

NEW METHOD FOR OPTIMIZED DESIGN OF NEW MATERIALS SYSTEMS INTENDED TO BE APPLIED AT ADDITIVE MANUFACTURING TECHNIQUES

OLIVIER GONZALEZ, D[jamila] S[oledad]; BORROS GOMEZ, S[alvador] & REYES POZO, G[uillermo]

Abstract: Based upon QFD methodology approach and quality engineering tools, it has been possible to deploy and to integrate a single document template for analysing and prioritising the interactions between the final application requirements of the refractory metal casting printed moulds, the printability requirements of the powder system and the 3DPrinting process parameters. This approach enables us to deploy the quality assurance for specific testing required through the development process of the alumina based materials system while reducing waste and variability and creating value through the process for its final application.

Key words: Additive Manufacturing, Materials development, Standardization, QFD, DFSS

1. INTRODUCTION

When developing materials for new additive manufacturing applications, it is necessary to use analysis tools to prioritize and to discriminate the most influencing variables over the final properties, throughout the studied process. From the quality assurance point of view, the basic criterion to evaluate is customer satisfaction. Also it is mandatory to introduce an optimization approach throughout the process in order to strategically prevent waste and to create value at every step of the process. Value at Materials Development for Additive Manufacturing can come from satisfying customer requirements or being producible at the selected AM technology, by reducing post processing tasks or by improving characterization reliability.

The rapid expansion of additive manufacturing has not been accompanied by the development of process standards that assure its correct and reliable application (Grimm, 2004). In this sense, the lack of standardization is one of the barriers this technology has to overcome to be used as production alternative. This work is based upon the development of a new Alumina powder based system intended to be used at 3D printing technique, for the printing of refractory casting moulds. The new material's development cycle has been analyzed from the point of view of a product development process. In a first approach the entire cycle has been deployed into its sub processes in order to identify the influencing variables over the final part. We wanted to base the qualification of the desired results over the customer demands for the final application. For this purpose we have applied the Quality Function Deployment method to deploy the quality requirements linked by the sub processes correlations (Revelle, 1998). This analysis lead to a higher understanding of the variables involved and showed the convenience of implementing standard methods. By assuring controlled conditions through the entire fabrication process of the material, variability of the resulting properties can be kept under minimum levels.

2. CASE STUDY

This study has been developed with the additive layered deposition of ceramic powder technique. This technology was

developed at MIT in 1989 as a 3DPrinting technique for prototyping. The Z310 3DPrinter used joins the particles together with a liquid binder that is selectively deposited to the powder through a conventional ink-jet printing head. The ejection of the liquid binder follows the sliced two dimensional profile of a computer model. The subsequent stacking and printing of powder layers on previously printed layers generates the complete three dimensional structure of the desired object. The function of the binder is to join adjacent powder particles of the same and neighbouring layers (Khalyfa, 2007).

The materials system studied was required to be at one hand, a mixture of powder components able to be agglomerated and which after processing would exhibit properties of a refractory castable system. As the substrate for this mixture, it was selected electro-fused alumina, Alodur® WSK (Treibacher Schlaifmittel, Italy) at refractory grades: F360 & F600 according to FEPA. For binding purposes at sintering, it was chosen hydratable alumina (Alphabond 300, Almatiss, Netherlands). This component works as hydraulic binder at high temperatures and it is calcium free, which enables a higher compaction of the ceramic matrix when sintered. As far as it interacts with water, provides hydrophilic properties to the mixture which contributes to the printability of the system (Goberis, 2004). To ensure the low temperature layer-by-layer consolidation, it was decided to add Dextrin from Potato Starch, a widely used binder. On the other hand, the aqueous dissolution employed to activate the binding mechanism was derived from the commercial dissolution provided by machine manufacturer. It was composed of Glycerol and anionic surfactant Triton X-100 (Sigma-Aldrich, Germany).

The objective of the study is to obtain and to validate a materials system to be properly printed and to comply with final application requirements of customer. Beginning with the raw materials described above, the study came throughout the fabrication process until the finished tool was ready. As far as it is not possible to evaluate tooling performance until the tool is used, the evaluation integrates all the steps of the process:

- Powder Material Preparation: Alphabond 300 (1%wt), Dextrin (9%wt) and Alumina Powder (90%wt) at refractory grades (F360, F600).
- Proprietary Binder Preparation: Aqueous dissolution prepared from surfactant Triton X-100 (1%wt) and Glycerol (9%wt).
- Layered Manufacturing: Prepared materials were charged into the Z310 3Dprinter. STL file obtained from Solid Works software was charged into controlling ZPrint software. Then required parts were printed, with fixed layer thickness (0.2 mm). Saturation was an evaluated parameter. The parts were left at 40°C during 20 hours and then were blown at 0.5 bar to eliminate residual powder.
- Infiltration. The parts were immersed into a liquid cianoacrylate bath (ZCorp, USA) at ambient temperature during 20 seconds.
- High Temperature Sintering. The parts were sintered at a Hobersal XG3-16 high temperature furnace. This is the final step to achieve final mechanical properties of the

refractory castable mould. Sintering parameters were studied during this work.

