Multiphase Jet Solidification – a new process towards metal prototypes and a new data interface

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Abstract

The production of metallic and ceramic parts with RP technologies is requested. Multiphase Jet Solidification (MJS) is a process which reveals good results to develop a commercial system due to this task. Low viscous materials (liquefied substances or powder–binder–pastes) are extruded through an x–y–z–controlled jet and parts of different materials e.g. stainless steel are fabricated layer by layer up to the final extension. The basic principle of the process and the current results will be presented. A slice format was designed for MJS, but it is also usable for other RP technologies. The goal is the development of a general slice interface for RP.

Introduction

Two Institutes of the Fraunhofer Gesellschaft, the Institute for Manufacturing Engineering and Automation in Stuttgart (IPA) and the Institute for Applied Materials Research in Bremen (IFAM) are developing an RP process suitable to produce metallic and ceramic parts directly. The sum of the experiences in manufacturing engineering and information processing at IPA and those in material research at IFAM turned out to build a good team to achieve this aim. After some preliminary examinations of different ideas the working–principle was developed and named "Multiphase Jet Solidification (MJS)". The working–principle will be explained in the first section and the results by producing parts with a first apparatus assembled and tested at IFAM will be shown. Subject of the second section are examinations and developments in information processing. A slice format is, as in most RP systems, base for the computation of the NC code for MJS. Aim of the current work is a slice format suitable for RP processes in general, whereby a first implementation was realized and tested to run MJS. The next task is the coordination of the different contributions to a 'de facto' slice standard. Such a standard is necessary, but its syntax and contents have still to be discussed.

Principle of MJS

The basic idea is to extrude material through a jet, similar to other apparatus such as the 3D Modeler of Stratasys or the Model Maker of Sanders Prototype. In contrast to these techniques the production of metallic and ceramic parts is the main aim of this development. Because of technological limits, pure materials with a high melting point can not be liquefied with the apparatus. Additional to the liquefied pure material, powder–binder–mixtures are used, if the melting point of the material is too high. In any case the material (mixture) is heated above its solidification point and deposited layer by layer. The melted substance solidifies when it gets into contact with the platform or the previous layer due to temperature, pressure decrease and heat transfer to the part and the environment.

For the present research a simple apparatus is used to test the general feasibility, parameters of the building process and different materials. The main components are an x–y–z–computer controlled positioning system (machine precision +/–0,01 mm, axis traversing 500*540*175 mm^3), a heated chamber and a jet system. The chamber is temperature–stabilized and can be varied within a range of 70 degree to 220 degree Celsius. The material is supplied as powder, pellets or bars. The material flow is controlled by a piston pressing the viscous material through the jet. The first test apparatus is shown in figure 1.

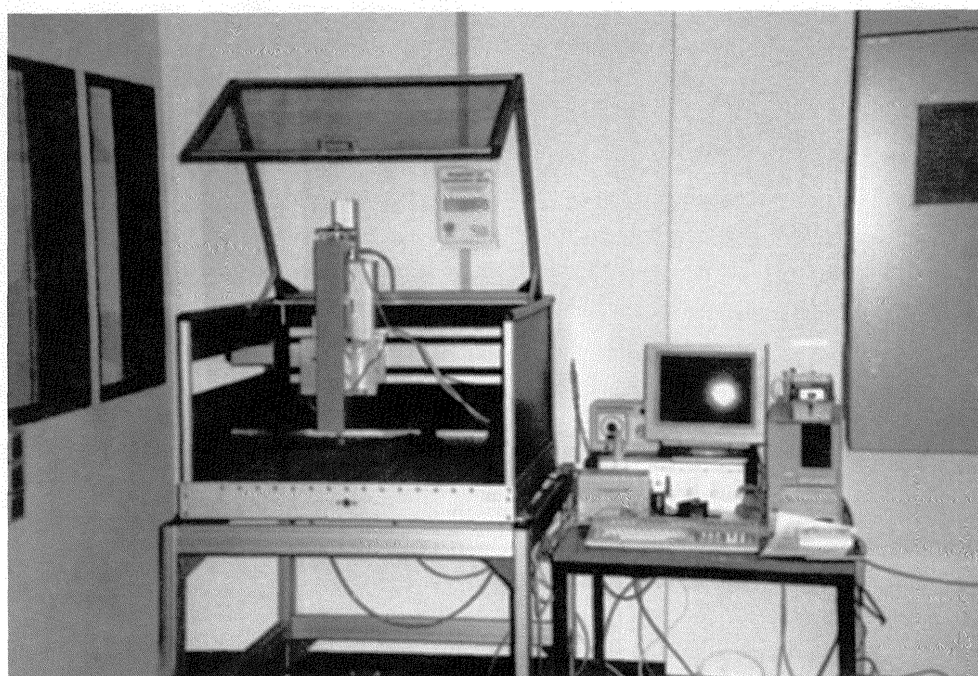

Figure 1: Alpha apparatus of Multiphase Jet Solidification

Production by liquefaction of metals

Metallic parts with a low melting point are directly fabricated by deposition out of the molten phase. The first experiments were accomplished with tin–bismuth alloys (melting temperature up to 180 degree Celsius) which are normally used for mould making and metal spraying. The microstructure of parts shows a good bonding between the layers.

