 %		
Specific Gravity	0.886 – 1.44 g/cc	1.13 g/cc	1.13 g/cc	1.13 g/cc	1.11 g/cc	1.13 g/cc
Shore D Hardness	47.0 – 83.0	81	80 -82	70 -74		
Flame Classification	HB – V -0					
Dielectric Strength kV/mm	23.6 – 500 kV/mm	14.6–15.2 kV/mm		14.1 kV/mm		
Dielectric Constant low frequency	2.30	4.6		5.33		
Manufacturing Process or Machine	Inj. Moulding	Various SLA (solid state laser)	Various SLA (solid state laser)	Various SLA (solid state laser)	SCS-8000 (solid state laser)	SCS-8000 (solid state laser)

Polypropylene-like Materials; SLA system, solid state (355nm) laser

Property	PP, moulded <i>www.matweb.com</i>	Accura 25 3DSystems	Accura Xtreme 3DSystems	RenShape SL 7540 Huntsman	RenShape SL 7545 Huntsman
Tensile Strength MPa	12.0 – 369 MPa	38 MPa	38 – 44 MPa	39 MPa	38 MPa
Tensile Modulus MPa	8.0 – 8250 MPa	1590-1660 MPa	1790-1980 MPa		
Elongation at break	2.5 – 900 %	13 – 20 %	14-22 %	22 %	17 %
Flexural Strength MPa	20.0 – 180 MPa	55 – 58 MPa	52 – 71 MPa	50 MPa	58 MPa
Flexural Modulus	26 – 6890 MPa	1380-1660 MPa	1520-2070 MPa		
IZOD Impact notched	10.9 J/cm (avg)	0.19 – 0.24 J/cm	0.35 – 0.52 J/cm	0.42 J/cm	34 J/m
IZOD Impact, un-notched	0.196 J/cm				
Heat Deflection Temperature @ 0.46 MPa	13.0 – 238 °C	58 – 63 °C	62 °C	57 °C	49 °C
Heat Deflection Temperature @ 1.82 MPa	37.0 – 149 °C	51 – 55 °C	54 °C	54 °C	46 °C
Glass Transition Temperature (Tg)		60 °C			
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	18.0 – 185 $\mu\text{m}/\text{m}^{\circ}\text{C}$	107 $\mu\text{m}/\text{m}^{\circ}\text{C}$			
Water Absorption	0.00 – 1.00 %				
Specific Gravity	0.886 – 1.44 g/cc	1.19 g/cc	1.19 g/cc		
Shore D Hardness	47.0 – 83.0	80			
Flame Classification	HB – V -0				
Dielectric Strength kV/mm	23.6 – 500 kV/mm				
Dielectric Constant low frequency	2.30				
Manufacturing Process or Machine	Inj. Moulding	Various SLA (solid state laser)	Various SLA (solid state laser)	SLA 5000 (solid state laser)	SLA Viper si2, 3500/5000/7000 (solid state laser)

Polypropylene-like Materials; SLA system, He -Cd (325nm) laser

Property	PP, moulded <i>www.matweb.com</i>	Somos 9110 <i>DSM Somos</i>	RenShape SL 7540 Huntsman		
Tensile Strength MPa	12.0 – 369 MPa	31 MPa	37 MPa		
Tensile Modulus MPa	8.0 – 8250 MPa	1590 MPa			
Elongation at break	2.5 – 900 %	15 – 21 %	24 %		
Flexural Strength MPa	20.0 – 180 MPa	44 MPa	55 MPa		
Flexural Modulus	26 – 6890 MPa	1450 MPa			
IZOD Impact notched	10.9 J/cm (avg)	0.55 J/cm	0.48 J/cm		
IZOD Impact, un-notched	0.196 J/cm				
Heat Deflection Temperature @ 0.46 MPa	13.0 – 238 °C	50 °C	58 °C		
Heat Deflection Temperature @ 1.82 MPa	37.0 – 149 °C		50 °C		
Glass Transition Temperature (T _g)					
Coefficient of Thermal Expansion $\mu\text{m/m}^\circ\text{C}$	18.0 – 185 $\mu\text{m/m}^\circ\text{C}$				
Water Absorption	0.00 – 1.00 %				
Specific Gravity	0.886 – 1.44 g/cc	1.13 g/cc			
Shore D Hardness	47.0 – 83.0	83			
Flame Classification	HB – V -0				
Dielectric Strength kV/mm	23.6 – 500 kV/mm				
Dielectric Constant low frequency	2.30				
Manufacturing Process or Machine	Inj. Moulding	Various SLA (He-Cd laser)	Various SLA (He-Cd laser)		

Polyethylene-like Materials; SLA system, solid state (355nm) & He -Cd (325nm) laser

Property	PE, moulded <i>www.matweb.com</i>	Somos 8110 <i>DSM Somos</i>	Somos 8120 <i>DSM Somos</i>		
Tensile Strength MPa	7.60 -136 MPa	18 MPa	26 MPa		
Tensile Modulus MPa	96.5 -449 MPa	317 MPa	276 – 703 MPa		
Elongation at break	13 -800 %	27 %	27 %		
Flexural Strength MPa	9.03 – 48.3 MPa	11MPa	26 MPa		
Flexural Modulus	24.8 -1380 MPa	310 MPa	690 MPa		
IZOD Impact notched	24.0 – 69.4 kJ/m ²	87 J/m	59 J/m		
IZOD Impact, un-notched					
Heat Deflection Temperature @ 0.46 MPa	40.0 – 50.6 °C	54 °C	54 °C		
Heat Deflection Temperature @ 1.82 MPa	23.0 -101 °C				
Glass Transition Temperature (T _g)	-85.0 – 40.5 °C				
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	180 -230 $\mu\text{m}/\text{m}^{\circ}\text{C}$				
Water Absorption	0.0100 %				
Specific Gravity	0.221 – 0.980 g/cc	1.11 g/cc	1.11 g/cc		
Shore D Hardness	38.0 – 60.0	77	76		
Flame Classification	HB				
Dielectric Strength kV/mm					
Dielectric Constant low frequency	2.00 – 2.60				
Manufacturing Process or Machine	Inj. Moulding	Various SLA (He-Cd laser)	Various SLA (solid state laser)		

Polycarbonate and Polycarbonate-like Materials; FDM system

Property	PC, moulded <i>www.matweb.com</i>	PC Stratasys	PC-ISO Stratasys	PC-ABS Stratasys
Tensile Strength	37.0 – 191 MPa	52 MPa	52 MPa	34.8 MPa
Tensile Modulus	1800-7580 MPa	2000 MPa	1.744 MPa	1827 MPa
Elongation at break	2.0 – 233 %	3 %	5 %	4.3 %
Flexural Strength	27.6 – 234 MPa	97 MPa	82 MPa	50 MPa
Flexural Modulus	1700 – 14900 MPa	2137 MPa	2193 MPa	1863 MPa
IZOD Impact, notched	60.0 kJ/m ²	53.39 J/a	53.39 J/a	123 J/a
IZOD Impact, un-notched	0.60 – 5340 J/cm	266.95 J/a	480.5 J/a	326 J/a
Heat Deflection Temperature @ 0.46 MPa	98.0 – 208 °C	138 °C	133 °C	110° C
Heat Deflection Temperature @ 1.82 MPa	77.8 – 185 °C	127 °C	127 °C	96° C
Glass Transition Temperature (T _g)	143 – 152 °C	161 °C	161 °C	125° C
Vicat softening	100 – 218 °C		139 °C	112 °C
Melt Point	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Specific Gravity	0.950 – 1.54 g/cc	1.2 g/cc	1.2 g/cc	1.2 g/cc
Rockwell Hardness	115 -123	115		R110
Flame Classification	HB	V2, 1.1 mm	HB	HB
Dielectric Strength kV/mm	15.0 – 38.0	15		35
Dielectric Constant @ low frequency	2.90 – 3.30	3.17	3.17	3.1
Manufacturing Process or Machine	Inj. Moulding	Vantage, Titan, FDM 400mc	Vantage, Titan	Vantage, Titan, FDM 400mc

Polycarbonate and Polycarbonate-like Materials; SLA system, solid state (355nm) laser

Property	PC, moulded <i>www.matweb.com</i>	Accura 60 3DSYSTEMS	ProtoTherm 12120 DSM Somos	
Tensile Strength	37.0 – 191 MPa	58 – 68 MPa	70.2 MPa	77.0 MPa
Tensile Modulus	1800-7580 MPa	2690-3100 MPa	3520 MPa	3250 MPa
Elongation at break	2.0 – 233 %	5 – 13 %	4.00 %	4.50 %
Flexural Strength	27.6 – 234 MPa	87 – 101 MPa	109 MPa	103 MPa
Flexural Modulus	1700 – 14900 MPa	2700-3000 MPa	3320 MPa	3060 MPa
IZOD Impact, notched	60.0 kJ/m ²	15 – 25 J/m	11.5 J/m	16.8 J/m
IZOD Impact, un-notched	0.60 – 5340 J/cm			
Heat Deflection Temperature @ 0.46 MPa	98.0 – 208 °C	53 – 55 °C	56.5 °C	126.2 °C
Heat Deflection Temperature @ 1.82 MPa	77.8 – 185 °C	48 – 50 °C	51.9 °C	110.7 °C
Glass Transition Temperature (T _g)	143 – 152 °C	58 °C	74 °C	111 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	4.10 – 117 $\mu\text{m}/\text{m}^{\circ}\text{C}$	71 $\mu\text{m}/\text{m}^{\circ}\text{C}$	80.7 $\mu\text{m}/\text{m}^{\circ}\text{C}$	66.3 $\mu\text{m}/\text{m}^{\circ}\text{C}$
Water Absorption	0.015 -0.400%		0.37 %	0.24 %
Specific Gravity	0.950 – 1.54 g/cc	1.21 g/cc	1.15 g/cc	1.15 g/cc
Rockwell Hardness	115 -123	(Shore D 86)	(Shore D 85.30)	(Shore D 86.70)
Flame Classification	HB			
Dielectric Strength kV/mm	15.0 – 38.0		15.5 kV/mm	16.4 kV/mm
Dielectric Constant @ low frequency	2.90 – 3.30		4.14	3.89
Manufacturing Process or Machine	Inj. Moulding	Various SLA (solid state laser)	UV Postcure Various SLA (solid state laser)	Thermal Postcure Various SLA (solid state laser)

