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REVIEW ON DESIGN OF EXPERIMENT AND A NEED OF MACHINING ON ACETAL HOMOPOLYMER INSTEAD OF INJECTION MOULDING

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ABSTRACT

Design of Experiments is a quality technology to achieve product excellence at lowest possible overall cost. Moulding tools and forming equipment used in the various plastic moulding processes are handmade one off creations. They can normally take weeks and months to manufacture with a very high cost. Due to the problems related with injection moulding of plastics and high cause of failure, this paper give the brief idea about design of experiment and a need of machining of Acetal homopolymer instead of injection moulding.

Index Terms—Design of experiment, Taguchi method, injection moulding, Acetal homopolymer

I. INTRODUCTION

Design of experiments was invented by Ronald A. Fisher in the 1920s and 1930s at Rothamsted Experimental Station, an agricultural research station 25 miles north of London. Design of experiments (DOE) is a very valuable tool to optimize product and process designs, to accelerate the development cycle, to reduce development costs, to improve the transition of products from research and development to manufacturing and to effectively trouble shoot manufacturing problems. Now a days, Design of Experiments is viewed as a quality technology to achieve product excellence at lowest possible overall cost. It refers to the process of planning, designing and analyzing the experiment so that valid and objective conclusions can be drawn effectively and efficiently. To find the conclusions from the experiment, it is necessary to integrate simple and powerful statistical methods into the experimental design methodology. The success of any industrial designed experiment depends on sound planning, appropriate choice of design, and statistical analysis of data and team work skills.

Where a plastics component is required and the numbers to be used are not more, then machining the component becomes more economical. All plastics materials can not be machined. The more rigid plastic are easier to machined. The more flexible and the softer plastics are not suitable for machining.

II. EXPERIMENTAL DESIGN PROCESS

- Determine the goals for Design Of Experiments
- Choose appropriate responses as output variables
- Choose appropriate factors as input variables
- Set appropriate factor levels or ranges.
- Design the experiment (precise estimate)
- Run the experiment
- Collect and analyze the data
- Determine and verify the response for optimal setting of factor
- Act on the results

III. CLASSIFICATION OF DESIGNS

- Completely Randomized
- Replication
- Latin Square
- Fuzzy logic
- Genetic algorithm (GA)
- Scatter search technique (SS)
- Fractional factorial

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- Response surface
- Taguchi's Design

Randomized Complete Block Design (RCBD) is a widely used tools to study some effect of interest while controlling for potential nuisance factor(s). It should not be confounded with covariance analysis whereby responses are adjusted a posterior to take into account nuisance factors. **Replication** is a process of running the experimental trials in a random sequence. Replication means repetitions of an entire experiment or a portion of it, under more than one condition. **Latin square design** (L.S. design) is an experimental design very frequently used in agricultural research. The conditions under which agricultural investigations are carried out are different from those in other studies for nature plays an important role in agriculture. **Fuzzy logic** has great capability to capture human commonsense reasoning, decision-making and other aspects of human cognition. Kosko (1997) shows that it overcomes the limitations of classic logical systems, which impose inherent restrictions on representation of imprecise concepts. **Genetic algorithm**, these are the algorithms based on mechanics of natural selection and natural genetics, which are more robust and more likely to locate global optimum. The cutting conditions are encoded as genes by binary encoding to apply GA in optimization of machining parameters. A set of genes is combined together to form chromosomes, used to perform the basic mechanisms in GA, such as crossover and mutation. **Scatter search technique** originates from strategies for combining decision rules and surrogate constraints. SS is completely generalized and problem-independent since it has no restrictive assumptions about objective function, parameter set and constraint set. It can be easily modified to optimize machining operation under various economic criteria and numerous practical constraints. It can obtain near-optimal solutions within reasonable execution time on PC. **Factorial designs** are used in experiments where the effects of varying more than one factor are to be determined. They are especially important in several economic and social phenomena where usually a large number of factors affect a particular problem. **Fractional factorial**, if the experimenter can reasonably assume that certain high-order interactions are negligible, then information on the main effects and low-order interactions may be obtained by running only a fraction of the complete factorial experiment. These fractional factorial designs are among the most widely used types of design in industry. **Response surface methodology** is a

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collection of experimental strategies, mathematical methods, and statistical inference which enable an experimenter to make efficient empirical exploration of the system of interest.