The accuracy of the parts is still limited due to the low viscosity and the surface tension of liquid metal. Therefore, the liquid metal contracts directly after the extrusion before solidification. First experiments by alloying particles into the metal in order to increase the viscosity are very promising.

The melting temperature of industrial relevant materials like metals, e.g. zinc and aluminium, is much higher than this of the tested alloys. Therefore, it is an important task to improve the apparatus towards higher temperatures.

Deposition of powder–binder mixtures

To produce prototypes of materials with higher melting points like ceramics and the most metallic alloys the use of powder–binder mixtures reveals good results. First, prototypes made of stainless steel were fabricated via a powder–binder mixture. At a certain temperature of about 100 degree Celsius the mixture has a suitable viscosity to extrude it via a nozzle. Because of low surface tension the material can be deposited very exactly without contraction. Subsequently the green parts are processed like a metal injection moulded (MIM) part by debinding and sintering to final density. The microstructure and the mechanical properties of the prototypes are comparable to MIM parts.

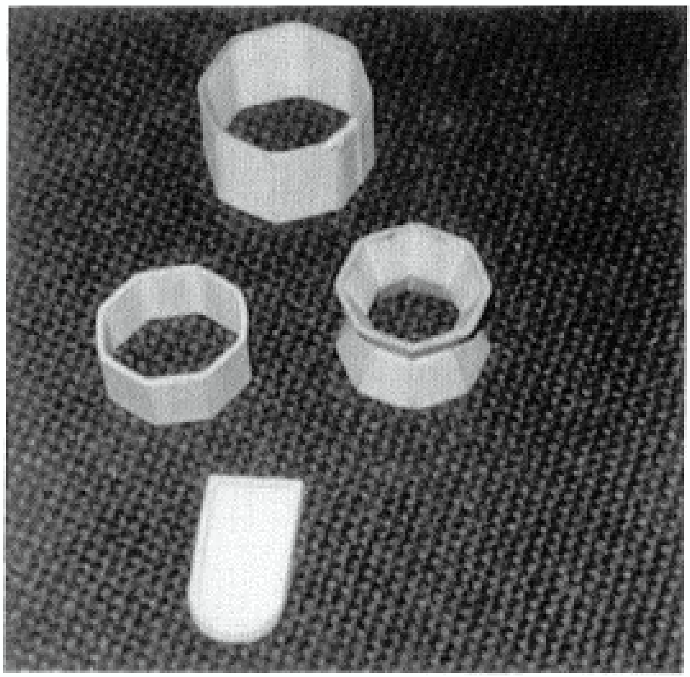

Figure 2: MJS parts in stainless steel

The accuracy of the parts is higher than of the liquefied metal process. The material behaviour of the mixture allows a greater overhang angle. But volume shrinkage of about 30% due to sintering must be taken into account when generating the control data. In MIM, the mixture is pressed with a high velocity into a mould. Powder–binder segregation caused by the different densities of metal powder and binder could often be observed. In MJS, this turned out to be no problem because of the low velocity of the material through the jet in comparison with MIM. A further advantage is, that the green parts can be easily finished to a very smooth surface. Figure 2 displays sintered metallic parts (average diameter is about 60 mm) out of stainless steel.

During sintering, special care has to be taken to avoid distortion by reducing the friction between the part and the support. The wall thickness of the prototypes is currently limited to about 15 mm due to the debinding–process. If thicker areas are necessary, it is possible to use hatches instead of filling the entire contour. Optimization of the binder components is a further task to increase the maximum wall thickness.

Experiments with other powder–binder mixtures in order to achieve titanium and copper parts have been carried out. The process turned out to be practicable for a wide range of materials. Also the production of ceramic parts like alumina and silicon carbide is in development.

The alternative to the sintering is the infiltration process. The debinded metallic part can be infiltrated by a second metal with a lower melting temperature. This metal is sucked up by the part due to a capillary effect. The benefit of this process is the fact that there is no need to account shrinkage.