Polycarbonate and Polycarbonate-like Materials; SLA system, He -Cd (325nm) laser

Property	PC, moulded <i>www.matweb.com</i>	WaterClear 10110 <i>DSM Somos</i>	ProtoTherm 12110 <i>DSM Somos</i>	
Tensile Strength	37.0 – 191 MPa	43.4 MPa	57.6 MPa	65.5 MPa
Tensile Modulus	1800-7580 MPa	2040 MPa	3430 MPa	2950 MPa
Elongation at break	2.0 – 233 %	37 %	5.00 %	3.8 %
Flexural Strength	27.6 – 234 MPa	57.7 MPa	108 MPa	98 MPa
Flexural Modulus	1700 – 14900 MPa	1720 MPa	3350 MPa	2730 MPa
IZOD Impact, notched	60.0 kJ/m ²	45 J/m	11.5 J/m	20.7 J/m
IZOD Impact, un-notched	0.60 – 5340 J/cm			
Heat Deflection Temperature @ 0.46 MPa	98.0 – 208 °C	51.2 °C	52.9 °C	154.9 °C
Heat Deflection Temperature @ 1.82 MPa	77.8 – 185 °C	44.9 °C	48.0 °C	151.3 °C
Glass Transition Temperature (T _g)	143 – 152 °C	41 °C	59.3 °C	135.1 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	4.10 – 117 $\mu\text{m}/\text{m}^{\circ}\text{C}$	109.2	85.5 $\mu\text{m}/\text{m}^{\circ}\text{C}$	64.9 $\mu\text{m}/\text{m}^{\circ}\text{C}$
Water Absorbtion	0.015 -0.400%	0.98 %	0.28 %	0.25 %
Specific Gravity	0.950 – 1.54 g/cc	1.12 g/cc	1.15 g/cc	1.15 g/cc
Rockwell Hardness	115 -123	(Shore D 83)	(Shore D 84.5)	(Shore D 86.4)
Flame Classification	HB			
Dielectric Strength kV/mm	15.0 – 38.0	15.3	16.6 kV/mm	17.8 kV/mm
Dielectric Constant @ low frequency	2.90 – 3.30	3.9	3.54	3.41
Manufacturing Process or Machine	Inj. Moulding	Various SLA (He-Cd laser)	UV Postcure Various SLA (He-Cd laser)	Thermal Postcure Various SLA (He-Cd Laser)

Polyamide and Polyamide-like Materials; SLS system

Property	Type 66 Nylon <i>www.matweb.com</i>	DuraForm PA <i>3DSystems</i>	PA 2200 <i>EOS GmbH</i>	PrimePart <i>EOS GmbH</i>	PA 2210 FR <i>EOS GmbH</i>
Tensile Strength	82.7 MPa	43 MPa			
Tensile Modulus	2930 MPa	1586 MPa			
Tensile Elongation	50 %	14 %			
Flexural Strength	103 MPa	48 MPa			
Flexural Modulus	3100 MPa	1387 MPa			
IZOD Impact, notched	32 J/m	32 J/m			
IZOD Impact, un-notched		336 J/m			
Heat Deflection Temperature @ 0.46 MPa		180 °C			
Heat Deflection Temperature @ 1.82 MPa	93.3 °C	95 °C			
Glass Transition Temperature (Tg)					
Coefficient of Thermal Expansion	99.0 µm/m°C	62.3 µm/m-°C			
Water Absorption 24hrs	0.300 %	0.07 %			
Specific Gravity	1.15 g/cc	1.00 g/cm3			
Hardness Shore D	80.0	73			
Flame Classification	V-2	HB			
Dielectric Strength kV/mm	15.7 kV/mm	17.3 kV/mm			
Dielectric Constant	3.60	2.73			
Manufacturing Process or Machine	Extruded	Sinterstation Pro Sinterstation HiQ	Various SLS System	Various SLS System	Flame resistant material, Various SLS System

Polyamide and Polyamide-like Materials; SLA system, solid state (355nm) laser

Property	Type 66 Nylon <i>www.matweb.com</i>	Accura SI 40 3DSystems			
Tensile Strength	82.7 MPa	57.2 – 58.7 MPa	73.9 – 74.2 MPa	61.5 – 61.7 MPa	69.6 – 73.8 MPa
Tensile Modulus	2930 MPa	2628-3321 MPa	2906-3321 MPa	2840-3048 MPa	2909-3186 MPa
Tensile Elongation	50 %	4.8 – 5.1 %	4.8 – 5.1 %	4.9 – 5.1 %	4.7 – 6.4 %
Flexural Strength	103 MPa	93.4 – 96.1 MPa	116.2 – 118.3 MPa	92.8 – 97 MPa	106.7 – 110 MPa
Flexural Modulus	3100 MPa	2836-3044 MPa	3113-3182 MPa	2618-2756 MPa	2840-2909 MPa
IZOD Impact, notched	32 J/m	22.5 – 27.2 J/m	22.5 – 30.9 J/m	22.3 – 29.9 J/m	22.3 – 29.9 J/m
IZOD Impact, un-notched					
Heat Deflection Temperature @ 0.46 MPa		51 °C	101 °C	54 °C	114 °C
Heat Deflection Temperature @ 1.82 MPa	93.3 °C	43 °C	82 °C	49 °C	89 °C
Glass Transition Temperature (Tg)		65.6 °C	74.9 °C	62 °C	72 °C
Coefficient of Thermal Expansion	99.0 µm/m°C	99.6 µm/m°C	60.8 µm/m°C	73.5 µm/m°C	67.1 µm/m°C
Water Absorption 24hrs	0.300 %				
Specific Gravity	1.15 g/cc	1.1 g/cc	1.1 g/cc	1.1 g/cc	1.1 g/cc
Hardness Shore D	80.0	82	84	86	86
Flame Classification	V-2				
Dielectric Strength kV/mm	15.7 kV/mm				
Manufacturing Process or Machine	Extruded	90-Minute UV Postcure	90-Minute UV +Thermal Postcure	90-Minute UV Postcure	90-Minute UV +Thermal Postcure
		SLA Viper si2, Various SLA (solid state)		SLA 7000, Various SLA (solid state)	

Polyamide and Polyamide-like Materials; SLA system, He -Cd (325nm) laser

Property	Type 66 Nylon <i>www.matweb.com</i>	WaterClear 10110 DSM Somos	Accura 45HC 3DSystems			
Tensile Strength	82.7 MPa	43.4 MPa	59 – 61 MPa			
Tensile Modulus	2930 MPa	2040 MPa	2760-2960 MPa			
Tensile Elongation	50 %	37 %	4.8 – 5.4 %			
Flexural Strength	103 MPa	57.7 MPa	94 – 101 MPa			
Flexural Modulus	3100 MPa	1720 MPa	2760-2900 MPa			
IZOD Impact, notched	32 J/m	45 J/m	11 – 16 J/m			
IZOD Impact, un-notched						
Heat Deflection Temperature @ 0.46 MPa		51.2 °C	58 °C	103 °C		
Heat Deflection Temperature @ 1.82 MPa	93.3 °C	44.9 °C	51 °C	86 °C		
Glass Transition Temperature (Tg)		41 °C	66 – 87 °C			
Coefficient of Thermal Expansion	99.0 µm/m°C	109.2	72			
Water Absorption 24hrs	0.300 %	0.98 %				
Specific Gravity	1.15 g/cc	1.12 g/cc	1.2 g/cc			
Hardness Shore D	80.0	83.0	87			
Flame Classification	V-2					
Dielectric Strength kV/mm	15.7 kV/mm	15.3				
Manufacturing Process or Machine	Extruded	Various SLA (He-Cd laser)	Various SLA (He-Cd laser)			
			No Postcure	With thermal postcure		

Glass filled Polyamide Materials; SLS and SMS systems

Property	Polyamide-Imide, Glass Filled <i>www.matweb.com</i>	DuraForm GF 3DSYSTEMS	Windform Pro B <i>CRP Technology</i>	SinterMask Material <i>Sin- terMask AB</i>	PA 3200 GF <i>EOS GmbH</i>
Tensile Strength	93.1 -205 MPa	26 MPa	47.05 MPa		
Tensile Modulus	6000-10800 MPa	4068 MPa	3612.4 MPa		
Tensile Elongation	3.0 – 7.0 %	1.4 %	3.81 %		
Flexural Strength	138 -338 MPa	37 MPa	96.14 MPa		
Flexural Modulus	4870-11700 MPa	3106 MPa	3366.9 MPa		
IZOD Impact, notched	32 -79 J/m	41 J/m	(Charpy 31.08 KJ/m2)		
IZOD Impact, un-notched		123 J/m	(Charpy 2.69 KJ/m2)		
Heat Deflection Temperature @ 0.46 MPa		179 °C			
Heat Deflection Temperature @ 1.82 MPa	210 -282 °C	134 °C	128.9 °C		
Melting point			180 °C	180 °C	
Coefficient of Thermal Expansion	16.2 – 46.8 µm/m°C	82.6 µm/m-°C			
Water Absorption 24hrs	0.180 -0.300 %	0.22 %			
Specific Gravity	1.22 – 1.61 g/cc	1.49 g/cc	1.21 g/cc		
Hardness Rockwell E	85.0 – 94.0	(Shore D 77)			
Flame Classification	V-0	HB			
Dielectric Strength kV/mm	27.6 – 32.6 kV/mm	8.7 kV/mm			
Dielectric Constant	4.20 – 6.50	6.27			
Manufacturing Process or Machine		Sinterstation Pro Sinterstation HiQ	Glass and Carbon filled Various SLS System	Selective Mask Sintering	Various SLS System

