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RAPIDPRE: A NEW ADDITIVE MANUFACTURING TECHNIQUE BASED ON REACTION INJECTION MOULDING

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Abstract: *This paper discusses a new Additive Manufacturing technique based on reactive extrusion. The approach allows the manufacture of high quality products from polyurethane materials with the possibility of composites and multiple materials in a single part. The use of these thermosetting polymers makes it possible to create parts that are better tailored to the final application and to prevent temperature based distortion during fabrication.*

Key words: *Reactive Injection Moulding, Additive Manufacturing Processes*

1. INTRODUCTION

In 1989 the additive extrusion technique, known as Fused Deposition Modelling (FDM), formed the base technology of the Stratasys Company. By this process, thin thermoplastic filaments are melted by heating and guided by a robotic device (extruder), controlled by a computer, to form three-dimensional objects. The material leaves the extruder in a liquid form and hardens almost immediately. The previously formed layer, which is the substrate for the next layer, must be maintained at a temperature just below the solidification point of the thermoplastic material, to assure good interlayer adhesion (Crump et al 1994).

This process only works with thermoplastic materials, which have properties strongly dependent on operating conditions such as extrusion temperature, environmental temperature and solidification time. As the process requires the melting of solid material it is a disadvantageous one from an energetic point of view.

One of the major problems associated with models produced by FDM is the "curl" effect. "Curl" corresponds to the curvilinear geometric distortion induced during the cooling phase (Pham & Gault 1998). Such distortion is due to changes in density of the material as it transforms from a melting state to a solid state. To reduce the impact of curl distortions different processes have been proposed. One involves the heating of the building chamber, thus reducing possible temperature differences. Another one involves extruding the build material at the lowest possible temperature.

2. THE PROPOSED SYSTEM

Rapid prototyping by reactive extrusion (RapidPRE) corresponds to a novel concept of rapid prototyping or manufacturing that produces thermosetting parts through a low-pressure extrusion process at room temperature of a mixture of polyol and isocyanate (or other chemical reactive materials). One key aspect of this process is the appropriate mixture of these chemical compounds performed in a chamber (mixing-head). The process is mainly based on the mixing and reaction of polyurethane (PU) materials. Other thermosetting materials can also be used, like epoxy and unsaturated polyester resins curing at room temperature or reinforced thermosetting material.

Polyurethanes (PU) are step-addition polymers formed by the reaction of di- or poly-isocyanates with diols or polyols. They represent a unique class of polymers whose properties can be easily tailored by the variation of its components.

The fabrication of models through Rapid PRE involves the following steps: -

1. CAD model generation
2. Model decomposition into sub-components or sub-parts using appropriate algorithms
3. Evaluation of the extruders' paths (and print-head paths) for both deposition of soluble wax material (support structures or soluble mould) and casting polyurethane material
4. Deposition of wax material to create walls for casting the thermosetting material
5. High pressure mixture of polyol and isocyanate (impingement stage) and low pressure extrusion of the obtained low viscosity mixture (casting stage)
6. High speed curing of the polymeric system at room temperature
7. "Demoulding" the part through water jet

This process enables the production of high quality parts in which materials show low shrinkage and the fabrication of the part is not made through the conventional layer-by-layer approach. Additionally, the combination of different types of polyols and isocyanates, without changing processing conditions, enables production of parts with a wide range of properties and colours (in fact different colour and properties - rubber like, rigid and foam - can be applied on the same part). It can also produce reinforced polyurethane parts or polyurethane foams. Another important advantage of this technology is the cost associated with the fabrication stage, materials and machine. Rapid prototyping by reactive extrusion involves the mixture of low viscosity compounds, which are extruded at low pressure and cured at room temperature.

The project will be focused in three main research areas:-

- Software for pre-processing, processing and pos-processing. New strategies based on the division of the part in geometric features will be implemented.
- Materials for part and moulds: development of optimised polyurethane materials for the RapidPRE process. We will develop three different types of materials: one rubber like material, one rigid material with and without fibers and the third a foam material (rigid and flexible). For the moulds the research team will develop a wax material or a polyethylene glycol based material. All materials will be characterised in terms of rheological performance, plus structural and thermal compatibility between the mould and part materials.