The **Taguchi method** developed by Genuchi Taguchi is a statistical method used to improve the product quality. The traditional experimental design procedures are too complicated and not easy to use. A large number of experimental work have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Taguchi methods have been widely utilized in engineering analysis and consist of a plan of experiments with the objective of acquiring data in a controlled way, in order to obtain information about the behavior of a given process. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost and discovering significant factors quickly. Taguchi's robust design method is a powerful tool for the design of a high quality system. The Taguchi method is a quality tool that helps improve the work efficiently.

It has the objective of designing the quality in each and every product and their corresponding process. In Taguchi technique, quality is measured by the deviation of quality characteristics from its target value. Therefore, the objective is to create a design that is insensitive to all possible combinations of uncontrollable factors and is at the same time effective and cost effective as a result of setting the key controllable factors at optimum levels. Taguchi offers a simple and systematic approach to optimize a performance, quality and cost. The quality of design can be improved by improving quality and productivity in various companywide activities. Those activities concerned with quality include in quality of product planning, product design and process design. S/N ratio and OA are two major tools used in robust design. S/N ratio measures quality with emphasis on variation and OA accomodates many design factors simultaneously.

Taguchi ideas can be distilled into two fundamental concepts:

(i) Quality losses must be defined as deviations from targets, not conformance to arbitrary specifications.

(ii) Achieving high system quality levels economically requires quality to be designed into product. Quality is designed, not manufactured into the product.

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IV. WHY TO MACHINE THE PLASTIC (ACETAL HOMOPOLYMER)

Moulding tools and forming equipment used in the various plastic moulding processes are invariably hand made one off creations. They can often take weeks and months to manufacture with a resultantly high cost. Where a plastics component is specified and the numbers to be used are not large, then machining the component becomes more economical. Not all plastics materials can be machined. The more rigid a plastic then the easier it is to be machined. The more flexible and the softer plastics are not suitable for machining. A highly crystalline stable form of polymerized formaldehyde, ACETAL. This strong, stiff plastic is increasingly prized by engineers for its physiological inertness, strength and rigidity, excellent dimensional stability, resilience and toughness and electrical properties. It is an excellent bearing material, with a low co-efficient of friction and good tribological (wear) properties in both wet and dry environments. Engineering machine shops like to work with acetyl/Ertacetal C because it machines easily and because of its excellent dimensional stability, which is primarily a result of the material's low thermal expansion and low moisture absorption.

Nowadays plastic has been widely employed in the industrial sector. The use of plastic with superior characteristics has increased in several sections such as equipment of precision, electronics and optics. Due to the need of high dimensional accuracy and good surface finish, components of plastic for these ends should be produced by means of machining processes instead of moulding processes.

V. PROBLEMS IN INJECTION MOULDING OF PLASTICS

The root causes of quality and consistency problems may or may not lie in the moulding process set-up. The mistakes of the earlier steps may not be possible to correct at the later steps. Some time it may be possible to correct partly. Such corrections are expensive. The problems originating from the present step can only be solved in the present step.

The most difficult to solve quality problems are

- Stress cracking
- Dimensional inconsistency / inaccuracy

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- Warpage
- Sink marks
- Weak weld lines

Quality problems in injection moulding can be traced to

- Part design and mould design,
- Polymer / additive characteristics,
- Machine specification (Limitation) and
- Process setting.

A. Stress cracking

Stress cracking can be classified in to

- Environment stress cracking and
- Solvent stress cracking.