Glass and Aluminium filled Polyamide Materials; SLS systems

Property	Polyamide-Imide, Glass Filled <i>www.matweb.com</i>	DuraForm AF 3DSystems	Windform GF ^{CRP} Technology	Windform PRO ^{CRP} Technology	Alumide EOS GmbH
Tensile Strength	93.1 -205 MPa	35 MPa	47.646 MPa	52.56 MPa	
Tensile Modulus	6000-10800 MPa	3960 MPa	4412.7 MPa	4964.8 MPa	
Tensile Elongation	3.0 – 7.0 %	1.5 %	2.5 %	2.92 %	
Flexural Strength	138 -338 MPa	44 MPa	81.73 MPa	79.13 MPa	
Flexural Modulus	4870-11700 MPa	3517 MPa	3355.2 MPa	4299.7 MPa	
IZOD Impact, notched	32 -79 J/m		(Charpy 2.95 KJ/m2)	(Charpy 3.81 KJ/m2)	
IZOD Impact, un-notched		130 J/m	(Charpy 31.86 KJ/m2)	(Charpy 17.75 KJ/m2)	
Heat Deflection Temperature @ 0.46 MPa		180 °C			
Heat Deflection Temperature @ 1.82 MPa	210 -282 °C	137 °C	125 °C	140 °C	
Glass Transition Temperature (Tg)		40 °C			
Coefficient of Thermal Expansion	16.2 – 46.8 µm/m°C	109 µm/m-°C			
Water Absorption 24hrs	0.180 -0.300 %				
Specific Gravity	1.22 – 1.61 g/cc		1.5 g/cc	1.42 g/cc	
Hardness Rockwell E	85.0 – 94.0	(Shore D 75)			-
Flame Classification	V-0				
Dielectric Strength kV/mm	27.6 – 32.6 kV/mm	0.18 kV/mm			
Dielectric Constant	4.20 – 6.50	14.5			
Manufacturing Process or Machine		Aluminium filled Sinterstation Pro Sinterstation HIQ	Glass and Aluminium filled Various SLS System	Glass and Aluminium filled Various SLS System	Various SLS System

Carbon Fibre filled Polyamide Materials; SLS systems

Property	Polyamide-Imide, 30% Graphite Fibre <i>www.matweb.com</i>	Windform XT ^{CRP} <i>Technology</i>	CarbonMide <i>EOS GmbH</i>	
Tensile Strength	152 MPa	77.85 MPa		
Tensile Modulus	8270 MPa	7320.8 MPa		
Tensile Elongation	2.5 %	2.6 %		
Flexural Strength		131.52 MPa		
Flexural Modulus		6248.5 MPa		
IZOD Impact, notched	48.1J/m	(Charpy 4.73 KJ/m2)		
IZOD Impact, un-notched		(Charpy 32.4 KJ/m2)		
Heat Deflection Temperature @ 0.46 MPa				
Heat Deflection Temperature @ 1.82 MPa	282 °C	175.4 °C		
Glass Transition Temperature (Tg)	275 °C			
Coefficient of Thermal Expansion	9.00 µm/m°C			
Water Absorption 24hrs	0.300 %			
Specific Gravity	1.47 g/cc	1.101 g/cc		
Hardness Rockwell E	91.0			
Flame Classification	V-0			
Dielectric Strength kV/mm				
Dielectric Constant				
Manufacturing Process or Machine	Extruded	Various SLS System	Various SLS System	

Nano-Composite Materials; SLA system, solid state (355nm) laser

Property	NCMT NanoPAC G2050H High Performance Polypropylene <i>www.matweb.com</i>	Accura Bluestone <i>3DSystems</i>	NanoForm 15120 <i>DSM Somos</i>		Somos NanoTool DSM <i>Somos</i>	
			UV Postcure	UV+Thermal postcure	UV Postcure	UV+Thermal postcure
Tensile Strength MPa	50.0 MPa	66 – 68 MPa	48 MPa	53 MPa	61.7 – 78.0	66.3 -80.3
Tensile Modulus MPa	5700 MPa	7600 -11700MPa	5000 MPa	5900 MPa	11000-11400	10400-11200
Tensile Elongation	3.00 %	1.4 – 2.4 %	2.1 %	1.2 %	0.7 – 1.0 %	0.7 – 1.0 %
Flexural Strength MPa		124 – 154 MPa	98 MPa	129 MPa	79-121 MPa	103-149 MPa
Flexural Modulus MPa		8300 – 9800 MPa	3630 MPa	4450 MPa	10200-10800	9960-10200
IZOD Impact, notched	48 J/m	13 – 17 J/m	15 J/m	15.9 J/m	0.12 – 0.15 J/m	0.14 -0.16 J/m
IZOD Impact, un-notched						
Heat Deflection Temperature @ 0.46 MPa		65 – 66 °C (With thermal post cure: 267-284 °C)	65.5 °C	269 °C	225 °C	258 -263 °C
Heat Deflection Temperature @ 1.82 MPa		65 °C	52.9 °C	115 °C	85 – 90 °C	104 °C
Glass Transition Temperature (Tg)		71 – 83 °C	39 °C	80 °C	57 – 62 °C	86 – 89 °C
Coefficient of Thermal Expansion $\mu\text{m/m}^\circ\text{C}$		33 – 44 $\mu\text{m/m}^\circ\text{C}$	111.9	50.9	30.4 -32.4	25.5 – 31.3
Water Absorption 24hrs			0.32 %	0.26 %	0.23 %	0.15-0.16 %
Specific Gravity	1.13 g/cc	1.78 g/cc	1.38 g/cc		1.65 g/cc	
Hardness Shore D		92	93	92	94	
Flame Classification						
Dielectric Strength kV/mm			16.4 kV/mm	15.9 kV/mm	15.6 -16.8	16.1 -16.9
Dielectric Constant			4.06	3.71	4.0	3.9
Manufacturing Process or Machine		SLA Viper si2, & 5000 & 7000 (solid state laser)	Various SLA (solid state laser)		Various SLA (solid state laser)	

Elastomers and Elastomer-like Materials; SLS system

Property	Natural Rubber, Vulcanized www.matweb.com	DuraForm Flex 3DSystems		
Tensile Strength	28.0 MPa	1.8 MPa	2.3 MPa	
Tensile Modulus	1.5 MPa	7.4 MPa	9.2 MPa	
Elongation at break	100 – 800 %	110 %	151 %	
Flexural Strength				
Flexural Modulus		5.9 MPa	7.8 MPa	
IZOD Impact, notched				
IZOD Impact, un-notched				
Heat Deflection Temperature @ 0.46 MPa				
Heat Deflection Temperature @ 1.82 MPa		-		
Glass Transition Temperature (T _g)				
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^\circ\text{C}$	225 $\mu\text{m}/\text{m}^\circ\text{C}$			
Water Absorbtion				
Specific Gravity	0.950 g/cc			
Hardness Shore A		60	67	
Flame Classification				
Manufacturing Process or Machine	Various....	As Produced	Infiltrated	
		Various SLS System		

Elastomers and Elastomer-like Materials; SLA system, solid state (355nm) laser

Property	Natural Rubber, Vulcanized <i>www.matweb.com</i>	Somos ULM 17220 <i>DSM Somos</i>	TSR 1920 D-MEC
Tensile Strength	28.0 MPa	3.47 MPa	3.9 MPa
Tensile Modulus	1.5 MPa		10 MPa
Elongation at break	100 – 800 %	75 %	81 %
Flexural Strength			
Flexural Modulus			
IZOD Impact, notched			
IZOD Impact, un-notched			
Heat Deflection Temperature @ 0.46 MPa			
Heat Deflection Temperature @ 1.82 MPa			
Glass Transition Temperature (T _g)			
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^\circ\text{C}$	225 $\mu\text{m}/\text{m}^\circ\text{C}$		
Water Absorbtion		1.15 %	
Specific Gravity	0.950 g/cc	1.12 g/cc	1.10 g/cc
Hardness Shore A		70	70
Flame Classification			
Dielectric Strength kV/mm		13.6 kV/mm	
Dielectric Constant		5.32	
Manufacturing Process or Machine	Various....	Various SLA (solid state laser)	Various SLA (Ar/LD laser)

Elastomers and Elastomer-like Materials; PolyJet System

Property	Natural Rubber, Vulcanized <i>www.matweb.com</i>	FullCure 970 Tan- goBlack <i>Objet Geome- tries</i>	FullCure 950 Tan- goGray <i>Objet Geome- tries</i>	FullCure 970 TangoPlus <i>Objet Geometries</i>
Tensile Strength	28.0 MPa	2 MPa	4.35 MPa	1.455 MPa
Tensile Modulus (20-50% elongation)	1.5 MPa			0.146 -0.263 MPa
Elongation at break	100 – 800 %	47.7 %	47 %	218 %
Flexural Strength				
Flexural Modulus				
IZOD Impact, notched				
IZOD Impact, un-notched				
Heat Deflection Temperatu- re @ 0.46 MPa				
Heat Deflection Temperatu- re @ 1.82 MPa				
Glass Transition Tempera- ture (Tg)		-10.7 °C	2.6 °C	-9.6 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^\circ\text{C}$	225 $\mu\text{m}/\text{m}^\circ\text{C}$			
Water Absorbtion				
Specific Gravity	0.950 g/cc			
Hardness Shore A		61	75	(scale D 27)
Flame Classification				
Dielectric Strength kV/mm				
Dielectric Constant				
Manufacturing Process or Machine	Various....	Eden 350, Eden 350V, Eden 500V, Connex 500	Eden 350, Eden 350V, Eden 500V, Connex 500	