- Rapid Manufacturing process.

In order to obtain good details and precision it is necessary to produce excellent mould features. To obtain this we will select an ink-jet printing device to test on the wax or polyethylene glycol based material and develop a mixing head and metering system for the polyurethane delivery. We will test several materials in the print-head and in the mixing head. Both mixing and printing devices will move in XYZ by CNC control. It is also necessary to ensure appropriate mixing, which strongly depends on the mixing head configuration (Trautmann & Piesche 2001).

Advantages of this process
- Easy to change materials
- Variety of materials available
- No exposure to toxic materials or lasers
- Good mechanical strength

Disadvantages of this process
- Supports are required
- The process is slow for models with a large mass
- The models have poor strength in the vertical direction
- Temperature fluctuations during production could lead to de-lamination
- Limited accuracy due to the diameter of the filament used
- The need of filament material
- Narrow processing window

This work developed mainly for Reaction Injection Moulding process (RIM), was been focused on the optimisation of (Gouveia et al 2008, Mateus et al 2008):
- mixing heads, and implementation of new active mixing strategies
- Study of the influence of mould material on final properties of polyurethane parts injected by RIM
- Simulation and prediction of properties of final injected parts

This Rapid Prototyping by Reactive Extrusion will produce design evaluation models, functional components and biomedical devices, with small and large components. These biomedical devices can include blood transfer systems and implants and our approach will lead to safer and more reliable devices. Composite structures can also be made through this process.

This project combines the knowledge from past reseach projects in the field of Rapid Prototyping and Polyurethanes Processing Mechanism. To carry out this project several techniques for materials characterisation will be used:
- Differential Scanning Calorimetry (DSC): DSC is widely used for both photo and heat activated thermosetting systems. DSC becomes less useful with resins like PUs that are mixing activated. To circumvent this problem, mixing and reaction calorimeters, are used together with breakable vessels, to measure the exothermic rate during the polymerisation process.
- Dynamic Mechanical Analysis (DMA): The DMA system is able to measure material properties such as elastic modulus, yield strength, shear strength, and stress relaxation while performing various mechanical testing procedures, such as stress-strain, fatigue, and creep. With the additional flexibility of an Environmental Chamber, this system is more than capable of characterizing material responses to stresses in a wide range of operating temperatures and loads.
- Scanning Electron Microscopy (SEM): Here a fine electron beam is scanned over a specimen (Polyurethane already formed) and the secondary or backscattered electrons are detected and converted to a signal that forms the image on the viewing screen.

5. CONCLUSION

This project aims at developing a beta-machine using the rapid prototyping by the reactive extrusion principle, a new rapid prototyping concept in terms of software, hardware and processing materials' approach. This project's core is the development and implementation of a software recognizing some geometric features on 3D CAD models, which decomposes it automatically into sub-components. It will also allow a proper layer-by-layer strategy to produce the "temporary mould" using wax-based materials or water soluble polymers like polyethylene glycol based material. On top of this, an extrusion system to produce multi-material, multi-color and heterogeneous parts using high speed curing PU systems will be developed and implemented too. This project will be focused on the following research domains:
- Software for pre-processing, processing and post-processing operations.
- Materials for part and temporary mould (support structure). Four different types of materials will be developed, namely a rubber- like material, a rigid one, foam materials (rigid and flexible) and biomedical PU systems. Some of these materials will be reinforced with small fibers. Furthermore we will develop a wax-based material and a polyethylene glycol based material for the temporary mould. All materials will be characterized in terms of their rheological behavior, mechanical and thermal properties and compatibility between the part material and its temporary mould material.
- Rapid Fabrication process. To obtain good details and precision on the parts produced it is necessary to ensure excellent temporary mould features. It is also important to guarantee an optimized mixing process of both polyol and isocyanate. Both mixing and printing devices will be developed.

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