Data preparation for RP

For discussions and developments on data handling in RP it is important to consider the present global activities in developing the common, object oriented 'Standard for the Exchange of Product Model Data' (STEP) /1/. In the future, the data describing geometry, topology, features, materials, tolerances, etc. can be used for the planning and rapid production of prototypes. The direct link to different technologies e.g. Virtual Reality, CAM and CAQ with one common throughout data model will become possible. In a common project of several Fraunhofer–Institutes activities to develop a STEP based data handling in RP will start this year. But international standardization needs a lot of time. Until STEP is applicable for RP, the industry needs fast and suitable solutions fitting the different applications best. The data handling, which will be discussed here, could be seen as an interim step until STEP is spread off in industry. Furthermore, the results in developing, using and testing the data format of this interim step will lead to a practical experience which inputs to the development of a STEP Application Protocol.

The exchange of the RP relevant geometry information of parts between CAD systems is based on 3D data, e.g. neutral data models (Initial Graphics Exchange Specification (IGES), interfaces of the 'Verband der deutschen Automobilindustrie' – VDA–FS, VDA–IS – /2/, etc.) or facet formats developed for RP (STL, CFL, etc.). Slice routines exist or all these formats. But the commonly used facet format is STL. Nearly all related CAD vendors offer an STL interface. The disadvantages of the STL syntax are sufficiently discussed. Nevertheless, there is no need for a new 'de facto' facet standard for RP. Time and energy to spread off a new facet format is very high compared with the benefits. Other facet formats, fitting some applications better should be used individually, but should not be used or spread off as an exchange format. Experience made in RP or other areas using facet formats (e.g. Virtual Reality and Finite Element Methods) should be included in the developments of STEP. Nevertheless, benefits of individual facet solutions in special application will be demonstrated later by the example of reverse engineering.

An essential point of the interim data handling is a 'de facto' standard for slice information additional to STL! Direct CAD slice interfaces become even more important. Unfortunately, there is a wide range of variations in slice formats. Nearly every vendor uses its own slice format e.g. SLC, CLI, HPGL. The content of this different slice formats varies from pure geometry information up to machine specific data.

Figure 3 gives an overview of the data handling using one common facet format and one common slice format. The most important benefit of the two 'de facto' standards will be, that users will have the choice to select the data handling (direct slice interface or slicing of STL) depending on which one fits their problems best.