Polyphenylsulfone, High Performance Material; FDM system

Property	PPSF <i>www.matweb.com</i>	PPSF <i>Strata-sys</i>		
Tensile Strength	69.6 – 76.0 MPa	55 MPa		
Tensile Modulus	2340-2500 MPa	2068 MPa		
Elongation at break	8.00 – 120 %	3 %		
Flexural Strength	91.0 – 185 MPa	110 MPa		
Flexural Modulus	2300-2540 MPa	2206 MPa		
IZOD Impact, notched	2.67 – 6.94 J/m	58.73 J/m		
IZOD Impact, un-notched	30.0 J/m	165.5 J/m		
Heat Deflection Temperature @ 0.46 MPa				
Heat Deflection Temperature @ 1.82 MPa	190 – 207 °C	189 °C		
Glass Transition Temperature (Tg)		230 °C		
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$	16.0 – 56.0 $\mu\text{m}/\text{m}^{\circ}\text{C}$	55 $\mu\text{m}/\text{m}^{\circ}\text{C}$		
Melt Point		Not Applicable		
Specific Gravity	1.28 – 1.31 g/cc	1.28 g/cc		
Rockwell Hardness		M86		
Flame Classification	V-0	V-0		
Dielectric Strength kV/mm	14.2 – 20.0 kV/mm	14.6 kV/mm		
Dielectric Constant @ low frequency	2.90 – 3.50	3.45		
Manufacturing Process or Machine	Inj. Moulding	Titan, FDM 400mc		

High Performance and General Purpose Materials; SLA system, solid state (355nm) laser

Property	DMX-SL 100 DSM Somos	Somos 7120 DSM Somos			Accura 10 3DSystems
Tensile Strength MPa	29.7–32.1 MPa	44 MPa	58 MPa	63 MPa	64 – 65 MPa
Tensile Modulus MPa	2256-2559 MPa	2222 MPa	2477 MPa	2588 MPa	3100-3307 MPa
Elongation at break	12.2 – 28.0 %	1.3 – 7.5 %	2.1 – 6.9 %	2.3 – 4.1 %	4.6 – 5 %
Flexural Strength MPa	68 MPa	89 MPa	108 MPa	113 MPa	91 – 94 MPa
Flexural Modulus	2282-2298 MPa	2570 MPa	2967 MPa	2877 MPa	2618-2756 MPa
IZOD Impact notched	61 – 71 J/m	25.2 J/m	27 J/M	32 J/m	16 – 18.2 J/cm
IZOD Impact, un-notched					
Heat Deflection Temperature @ 0.46 MPa	43.4 – 45.3 °C				59 °C
Heat Deflection Temperature @ 1.82 MPa	40.8 – 41.4 °C	Up to 65 °C	Up to 70 °C	Up to 97 °C	53 °C
Glass Transition Temperature (Tg)	37 °C				61 °C
Coefficient of Thermal Expansion $\mu\text{m/m}^{\circ}\text{C}$	124.0 -134.1				67.9 $\mu\text{m/m}^{\circ}\text{C}$
Water Absorption	0.82 – 0.85 1%				
Specific Gravity	1.17 g/cc	1.13 g/cc	1.13 g/cc	1.13 g/cc	
Shore D Hardness	80	88	88	88	86
Flame Classification					
Dielectric Strength kV/mm	14.1 – 15.8				
Dielectric Constant low frequency	4.2 – 4.5				
Manufacturing Process or Machine	Various SLA (solid state laser)	Green parts	UV Postcure	UV+Thermal Postcure	SLA Viper si2, 3500/5000/7000 (solid state laser)
		Various SLA (solid state laser)			

General Purpose Materials; SLA system, solid state (355nm) laser

Property	RenShape SL 5510 <i>Huntsman</i>		RenShape SL 5530 <i>Huntsman</i>		RenShape SL 7520 <i>Huntsman</i>	RenShape SL 7570 <i>Huntsman</i>
Tensile Strength MPa	66 MPa	77 MPa	59 MPa	59 MPa	64 MPa	59 MPa
Tensile Modulus MPa						
Elongation at break	5 %	5 %	4 %	4 %	6 %	6 %
Flexural Strength MPa	103 MPa	99 MPa	75 MPa	115 MPa	100 MPa	96 MPa
Flexural Modulus						
IZOD Impact notched	26 J/m	27 J/m	21 J/m	21 J/m	17 J/m	25 J/m
IZOD Impact, un-notched						
Heat Deflection Temperature @ 0.46 MPa	54 °C	62 °C	78 °C	68 °C	54 °C	55°C
Heat Deflection Temperature @ 1.82 MPa	47 °C	53 °C	57 °C	56 °C	49 °C	
Glass Transition Temperature (Tg)						
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$						
Water Absorption						
Specific Gravity						
Shore D Hardness						
Flame Classification						
Dielectric Strength kV/mm						
Dielectric Constant low frequency						
Manufacturing Process or Machine	SLA Viper si2, (solid state laser)	SLA 350/3500/5000 (solid state laser)	SLA 350/3500/5000 (solid state laser)	SLA 7000 (solid state laser)	SLA 7000 (solid state laser)	Various SLA (solid state laser)

General Purpose Materials; SLA system, solid state (355nm) laser

Property	RenShape SL 7510 <i>Huntsman</i>			SCR 701 <i>D-MEC</i>	SCR 740 <i>D-MEC</i>	SCR 11120 <i>D-MEC</i>	SCR 802 <i>D-MEC</i>
Tensile Strength MPa	57 MPa	44 MPa	51 MPa	75 MPa	62 MPa	47 MPa	85 MPa
Tensile Modulus MPa				3300 MPa	3000 MPa	2650 MPa	9200 MPa
Elongation at break	10 %	14 %	4 %	6 %	3 %	20 %	2 %
Flexural Strength MPa	MPa	82 MPa	61 MPa	104 MPa	110 MPa	63 MPa	120 MPa
Flexural Modulus				3100 MPa	2800 MPa	2040 MPa	8900 MPa
IZOD Impact notched	37 J/m	32 J/m	27 J/m	25 – 27 J/cm	29 J/cm	30 J/cm	
IZOD Impact, un-notched							
Heat Deflection Temperature @ 0.46 MPa	58 °C	51 °C	51 °C				
Heat Deflection Temperature @ 1.82 MPa	49 °C	47 °C	45 °C	53 °C	100 °C	46 °C	250 °C
Glass Transition Temperature (Tg)				82 °C	135 °C	43 °C	133 °C
Coefficient of Thermal Expansion $\mu\text{m/m}^\circ\text{C}$							
Water Absorption							
Specific Gravity				1.13 g/cc	1.13 g/cc	1.12 g/cc	1.59 g/cc
Shore D Hardness				87			92
Flame Classification							
Dielectric Strength kV/mm							
Dielectric Constant low frequency							
Manufacturing Process or Machine	SLA 350 & 3500 (solid state laser)	SLA 5000 (solid state laser)	SLA 7000 (solid state laser)	SCS-2000 (solid state laser)	Thermal Postcure SCS-8000 (solid state laser)	SCS-8000 (solid state laser)	SCS-2000 (solid state laser)

General Purpose Materials; SLA system, He -Cd (325nm) laser

Property	Somos 7110 <i>DSM Somos</i>			SCR 751 <i>D-MEC</i>	SCR 950 <i>D-MEC</i>
Tensile Strength MPa	44 MPa	56 MPa	69 MPa	80 MPa	51 MPa
Tensile Modulus MPa	1758 MPa	2117 MPa	2413 MPa	3400 MPa	2000 MPa
Elongation at break	4.7 – 7.4 %	5.4 – 7.1 %	4.2 – 4.9 %	5 %	8 %
Flexural Strength MPa	59 MPa	85 MPa	110 MPa	115 MPa	75 MPa
Flexural Modulus	1710 MPa	2434 MPa	2668 MPa	3300 MPa	2600 MPa
IZOD Impact notched	26.2 J/m	27.8 J/m	34.2 J/m		
IZOD Impact, un-notched					
Heat Deflection Temperature @ 0.46 MPa					
Heat Deflection Temperature @ 1.82 MPa	45 -54 °C	59 – 72 °C	77 -89 °C	56 °C	64 °C
Glass Transition Temperature (Tg)				108 °C	121 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$					
Water Absorption					
Specific Gravity	1.13 g/cc	1.13 g/cc	1.13 g/cc	1.13 g/cc	1.10 g/cc
Shore D Hardness	81	82	85	88	85
Flame Classification					
Dielectric Strength kV/mm					
Dielectric Constant low frequency					
Manufacturing Process or Machine	Green parts	UV Postcure	UV+Thermal Postcure	SCS-1000HD (He -Cd laser)	SCS-2000 (solid state laser)

General Purpose Materials; SLA system, LD laser

Property	HS-680 <i>CMET</i>	TSR-820 <i>CMET</i>	TSR-821 <i>CMET</i>	TSR-828 <i>CMET</i>	TSR-829 <i>CMET</i>
Tensile Strength MPa	80 MPa	78 MPa	49 MPa	55 -60 MPa	46 MPa
Tensile Modulus MPa	2380 MPa	2840 MPa	1800 MPa	MPa	1750 MPa
Elongation at break	3-4 %	6 %	13 -15 %	8 -10 %	8 %
Flexural Strength MPa	100 MPa	108 MPa	70 MPa	80 -90 MPa	68 MPa
Flexural Modulus	3200 MPa	3060 MPa	2225 MPa	2500-2600 MPa	2070 MPa
IZOD Impact notched J/m	25 J/m	28 -32 J/m	48 -49 J/m	30 -40 J/m	34 J/m
IZOD Impact, un-notched					
Heat Deflection Temperature @ 0.46 MPa					
Heat Deflection Temperature @ 1.82 MPa	56 °C	62 °C	49 -52 °C	52 -53 °C	49.4 °C
Glass Transition Temperature (Tg)					
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$					
Water Absorption					
Specific Gravity	1.15 g/cc	1.13 g/cc	1.12 g/cc	1.14 g/cc	1.07 g/cc
Hardness Shore D	85 -87	87	82 -85	84 -86	83
Flame Classification					
Dielectric Strength kV/mm					
Dielectric Constant @60Mhz					
Manufacturing Process or Machine	Various SLA (LD laser)	Various SLA (LD laser)	Various SLA (LD laser)	Various SLA (LD laser)	Various SLA (LD laser)