It can occur in almost any plastic. However, it is more common with amorphous thermoplastics. The solvent actually replaces the polymer at the surface of the part. The bond between polymer and the solvent molecule is weaker than the original bond between the polymer chains and does not contribute to the strength of the material. In other words, the solvent weakens the strength of the polymer. If the stresses either moulded into the part or applied externally to the part exceed the strength of the weakened polymer, the material ruptures at the surface. Solvent then penetrates deeper and the cracks extend further into the part over a period of time.

B. Understanding Dimensional consistency

Shrinkage and Warpage, Dimensional in-consistency and warpage are on account of shrinkage behaviour of the plastic melt in mould. Plastic melt shrinks volumetrically- in all three dimensions. If shrinkages are equal in all the three directions, then part size reduce with out any distortion. In reality, it does not happen that way. Shrinkages along the direction of flow is more than that in transverse direction. This is called area shrinkage and it is with constrains. Wall thickness reduces due to shrinkage with out any constrain. This unequal shrinkage causes distortion of the part that is called warpage. Linear shrinkage can be influenced by restrains in the mould, Crystallinity and

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orientation.

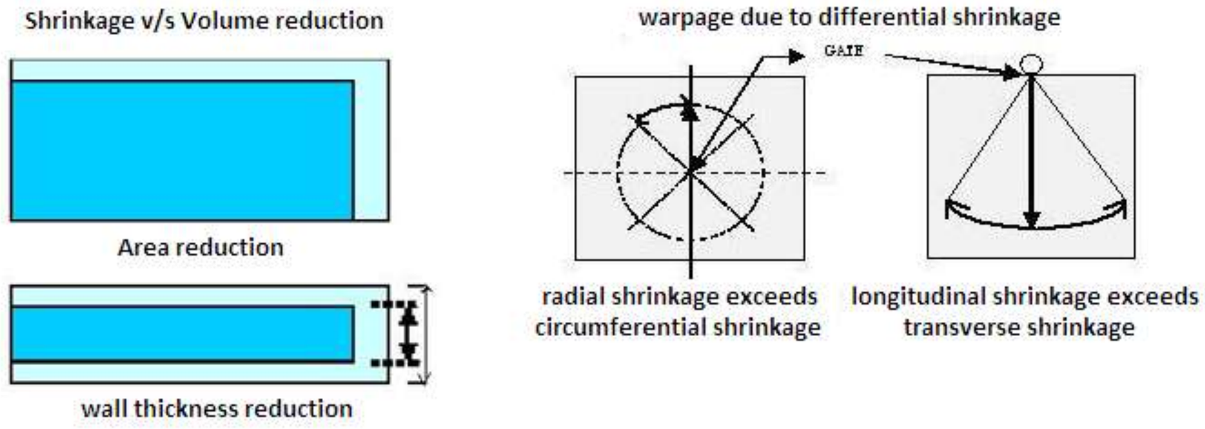

Figure 1. shrinkage and warpage

Shrinkage and Crystallinity, Crystalline content increases with lowering of cooling rate and decreases with faster cooling rate. Higher crystallinity means higher shrinkage. It means that part dimensions could be controlled by controlling cooling rate in different areas of the mould when wall thickness is not constant. Cooling rate could be increased by using Ba-Cu insert in the mould.