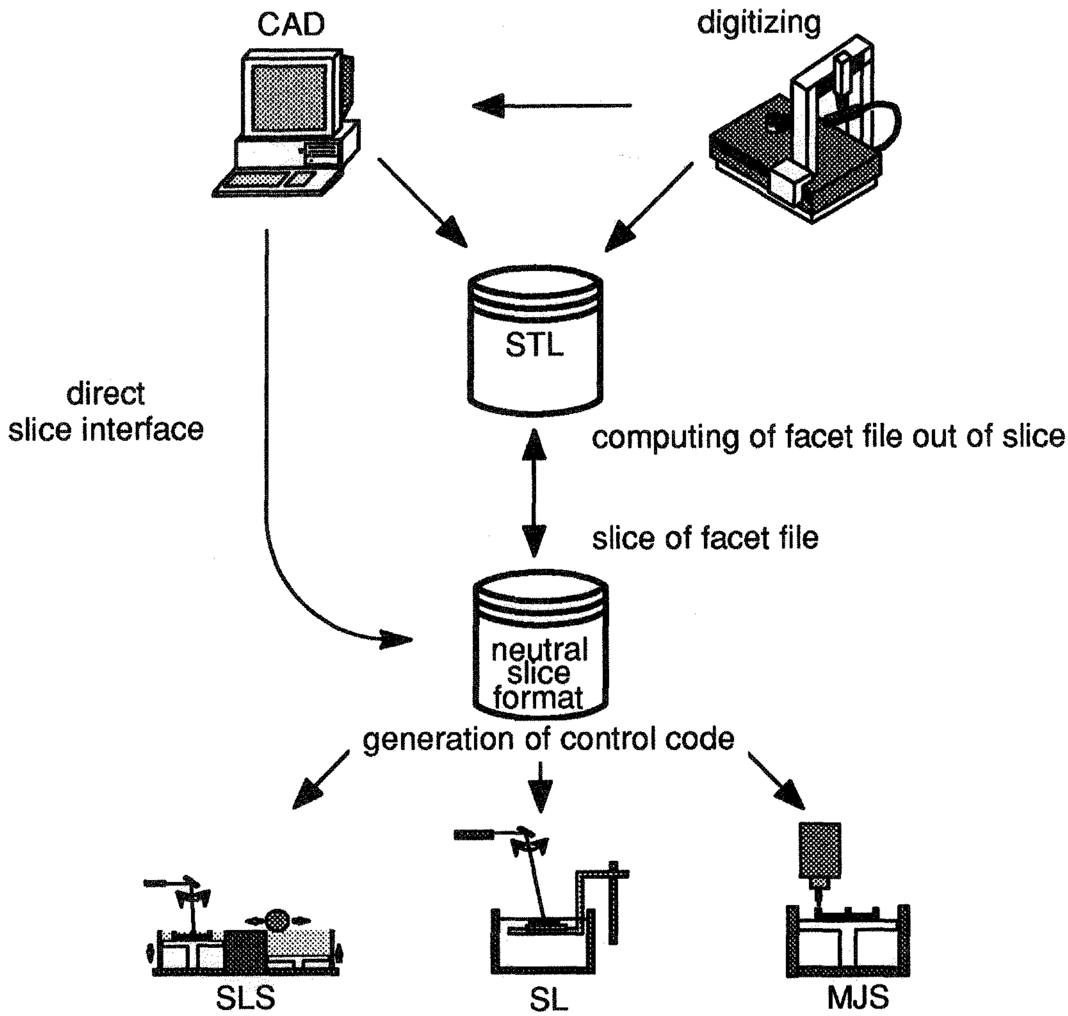

Figure 3 : Data handling in RP

The opinions on direct slicing and on slicing of facets break up in a wide range, dependant on experiences, habits and strategical aims. From a mathematical point of view, there is no difference. The accuracy depends on the quality of the software and not on the choice. The mathematical expenditure to compute a facet format and slice it afterwards is in general equal to the direct slicing. In practise, there are a lot of differences in quality, ergonomics, time and costs dependant on the available software and on the special application. In our opinion, the users should be able to decide themselves. But in fact, the users mostly do not have the choice, because there is a lack of a 'de facto' slice standard and due to this, a lack of software tools supporting direct slicing.

Improved facet description for reverse engineering

Reverse engineering plays an important role in Rapid Product Development. Independant of the individual sensor the result of the digitizing process is point data. Software for automatic detection and computation of regular geometries and freeform surfaces based on a spline description is complex and difficult to realize. The current available solutions are limited in their abilities. As shown in figure 3, an alternative to link digitizing to RP is to compute a facet presentation of the geometry. A problem is, that a part has to be measured from different views. The result is a number of records with overlapping areas. The hardware installation and software at IPA enables to compute a facet description of the measured areas. Contraction of the point data set and smoothing of the surface is also possible. Furthermore, a software tool to handle, to change and to close the surface according to different applications was developed.

The objective of this tool will become clear with the following example of application. "The hilt of a butcher knife is often designed by manual manufacturing of a physical model. A property of this model is, that one side of the hilt is not the exact reflecting surface of the other. So, the first step to produce a prototype is to determine the better side and to digitize it from selected directions. The point data set leads to a facet file describing the better side of the hilt and due to the measurement process some areas of the other side. To achieve a closed description of the whole hilt the facet file has to be limited by a plane and the mirror image has to be computed."

Data files in reverse engineering do not seldom have millions of facets. Therefore, speed is an important request for the software tools. The STL format turned out to be less suitable to that issue. Access time to selected information is too slow. Therefore we use an own format designed for this demand. Similar to CFL we have a list with the values of all points. The triangles are described using the numbers of the edge points. In addition, we sort the triangles related to the software tools used for special applications. Optional files describing the sorted stock enable very quick algorithms to handle the facet information. If we use our facet format, sort it according to the application and do the mapping to an STL file at the end, it turned out that this way is much faster than handling the STL file.

Neutral slice format

Slices are the lowest common denominator among RP systems. For several reasons the users request for a neutral slice format becomes even higher. The choice between different RP systems in product development increases. Users want to apply the same software for different RP systems as well as they prefer direct slice. Some benefits of a 'de facto' slice format are:

- Software developers have free access to the syntax. The free access simplifies the development of software tools improving the data handling. For the users the choice between different software tools would raise.
- CAD vendors are surely more willing to develop a slice interface, if there is one common format.
- In medical application the output of tomographs is slice information. A common direct link to nearly all RP systems would be available.
- Corrections of failures in the geometry description are easier to make in some cases.
- In developing new RP systems there is no need to develop an individual slicer.

Admittedly, there are a lot of applications where the use of slice information has disadvantages. One is that it is not usable to exchange geometry information for LOM, because the slice thickness varies online during the process. Furthermore, there are disadvantages in manipulating the part e.g. rotating of sliced parts. But once again, it should not replace a facet format but it should supplement it. The decision which one to use for the different applications is task of the users.