General Purpose Materials; SLA system, LD laser

Property	HS-680 <i>CMET</i>	TSR-750 <i>CMET</i>		
Tensile Strength MPa	80 MPa	75 MPa		
Tensile Modulus MPa	2380 MPa			
Elongation at break	3-4 %	1 -2 %		
Flexural Strength MPa	100 MPa	133 MPa		
Flexural Modulus	3200 MPa	14500 MPa		
IZOD Impact notched J/m	25 J/m			
IZOD Impact, un-notched				
Heat Deflection Temperature @ 0.46 MPa				
Heat Deflection Temperature @ 1.82 MPa	56 °C	264 °C		
Glass Transition Temperature (Tg)				
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$				
Water Absorption				
Specific Gravity	1.15 g/cc	1.50 g/cc		
Hardness Shore D	85 -87	93		
Flame Classification				
Dielectric Strength kV/mm				
Dielectric Constant @60Mhz				
Manufacturing Process or Machine	Various SLA (LD laser)	Various SLA (LD laser)		

General Purpose Clear and Hearing Aid Materials; PolyJet System

Property	FullCure 720 Transparent <i>Objet Geometries</i>	FullCure 640 Clear <i>Objet Geometries</i>	FullCure 660 Ro- seClear <i>Objet Geometries</i>	FullCure 680 Skin- Tone <i>Objet Geometries</i>
Tensile Strength	60.3 MPa	43.1 MPa	43.1 MPa	56 MPa
Tensile Modulus	2870 MPa	1931MPa	1931MPa	2700.6 MPa
Elongation at break	20 %	18 %	18 %	10.4 %
Flexural Strength	75.8 MPa	63.2 MPa	63.2 MPa	92.8 MPa
Flexural Modulus	1718 MPa	1833 MPa	1833 MPa	2590 MPa
IZOD Impact, notched	21.3 J/m	32.7 J/m	32.7 J/m	22.2 J/m
IZOD Impact, un-notched				
Heat Deflection Temperature @ 0.46 MPa	48.4 °C	46.1 °C	46.1 °C	65.5 °C
Heat Deflection Temperature @ 1.82 MPa	44.4 °C	41.5 °C	41.5 °C	51.3 °C
Glass Transition Temperature (Tg)	48.7 °C	63.3 °C	63.3 °C	58.5 °C
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$				
Water Absorbtion	1.72 %	1.02 %		
Specific Gravity				
Hardness Shore D	83	84	84	85
Flame Classification				
Dielectric Strength kV/mm				
Dielectric Constant				
Manufacturing Process or Machine	Eden 250, Eden 260, Eden 350, Eden 350V, Eden 500V, Connex 500	Eden 260, Eden 350, Eden 350V	Eden 260, Eden 350, Eden 350V	Eden 260, Eden 350, Eden 350V

General Purpose Opaque Materials; PolyJet System

Property	FullCure 830 VeroWhite <i>Objet Geometries</i>	FullCure 840 VeroBlue <i>Objet Geometries</i>	FullCure 870 VeroBlack <i>Objet Geometries</i>	
Tensile Strength	49.8 MPa	55.1 MPa	50.7 MPa	
Tensile Modulus	2495 MPa	2740 MPa	2192 MPa	
Elongation at break	20 %	20 %	17.7 %	
Flexural Strength	74.6 MPa	83.6 MPa	79.6 MPa	
Flexural Modulus	2137 MPa	1983 MPa	2276 MPa	
IZOD Impact, notched	24.1 J/m	23.6 J/m	23.9 J/m	
IZOD Impact, un-notched				
Heat Deflection Temperature @ 0.46 MPa	47.6 °C	48.8 °C	47 °C	
Heat Deflection Temperature @ 1.82 MPa	43.6 °C	44.8 °C	42.9 °C	
Glass Transition Temperature (T _g)	58 °C	48.7 °C	62.7 °C	
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$				
Water Absorbtion	1.47 %	1.87 %		
Specific Gravity				
Hardness Shore D	83	83	83	
Flame Classification				
Dielectric Strength kV/mm				
Dielectric Constant				
Manufacturing Process or Machine	Eden 250, Eden260, Eden 350, Eden 350V, Eden 500V, Connex 500	Eden 250, Eden260, Eden 350, Eden 350V, Eden 500V, Connex 500	Eden 250, Eden260, Eden 350, Eden 350V, Eden 500V, Connex 500	

General Purpose Materials; 3DPrinting System

Property	Acrylic, General Purpose www.matweb.com	Voxeljet material (Modified acrylic) Voxeljet Technology GmbH		
Tensile Strength	19.3 – 90.0 MPa	19 MPa		
Tensile Modulus	950 -4500 MPa	1700 MPa		
Elongation at break	1.0 – 85.0 %	2.9 %		
Flexural Strength	33.1 – 143 MPa			
Flexural Modulus	1170 -3590 MPa			
Charpy Impact, notched	0.60 J/cm2			
Charpy Impact, un-notched	0.200 – 1.30 J/cm2			
Heat Deflection Temperature @ 0.46 MPa	73.0 – 166 °C			
Heat Deflection Temperature @ 1.82 MPa	51.7 – 106 °C			
Glass Transition Temperature (Tg)	100 – 122 °C	65 °C		
Coefficient of Thermal Expansion $\mu\text{m/m}^\circ\text{C}$	54.0 – 150 $\mu\text{m/m}^\circ\text{C}$			
Water Absorbtion	0.300 – 2.0 %			
Specific Gravity	0.94 – 1.21 g/cc			
Hardness Rockwell R	69.0 – 95.0			
Flame Classification	HB			
Dielectric Strength kV/mm	17.7 – 60.0 kV/mm			
Dielectric Constant @low frequency	3.00 – 3.80			
Manufacturing Process or Machine	Inj. Moulding	Infiltration: Epoxy/wax Voxel-jet		

Metallic Composite Materials; Copper and Steel Based

Property	DirectMetal 20 <i>EOS GmbH</i>	DirectSteel 20 <i>EOS GmbH</i>	S3 <i>ProMetal</i>	S4 <i>ProMetal</i>	S4H <i>ProMetal</i>	LaserForm A6 <i>3DSystems</i>
Tensile Strength			406 MPa	682 MPa	756 MPa	610 MPa
Yield strength			234 MPa	455 MPa	572 MPa	470 MPa
Tensile Modulus			148 GPa	147 GPa	151 GPa	138 GPa
Elongation at break			8.00 %	2.30 %	3.8 %	2.0 – 4.0 %
Thermal Conductivity						39 W/mk
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^\circ\text{C}$						7.45 $\mu\text{m}/\text{m}^\circ\text{C}$
Specific Gravity						7.8 g/cc
Hardness Rockwell			HRB 60	HRC 25 – 30	HRC 30 – 35	C 10–20 Polished C 39 Heat treated
Manufacturing Process or Machine	EOSINT M250 XT EOSINT M270	EOSINT M250 XT EOSINT M270	ProMetal R1 ProMetal R2	ProMetal R1 ProMetal R2	ProMetal R1 ProMetal R2	Sinterstation Pro Sinterstation HiQ
Description	Fine-grained bronze-based, multicomponent metal powder. Composition of materials permits high building speeds and expand during liquid phase sintering allowing for high building accuracy.	Fine-grained steel-based, multicomponent metal powder. Slower building speed compared to DirectMetal 20. Mechanical properties are generally higher in x-y plane than z-plane.	316 Stainless steel + bronze Produces green bodies, requires secondary post processing in a furnace	420 Stainless steel + bronze Produces green bodies, requires secondary post processing in a furnace	420 Stainless steel + bronze Produces green bodies, requires secondary post processing in a furnace	A6 tool steel + bronze Produces green bodies, requires secondary post processing in a furnace
Typical applications	Injection moulds for ~10000-100000 parts in standard thermoplastics, Direct manufacturing of functional prototypes and parts with less demanding material requirements	Injection moulds for up to millions of parts in standard thermoplastics. Die casting moulds for up to several thousands in light alloys. Metal stamping tools. Direct manufacturing of functional parts	Functional prototypes, replacement parts, etc. Injection moulds, casting moulds, etc.	Functional prototypes, replacement parts, etc. Injection moulds, casting moulds, etc.	Functional prototypes, replacement parts, etc. Injection moulds, casting moulds, etc.	Tooling inserts for injection moulding and die casting Direct metal parts