3. CASE ANALYSIS

In order to study the development process in a structured way that enabled us to focus on the desired results, and to introduce an optimization approach which creates value through the entire process, it was applied the Quality Function Deployment Method. The main approach of QFD is to include the voice of customer as the cornerstone to design our process parameters and quality assurance metrics. For this issue it was launched a survey addressed to target customers whom gave their point of view about their actual needs in relation to the refractory casting moulds. In order to promote a structured insight of the different factors and variables affecting the different sub processes, and to obtain the input data to feed QFD analysis there has been applied several tools inspired at the Design for Six Sigma Methodology -which purpose is to identify, quantify and eliminate or control the sources of variation of the key properties measured. First, it was developed a workflow chart in order to have a schematic insight about the functional steps of the process. It was found that four principal sub-processes had to be considered: preparation of the printing materials, printing, post-processing of the part and final performance of the part. As a control step it was applied a characterization of the material obtained, through test specimens and standard testing measurements, before the final 3D solid was printed. If the material obtained complied with required quality, then it would be printed and applied for a definitive investment casting mould. Once the process has been mapped, the workflow chart obtained was used as the basis for a deeper analysis of the variables involved. Taking inspiration in the lean approach present at Six Sigma philosophy, it was decided to continue the analysis of the process with the SIPOC diagram. Here it is considered the specific information related to Suppliers, Inputs of the process, Sub process Steps Deployment, Outputs required and specially the voice of customer is the pulling criteria explicitly expressed at this tool. The insights obtained were multiple because they allowed observing the process from the objectives point of view and this is a key factor to discover, eliminate and prevent further waste. It were also deployed the sub processes and it was applied the SIPOC tool to analyze sub processes requirements and variable relationships. The deployment of every sub process obtained by SIPOC was the base for standards creation. Affinity diagram was a powerful tool to promote deep understanding about the factors that can be generating undesired effects. Within this study it was used to deploy and to organize the possible causes of trouble observed through the development: heterogeneously agglomerated mixture appearance, poor powder packing, bleeding, etc. The possible reasons listed were useful to identify noise factors that can be minimized by following standard procedures. Finally the chosen properties to be measured were related to the independent variables possibly affecting the results through the use of the cause effect diagram.

The use of Quality Function Deployment (QFD) enabled to determine specific measurable parameters coming from two important inputs, the final part user specifications listed as desired quality and the layered manufacturing specific process requirements. In the case of materials development, there is the particularity that the raw materials have to be processed in several steps before the final application can be achieved. To apply the deployment in this case it must be used a cascade series of matrices which are linked by the dependent relationships of the variables through the subsequent sub processes.

At the first matrix were introduced the customer requirements in the "customer words", then it was deployed the first level of process properties related to mechanical

characterization of the sintered part, weight, fabrication method, lineal dimensional variation. After, it was deployed the next level of process properties where it was proposed how to achieve that mechanical properties through process controlled conditions like sintering temperature, sintering time, density of sintered part, linear dimensional variation, printability of the material, etc. The next step was to deploy how to achieve that sintering temperature, density of sintered part, printability of the material system, etc. It resulted on the measurement of prepared materials properties like BET specific surface for the powder mixture, viscosity and surface tension for liquid binder mixture. This deployment is related to the quality control of 3D printing materials system preparation and process conditions of the layered manufacturing. Finally the last matrix reflected the need to determine standard procedures to control variability over the process since the former steps. The proposed standards procedures were as follows: Infiltration, BET Surface measurement of the mixture, preparation of liquid binder, preparation of powder mixture, measurement of linear dimensions variations, within several other procedures.

Finally it has been selected seven independent variables to be studied on an experimental basis in order to determine quantitatively their influence over mechanical properties, dimensional variation and density of the materials system developed. It was proposed a Plackett-Burman Design of Experiments to obtain a statistical indication of the main variables influencing the results.

4. CONCLUSION

It is possible to reduce variability and to optimize the final properties required for a new materials system, through the adoption of a structured analysis of the development process. In this study it was decided to implement standard procedures to eliminate variability and to reduce possible noise over the performance properties of the layered manufactured part. The analysis has been conducted using Quality Function Deployment approach and quality engineering tools like process mapping, SIPOC diagram, affinity diagram. The analysis provides a reliable base of inputs for quantitative optimization of final properties to be studied on further research.

5. REFERENCES

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