Examinations to such a slice format were done in a European project. The format requirements and the results have been published /3/. The format Layer Exchange ASCII Format (LEAF) was developed but has not been realized. It has an object oriented structure where instances of an object of given classes can be created. The only 2D primitive supported by LEAF are polylines. The physical representation of LEAF uses keywords determining the following syntax.

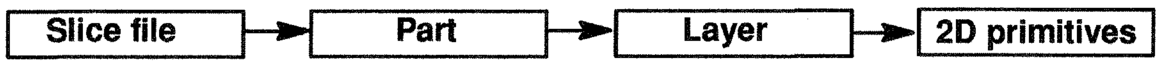

Figure 4 : Object class tree of LEAF /3/

Further work was done in another European project. Recently CLI, the slice format of EOS, has been improved. The new version should be suitable for most RP systems. System dependant information can be presented in the header section. Unfortunately, the latest version is not distributed until now, so a final comment is not possible.

One task of the slice format at IPA is to run MJS as well as a Laser Modeling System of Fockele & Schwarze. The second task is to get experience for the development of the slice part of an RP STEP Application Protocol. Therefore, an object class tree (figure 4) as it is used in LEAF is the basic structure, too. The slice file should describe the product's geometry. However, the geometry of the RP part often deviates from this according to a special application. For investment casting the stereolithography part is produced with the QuickCast build style or only the shell of the part is produced. With MJS it is often of advantage to use special fill strategies due to the following sinter process. E.g. the format must be capable to contain this information.

Regular geometries are often sliced in direct slice processes. Therefore, the slice result is a summary of regular 2D primitives, e.g. lines, arcs, circles and ellipses. These primitives should be handled as primitives and not as a sum of polygon lines due to storage space.

Good experience was maid with a structure that allows a direct link between 'inner' borders to the surrounding 'outer' border (figure 5). The computation of NC code turned out be easier and faster.

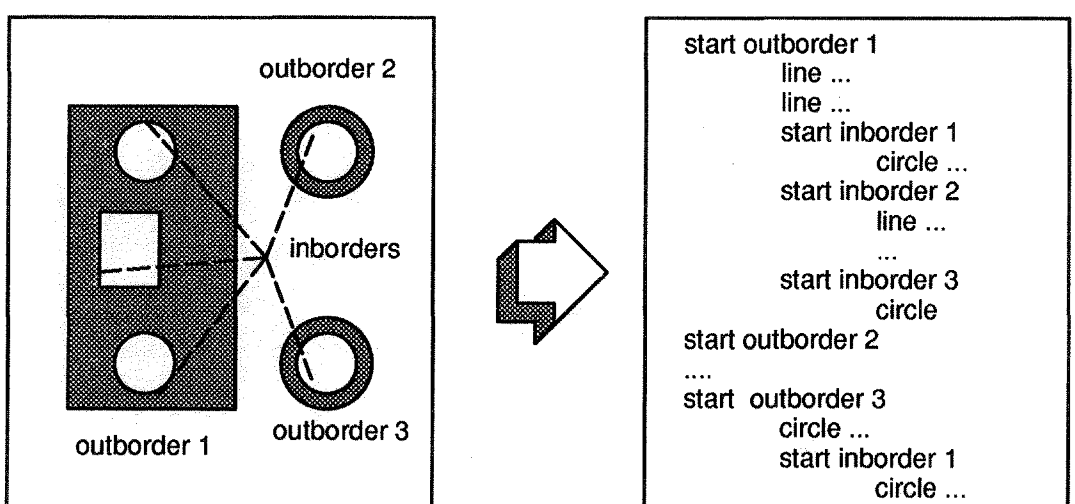

Figure 5: Slice and diagrammatic structure of slice 2D primitives

Efforts to bring the experience of CLI, LEAF and those made during the design of IPA's format together and to coordinate the activities were started. Different questions about contents and syntax of the format have to be discussed. But it will surely be a compromise between the demand to an early available format and the demand to a 'perfect' format. Nevertheless, long term aim is STEP.

Conclusion

The advantage of the MJS–process is the high flexibility of materials, e.g. high melting metals and ceramics, and the simplicity of the apparatus. The future developments will improve accuracy and the number of materials.

The applications of the RP technologies are still increasing. Easy and free choice of RP systems and available software tools fitting to the special equipment and application of the users is required. The acceptance of a 'de facto' slice standard by all RP vendors would probably improve the present situation in data handling. Both a facet and a slice description should be part of a STEP based data handling in RP

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