Stainless steels

Property	EOS Stain- lessSteel 17-4 <i>EOS GmbH</i>	CL 20ES Stainless steel <i>ConceptLaser GmbH</i>	LENS 316 Stainless steel <i>Optomec</i>	SS 316L <i>Accufusion</i>	SS 420 <i>Accufusion</i>
Tensile Strength		570 MPa	661 MPa	Vertical 540 MPa Horizontal 560 MPa	1394 MPa
Yield strength		470 MPa	276 MPa	Vertical 328 MPa Horizontal 344 MPa	1087 MPa
Tensile Modulus					213 GPa
Elongation at break		>30 %	67 %	Vertical 43% Hori- zontal 35 %	1.6 %
Thermal Conductivity		Ca. 15 W/mk			
Coefficient of Thermal Expan- sion $\mu\text{m}/\text{m}^\circ\text{C}$					
Specific Gravity					
Hardnessl		HRC 20		HV 280	HRC 53
Manufacturing Process or Machine	EOSINT M270	M1 Cusing, M2 Cusing, M3 Linear	LENS 750, LENS 850R	Accufusion LC	Accufusion LC
Description	Fine-grained pre- alloyed SS powder. Corresponds to US classification 17-4 PH and European 1.4542. Good corrosion re- sistance and mechani- cal properties.	Corresponds to Euro- pean classification 1.4404, Acid and corro- sion resistant stainless steel powder	Corresponds to US classification "Stainless steel 316"	Corresponds to US classification "Stainless steel 316"	Corresponds to US classification "Stainless steel 420"
Typical applications	Parts that require high corrosion resistance and ductility. Functional prototypes and small series products, indi- vidualized products and spare parts	Tool components Func- tional parts		Structural, corrosion resistant applica- tions	Tools moulds and dies

Stainless steels

Property	LENS 17-4PH Stainless steel <i>Optomec</i>	LENS PH 13-8 Mo Stainless steel <i>Optomec</i>	LENS 304 Stainless steel <i>Optomec</i>	LENS 420 Stainless steel <i>Optomec</i>
Tensile Strength				
Yield strength				
Tensile Modulus				
Elongation at break				
Thermal Conductivity				
Coefficient of Thermal Expansion $\mu\text{m/m}^\circ\text{C}$				
Specific Gravity				
Hardness				
Manufacturing Process or Machine	LENS 750, LENS 850R	LENS 750, LENS 850R	LENS 750, LENS 850R	LENS 750, LENS 850R
Description	Precipitation hardening magnetic stainless steel. Corresponds to US classification "17-4PH stainless steel"	Precipitation hardening magnetic stainless steel. Corresponds to US classification "PH 13-8 Mo stainless steel"	Corresponds to US classification "304 stainless steel"	Corresponds to US classification "Stainless steel 420"
Typical applications	Often used for aircraft, dental, marine, medical, surgical, and applications where high levels of strength and hardness, and good corrosion resistance is required	Airframe structurals, missile components, valve parts, fasteners, chemical process equipment.		Tools moulds and dies

Maraging steels

Property	EOS MaragingSteel MS1 EOS GmbH	CL 50WS Hot-work steel <i>ConceptLaser GmbH</i>			CL 60DG Hot-work steel <i>ConceptLaser GmbH</i>		
Tensile Strength MPa		950 MPa	1800 MPa	1550 MPa	950 MPa	1800 MPa	1550 MPa
Yield strength		1100 MPa	1900 MPa	1650 MPa	1100 MPa	1900 MPa	1650 MPa
Tensile Modulus		140 GPa	160 GPa	160 GPa	140 GPa	160 GPa	160 GPa
Elongation at break		4.0 %	>2 – 3 %	>2 – 3 %	4.0 %	>2 – 3 %	>2 – 3 %
Thermal Conductivity		Ca 14 W/mk	Ca 14 W/mk	Ca 14 W/mk	Ca 14 W/mk	Ca 14 W/mk	Ca 14 W/mk
Coefficient of Thermal Expansion $\mu\text{m/m}^\circ\text{C}$							
Specific Gravity							
Hardness Rockwell	Up to ~55HRC	HRC 35-40	HRC 54	HRC 48	HRC 35-40	HRC 54	HRC 48
Manufacturing Process or Machine	EOSINT M270	M1 Cusing, M2 Cusing, M3 Linear			M1 Cusing, M2 Cusing, M3 Linear		
Description	Fine-grained maraging steel powder. Corresponds to US classification 18 maraging 100, European 1.2709 and German X3NiCoMoTi18-9-5. High strength and toughness.	Hot-work steel Corresponds to European classification 1.2709 Untempered	Hot-work steel Corresponds to European classification 1.2709 Tempered 490 °C	Hot-work steel Corresponds to European classification 1.2709 Tempered 540 °C	Hot-work steel Corresponds to European classification 1.2709 Untempered	Hot-work steel Corresponds to European classification 1.2709 Tempered 490 °C	Hot-work steel Corresponds to European classification 1.2709 Tempered 540 °C
Typical applications	Heavy duty injection moulds for millions of parts in standard thermoplastics. Die casting moulds for up to several thousands in light alloys. Metal stamping tools. Direct manufacturing of heavily loaded functional parts	Production of end-use components as well as tool inserts for injection moulding			Production of end-use components as well as tool inserts for pressure die casting of light metal alloys		

Maraging steels

Property	CL 90RW Hot-work steel <i>ConceptLaser GmbH</i>		CL 91 RW Hot-work steel <i>ConceptLaser GmbH</i>
Tensile Strength MPa	570 MPa	1000 MPa	1600 MPa
Yield strength	850 MPa	1100 MPa	1700 MPa
Tensile Modulus	135 GPa	135 GPa	Ca 140 GPa
Elongation at break	2.5 %	>1 %	Ca 2 %
Thermal Conductivity	13 W/mk	13 W/mk	Ca 13 W/mk
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$			
Specific Gravity			
Hardness Rockwell	HRC 35 – 40	HRC 45-48	HRC 48 -50
Manufacturing Process or Machine	M1 Cusing, M2 Cusing, M3 Linear		M1 Cusing, M3 Linear
Description	Untempered Hard stainless steel powder with high content of chrome Comparable to European classification 1.2083	Tempered 510 °C Hard stainless steel powder with high content of chrome Comparable to European classification 1.2083	Tempered 525 °C Hard stainless steel powder with high content of chrome
Typical applications	Production tool components for serial injection moulding of packaging and medical products		Production tool components for serial injection moulding of packaging and medical products

Tool steels (with carbon)

Property	CPM-9V Tool steel <i>Accufusion</i>	H-13 Tool steel <i>Accufusion</i>	LENS H13 Tool steel <i>Optomec</i>	LENS S7 Tool steel <i>Optomec</i>
Tensile Strength	Vertical 1315 MPa	Vertical 2064 MPa		
Yield strength	Vertical 821 MPa	Vertical 1288 MPa		
Tensile Modulus	234 GPa	216 GPa		
Elongation at break	Vertical 3 %	Vertical 6 %		
Thermal Conductivity				
Coefficient of Thermal Expansion $\mu\text{m}/\text{m}^{\circ}\text{C}$				
Specific Gravity				
Hardness	HRC 50	HV 660		
Manufacturing Process or Machine	Accufusion LC	Accufusion LC	LENS 750, LENS 850R	LENS 750, LENS 850R
Description	Corresponds to US classification "Tool steel CPM-9V"	Corresponds to US classification "Tool steel H13"	Corresponds to US classification "H13 tool steel"	Corresponds to US classification "S7 tool steel" High degree of toughness moderate wear resistance
Typical applications	Cutting tools and dies	Moulds and dies	Moulds and dies	Used for heavy-duty punching and shearing tools. Also for hardened backup plates and punch die holders.

Titanium alloys

Property	EOS Titanium Ti64 / Ti64ELI <i>EOS GmbH</i>	CL 40Ti Titanium TiAl64V <i>ConceptLaser GmbH</i>	LENS Ti 6-4 Titanium <i>Optomec</i>	LENS CP Ti Titanium <i>Optomec</i>	LENS Ti 6-2-4-2 Titanium <i>Optomec</i>	LENS Ti 6-2-4-6 Titanium <i>Optomec</i>
Tensile Strength			955 MPa			
Yield strength			848 MPa			
Tensile Modulus						
Elongation at break			15 %			
Thermal Conductivity						
Fatigue strength@600MPa			>10 000000			
Specific Gravity						
Hardnessl						
Manufacturing Process or Machine	EOSINT M270	M2 Cusing	LENS 750, LENS 850R	LENS 750, LENS 850R	LENS 750, LENS 850R	LENS 750, LENS 850R
Description	Fine-grained pre-alloyed titanium powder. Good corrosion resistance and biocompatibility.	Ti6Al4V is the most widely used titanium alloy.	Ti AL6V4 alloy with material properties equal or superior to wrought material after LENS processing			
Typical applications	Parts that require high mechanical properties and low specific weight for example structural and engine components for aerospace and motor racing applications, biomedical implants	Aerospace and motor racing applications, biomedical implants	Aerospace and motor racing applications, biomedical implants			

Titanium alloys

Property	Ti-6AL-4V Titanium alloy <i>Accufusion</i>	Ti6AL4V Titanium alloy <i>Arcam AB</i>	Ti6AL4V ELI Titanium alloy <i>Arcam AB</i>		
Tensile Strength	Thin wall 1157 MPa Thick wall 979 MPa	970 – 1030 MPa	950 – 990 MPa		
Yield strength	Thin wall 1062 MPa Thick wall 899 MPa	910 – 960 MPa	910 – 940 MPa		
Tensile Modulus	Thin wall 116 GPa Thick wall 121 GPa	120 GPa	120 GPa		
Elongation at break	Thin wall 6 % Thick wall 11 %	12 – 16 %	12 – 16 %		
Thermal Conductivity					
Fatigue strength@600MPa	10 000000	>10 000000	>10 000000		
Specific Gravity					
Hardness	HV 360	HRC 30 -35	HRC 30 -35		
Manufacturing Process or Machine	Accufusion LC	Arcam S12 Arcam A2	Arcam S12 Arcam A2		
Description	Most widely used titanium alloy. Properties after processing similar or superior to wrought material	Ti6Al4V is the most widely used titanium alloy. Properties after processing similar or superior to wrought material	Ti6Al4V is the most widely used titanium alloy, ELI stands for Extra Low Interstitial providing increased ductility and enhanced properties at cryogenic temperatures		
Typical applications	Aerospace structures, medical devices	Direct Manufacturing of parts and prototypes for racing and aerospace industry, Biomechanical applications, Marine applications, Chemical industry, Gas turbines etc.	Biomedical implants, Marine applications, Aircraft components Cryogenic applications		