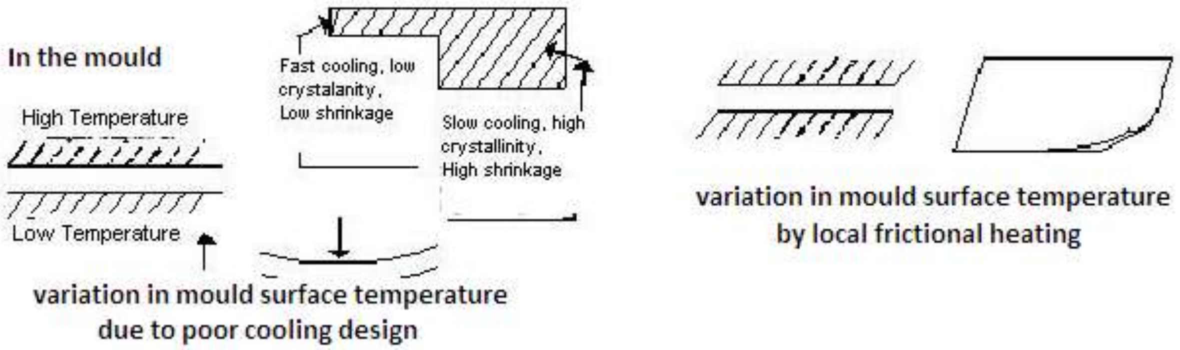

Figure 2. Shrinkage and Crystallinity

Shrinkage and Orientation, Alignment of polymer chains are stretched in parallel -oriented- with shearing. With high cooling rate this orientation can be trapped in the moulded part. This can result in stressed area in the moulded part. With low cooling rate the stretched chain gets chance to relax and hence shrink to natural chain. Hence shrinkage in the direction of orientation is more.

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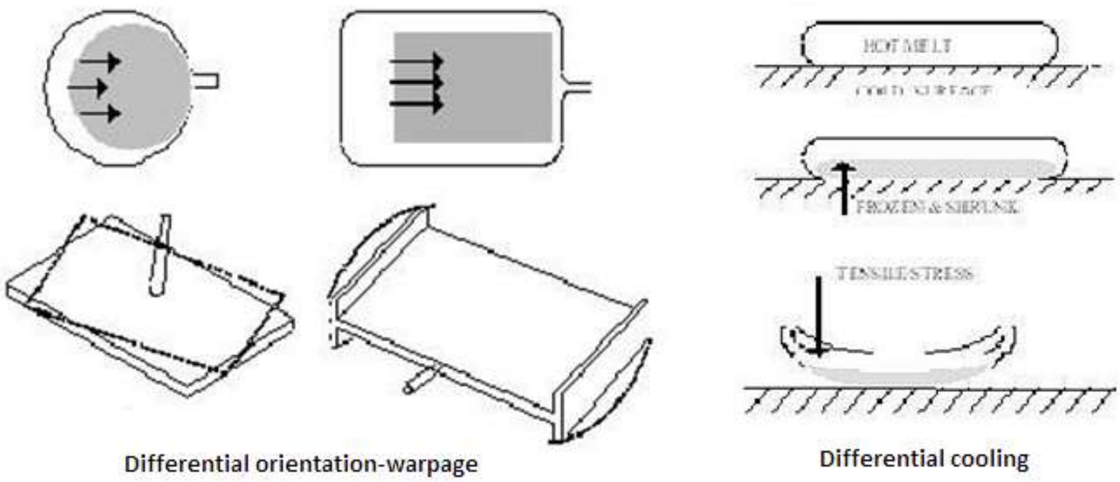

Figure 3. Shrinkage and Orientation

Sink mark in moulding, Thermoplastic melt is highly compressible. It can be compressed up to 15% under pressure. Therefore, if increase in volume due to raise in temperature is 29%, then 15% compressed. Volume cannot replace the void created by shrinkage due to falling temperature of melt during follow-up pressure phase in injection moulding. Hence under such condition sink marks are unavoidable. It can be made acceptable by designing the part without much variation in wall thickness and without large mass of melt at any region in the part. Variation in Wall Thickness causes sink mark.