Cobalt based alloys

Property	Stellite 6 <i>Accufusion</i>	ASTM F75 Cobalt Chrome alloy <i>Arcam AB</i>	EOS Cobalt Chrome MP1 <i>EOS GmbH</i>	EOS Cobalt Chrome SP1 <i>EOS GmbH</i>	LENS CoCr <i>Optomec</i>
Tensile Strength	Vertical 1245 MPa Horizontal 1362 MPa	900 MPa			
Yield strength	Vertical 751 MPa Horizontal 1023 MPa	600 MPa			
Tensile Modulus					
Elongation at break	Vertical 3% Horizontal 3 %	10 %			
Thermal Conductivity					
Fatigue strength@600MPa					
Specific Gravity					
Hardness	HRC 58	HRC 34			
Manufacturing Pro- cess or Machine	Accufusion LC	Arcam S12, Arcam A2	EOSINT M270	EOSINT M270	LENS 750, LENS 850R
Description	Wear resistant cobalt chrome alloy	ASTM F75 is widely used for orthopaedic implants. Medium strength and stiffness combined with high corrosion resistance and good biocompati- bility.	Fine-grained pre-alloyed cobalt- chrome-molybdenum powder. Conforms to the composition of UNS R31538 and meets the requirements of ISO 5832-4 and ASTM F75 as well as ISO 5832- 12 and ASTM F1537	Fine-grained pre- alloyed cobalt-chrome- molybdenum powder. Conforms to the com- position of UNS R31538 and meets the require- ments of ISO 5832-4 and ASTM F75 as well as ISO 583212 and ASTM F1537	
Typical applications	(Aerospace) vane plugs, fuel metering pins, spacer bushings, (bearings) ball blanks, race blanks, (valve seat inserts) diesel engine exhaust, fluid valve seats, saw cutter inserts, miscel- laneous wear parts.	Direct Manufacturing of orthopaedic im- plants for hips femoral knees and tibial trays, prosthesis and aero- space applications.	Biomedical implants; spinal, knee, hip bone, toe and dental. Parts that require high mechani- cal properties at elevated tem- peratures; turbines engine parts, cutting parts. Parts with small features that require high strength.	AS Cobalt Chrome MP1 but developed to fulfil the requirements for dental restorations, such as being veneered with ceramic material.	

Nickel based alloys

Property	IN-625 <i>Accufusion</i>	IN-738 <i>Accufusion</i>	CL 100NB <i>ConceptLaser GmbH</i>	LENS Inconel 625 <i>Optomec</i>	LENS Inconel 713 <i>Optomec</i>	LENS Inconel 718 <i>Optomec</i>	LENS Hastelloy X <i>Optomec</i>
Tensile Strength	Vertical 744 MPa Horizontal 797 MPa	Vertical 1202 MPa Horizontal 1084 MPa					
Yield strength	Vertical 477 MPa Horizontal 518 MPa	Vertical 869 MPa Horizontal 880 MPa					
Tensile Modulus							
Elongation at break	Vertical 48 % Horizontal 31 %	Vertical 18 % Horizontal 7 %					
Thermal Conductivity							
Fatigue strength@600MPa							
Specific Gravity							
Hardness	HV 283						
Manufacturing Process or Machine	Accufusion LC	Accufusion LC	M2 Cusing	LENS 750, LENS 850R	LENS 750, LENS 850R	LENS 750, LENS 850R	LENS 750, LENS 850R
Description	Inconel 625, Heat resistant Nickel super alloy	Inconel 738, Heat resistant Nickel super alloy	Inconel 718, Heat resistant Nickel super alloy.	Inconel 625, Heat resistant Nickel super alloy	Inconel 713, Heat resistant Nickel super alloy	Inconel 718, Heat resistant Nickel super alloy	Hastelloy X, Heat resistant Nickel super alloy
Typical applications	Aerospace components, corrosion resistant applications	Hot section gas turbine blades	Components subjected to high temperatures, gas turbine blades	Aerospace components, corrosion resistant applications		Components subjected to high temperatures , gas turbine blades	In the gas turbine, aerospace, and chemical process industries.

Aluminium alloys

Property	Al4047 <i>Accufusion</i>	LENS 4047 <i>Optomec</i>	CL 30 Al <i>ConceptLaser GmbH</i>	CL 31 Al <i>ConceptLaser GmbH</i>	
Tensile Strength	Vertical 317 MPa				
Yield strength	Vertical 139 MPa				
Tensile Modulus	74 GPa				
Elongation at break	Vertical 9 %				
Thermal Conductivity					
Fatigue strength@600MPa					
Specific Gravity					
Hardness					
Manufacturing Process or Machine	Accufusion LC	LENS 750, LENS 850R	M2 Cusing	M2 Cusing	
Description	Aluminium alloy 4047	Aluminium alloy 4047	Aluminium alloy AlSi12	Aluminium alloy AlSi10Mg	
Typical applications	Prototypes and components	Prototypes and components	Prototypes and components	Prototypes and components	

FGMs; Substrate Compatibility, Powder Injection Processes: DMD

	Substrate material								
DMD material	Tool steel	Stainless steel	Low C Steels	Cast Iron	Ni alloys	Co alloys	Cu-alloy	Ti alloys	Hardness HRC
H13	OK!	OK!	OK!	OK!					54 – 58
P20	OK!	OK!	OK!	OK!					36 – 44
P21	OK!	OK!	OK!	OK!					54 – 49
S7	OK!	OK!	OK!						52 – 54
420SS	OK!	OK!	OK!						48 – 52
316LSS	OK!	OK!	OK!						23
17-4 PH SS	OK!	OK!	OK!						22
CPM1V	OK!	OK!	OK!						60 – 62
Invar	OK!		OK!						RB 75 – 78
Stellite 21	OK!	OK!	OK!			OK!			30 – 35
MERL 72					OK!	OK!			
Stellite 6	OK!	OK!	OK!		OK!	OK!			46 – 50
Stellite 706	OK!		OK!			OK!			42 – 46
IN 718	OK!		OK!	OK!	OK!	OK!	OK!		22 – 24
Waspalloy					OK!	OK!			30
Inc 738					OK!	OK!			
IN 625	OK!		OK!	OK!	OK!	OK!			13
C-276	OK!	OK!	OK!	OK!	OK!	OK!			32 – 35
Nistelle C	OK!		OK!	OK!	OK!	OK!			32 – 34
Ferrous base +Carbide	OK!	OK!	OK!						50 – 60
Non-ferrous base +Carbide	OK!	OK!	OK!			OK!			45 – 60
CP Ti								OK!	32 – 35
Ti-6Al-4V								OK!	36 -40

Courtesy of POMGroup

10 RM Networking

10.1 RM Technology Platform

What is the RM platform?

It is a community of (mainly industrial stakeholders) defining research and development priorities, timeframes and action plans on a number of strategically important issues related to RM. The European Commission supports these activities, and gives the opportunity to contribute to the **FP7** work programme.

Objective

The objective of the RM-Platform is to contribute to a coherent strategy, understanding, development, dissemination and exploitation of Rapid Manufacturing (RM) as enabling technology to strengthen the European economy.

More information at: www.rmplatform.com.

11 Appendices

Cases attached.

ABB HIGH PERFORMANCE MACHINERY DRIVE

Part dimensions (WDH)	165*467*225
Part material	Polyuretan
Machine	Laser sintering

This is a typical rapid prototyping case, where modern RP methods have been used to realise functional prototypes for simulation and testing before manufacturing the injection molds.

All the plastic parts, six (6) altogether, have been manufactured with laser sintering. These prototypes have been used in vibration tests, cooling tests and designing the package for the product. In this case the prototypes showed some problematic areas in the product, and some minor changes were made before manufacturing the injection molds.



Contact Information:

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ADAPTER

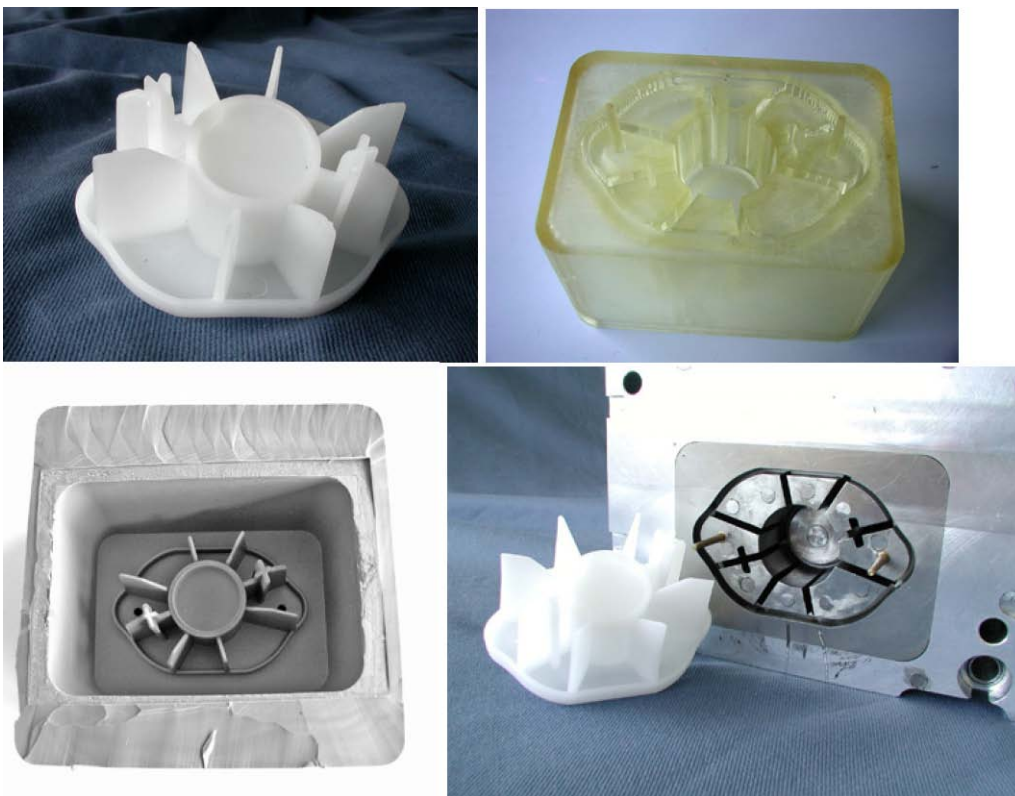
	235x170x45 mm
Part material	PP
Machine	DMLS, Similar to Keltool
Delivery time	3 weeks
Tool price	4800 Euro

Part and process description

Lead time 150 h:

- Engineering (15h)
- SLA master manufacturing (22h +34h)
- Silicone rubber mould manufacturing – Green part manufacturing -Sintering and infiltration – Working hours (40 h)

The figures show the SLA master, rubber mold, and the tool and the part.



Contact Information:

Prototal AB, Sweden
<http://www.prototal.se>



AEROSPACE

Part dimensions	Ø 87 x 140 mm
Part material	Ti6Al4V
Machine	Arcam EBM S12
Delivery time	8 h
Part weight	625 g

Part and process description



Contact Information:
Arcam AB
<http://www.arcam.com>



POT LID

Part dimensions (WDH)	Ø 1150 mm, 250 mm
Part material	Stainless steel, 1 mm
Machine	Incremental forming machine

Part and process description

Incremental sheet forming (ISF) is a rapid manufacturing method for sheet metal products. It is suitable for rapid prototyping and manufacturing in small series.

In this case study ISF has been used in rapid manufacturing application. The case part is a lid for a porridge pot used in food industry. Manufacturing the part is difficult due to its dimensions. It could be formed by deep drawing or spin lathing, but the size is too large for most of the machinery. Using ISF enabled forming of the product, and since there was only two parts needed, it was economically reasonable.

This particular case was formed with very simple support tool: a simple steel plate, with a hole in the middle. The part was formed up side down so that the cone was pressed in to the hole in the support tool. The forming tool used in this application had 30 mm diameter. The Z-step used was 1,0 mm on the shallow surfaces and 0,5 mm on the steep wall areas.

The geometry of the part is rather difficult for ISF because of the large shallow surface area. If it is formed with a small diameter tool, the tool marks are disturbingly visible on the surface of the sheet. As the part is a final product, and not a prototype, the good surface quality was essential for the customer. Forming on the concave surface ensured very good surface quality on the outside of the lid, and sufficient surface quality on the inside.

Using ISF in this application saved both costs and time. Deep drawing would have required large hard tools, which are very expensive. Spin lathing is such a rare process, that the machinery was not easily available. ISF provided a inexpensive, effective and high quality solution to the problem, and resulted in good quality parts for the need.



Contact Information:

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<http://www.smi.fi>

TERMINAL CONNECTOR

	120 x 70 x 40
Part material	SLS Pa 2200
Machine	SLS 380
Delivery time	Day to day

Part and process description

With Rapid Manufacturing (RM) final products can be produced to the end-user by means of 3D technologies and other digital data.

Emerson Process Management Marine Solutions' new connection terminal is designed and produced at Danish Technological Institute's SLS machine. The terminal consists of four parts but is manufactured in just two pieces. The actual terminal including axles is constructed in one piece whereas a "lid" which covers the electric cables makes up the other part of the terminal.

Centre for Product Development carried out a product revision on the existing connection terminal which resulted in an optimization of the product to process by using the degree of freedom which the technology allows a product to have when it has several functionalities.

The final result was the new terminal which both has a construction that is easy to assemble and a sturdy design. And the price of the terminal is only one third of the predecessor's price.

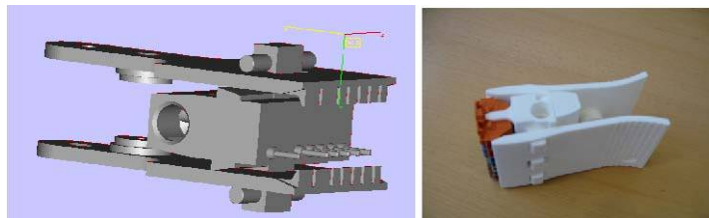
Emerson Process Management Marine Solutions (former Damcos) delivers equipment to marine companies and uses the terminal to connect six cables to one connection block in a jiffy when they control their electro-hydraulic units before the final assemblage.

The design of the terminal makes it impossible to misconnect the cables.

With the relatively small amount that Emerson Process Management Marine Solutions needs – maybe 10-15 parts divided among the different departments in Denmark, China and Korea – Rapid Manufacturing offers a great solution at a reasonable price.

Furthermore, the design is remarkably improved compared to the original terminal, which was cut out of plastic blocks, assembled by several pieces and mounted with cylinder pins as axles.

Besides, for Emerson Process Management Marine Solutions it was advantageous to have the finished parts delivered in short time instead of loading own working machines that had a long delivery time.



Contact Information:

Emerson, Ulrik Dantzer
<http://www.emersonprocess.dk/>

MOUNTING FIXTURE IN THE EOS MACHINES

Part dimensions (WDH)	
Part material	PA 2200
Machine	SLS : Laser-Sintering on EOSINT P

“Catalog Solution”

- Complicated screw-design
- 20 parts
- Costs 30 Euro / piece with 5 Euro for mounting + working-time at the installation

“Individual Solution”

- 2 directly integrated hinged joints and spring catches
- 2 parts (sintered + moss-band)
- Costs about 25 Euro / piece, negligible for mounting, no working-time at the installation



Contact Information:

Eos GmbH, Germany
www.eos.info

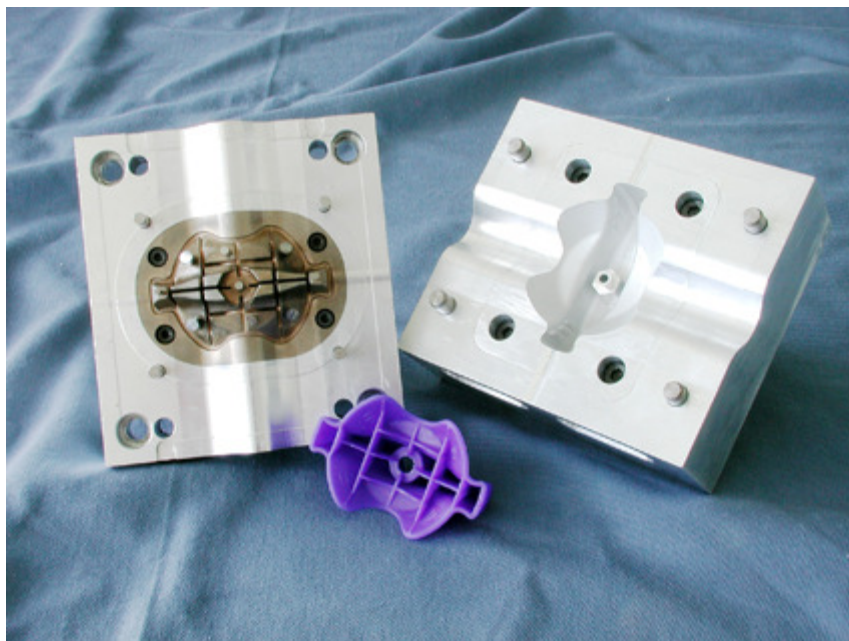
HANDLE

Machine	DMLS
Delivery time	40h

Process steps:

- FFF or milled master tool pattern
- Silicon mould casting
- Green part manufacturing
- Sintering and infiltration

Demands for short delivery time -Geometry (fine features) – Moderate surface demands.



Contact Information:

Prototal AB, Sweden
<http://www.prototal.se>



POWER SECURE

	70 x 25 x 15 mm
Part material	Nylon PA2200
Machine	SLS 380
Delivery time	Day to day

Part and process description

With Rapid Manufacturing (RM) final products can be produced to the end-user by means of 3D technologies and other digital data.

The company PowerSecure contacted Centre for Product Development, when it had invented PowerStop. The company asked for help to design the cabinet to the system, and since the ideas of the invention were still on a preliminary stage, a lot of development had to be carried out.

Centre for Product Development designed and produced small series of the cabinets by means of the centre's SLS machine.

SLS is typically used for Rapid Prototyping and is advantageous since you can test the construction of the individual parts thoroughly during the prototyping.

The machine can manufacture quite small series, and any changes of the construction can be made directly in the 3D drawing, from which the SLS machine constructs the unit.

PowerSecure has applied for universal patent on PowerStop, and so far there is no indication that anyone else has got the same idea.

-It is a totally new way to protect against theft. With other burglar alarms, the stolen units will still have a value. Equipment using PowerStop has no value when it has been stolen, says Johnny Jensen from PowerSecure who hopes that the system will become so successful that the manufacturers of electronic equipment see it as an advantage on the long view to incorporate it in their products.

PowerStop has been subject to several technical tests and has been tested by different users in Denmark.



Contact Information:
Power Secure ApS, **Johnny Jensen**
www.powersecure.dk



norden

Nordic Innovation Centre

Nordic Innovation Centre

Nordic Innovation Centre (NICE) is an institution under the Nordic Council of Ministers facilitating sustainable growth in the Nordic economies.

Our mission is to stimulate innovation, remove barriers and build relations through Nordic cooperation. We encourage innovation in all sectors, build transnational relationships, and contribute to a borderless Nordic business region.

We work with private and public stakeholders to create and coordinate initiatives which help Nordic businesses become more innovative and competitive.

Nordic Innovation Centre is located in Oslo, but has projects and partners in all the Nordic countries.

For more information: www.nordicinnovation.net