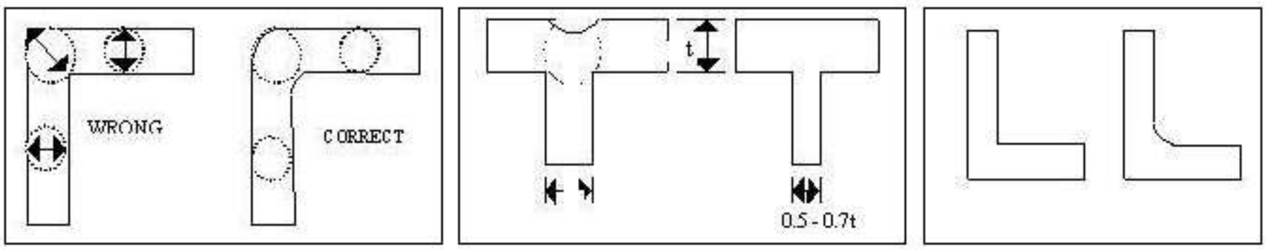

Figure 4. Sink mark in moulding

Weld line in moulding, Weld line occurs when two melt streams join. Melt stream gets divided at cut out (core) in the part and they join at the other end of the cut out. Normally weld line region is filled at the end of injection stroke or during pressure phase. Strength of the weld line is weak when partially frozen melt front meet. The orientation at the joint remains perpendicular to direction of

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flow -a sign of weakness. Weld line can form by melt stream flowing in same direction or in opposite direction. It is not possible to eliminate weld line, but it can be made sufficiently stronger or its position can be altered.

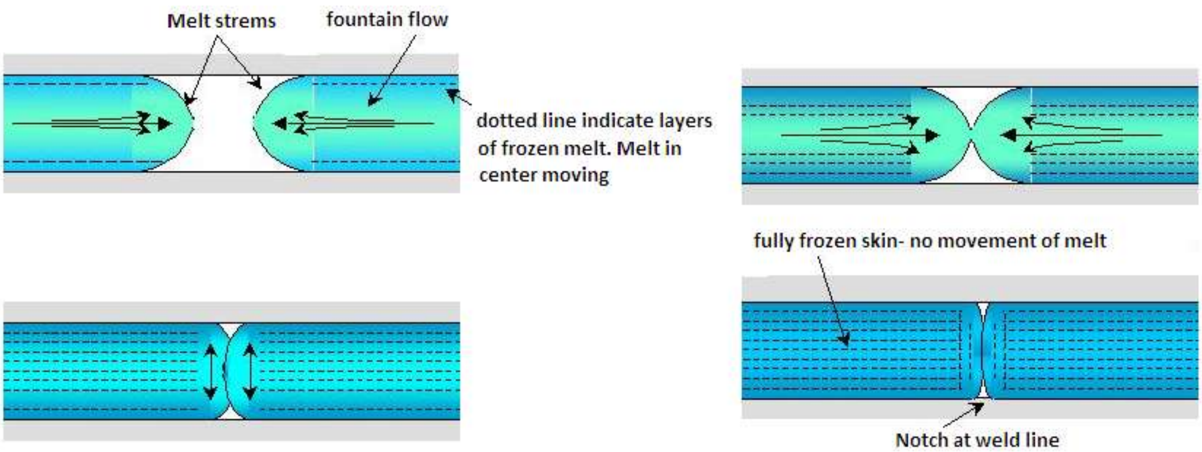

Figure 5. Weld line in moulding

Table 1. Factors influencing quality consistency in processing and quality in performance.

Materials: Characteristics of Polymer	**Mould: Design factors in Part and; Mould**	**Machine: Specification to meet the requirement of Part& Mould**
Molecular weight, Melt flow index (MFI), pvT characteristics, Response to shear rate (Shear thinning)and limitation, Heat and Thermal stability,Shrinkage behavior,Maximum flow ratio	Gate location, size and type,Sprue / runner size balanced type,Air vent, Wall thickness uniform & capable of promoting balancing of melt flow, Balancing of flow in un-symmetric part geometry, mould release	Maximum shot capacity of plasticating unit,Residence time, platicating rate Maximum injection rate, Number of stroke controlled steps for filling phase, Maximum injection pressure, Number of time controlled steps for pressure phase, clamp force

VI. CONCLUSION

The following conclusions can be drawn based on the above study:

- Taguchi's Method of parameter design can be performed with lesser number of experimentations as compared to other method of design analysis. Thus this paper illustrates the application of the Taguchi method in the optimization.
- As the price of metals continues to increase day by day, product designers are looking for ways to replace machined metal parts with plastic parts, and machine shops are getting more opportunities on jobs that call for machining plastics, and they are finding it profitable.

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