The Concept of Solid Modelling in The Plastic Injection Moulding Process - Review

Mr. Nitin A. Kharche[1]
P.G Student, Department of Mechanical Engineering
J.N.E.C Aurangabad, Maharashtra,India

Dr. S. D. Deshmukh[2]
Professor ,Department of Mechanical Engineering
J.N.E.C, Aurangabad, Maharashtra,India

Prof. R. B. Patil[3]
Professor,Department of Mechanical Engineering
J.N.E.C, Aurangabad, Maharashtra,India

Abstract

This paper seeks to outline the concept of the solid model within the injection moulding process in greater detail and to document its downstream technological advantages of it.Now a day, successful design in the injection moulding Process is currently undergoing a revolution. The CAE technology is changing rapidly with advances in computer hardware &software, computer graphics, and rapid prototyping technologies.Solid Modeling is used for the communication value of realistic shaded images & also used for communicating geometric information. Solid modelling has become a core communication cornerstone of concurrent engineering. Engineering experience of CAE tools and concurrent engineering has not always matched their expectations. With the advances in rapid prototyping technologies, CAE users are surprisingly reporting that the major benefit of a computer model is that they can produce prototypes faster. However, the idea that the major advantage of CAE tools is reduced 'time to market' is being challenged by many companies. They have come to realise that while reduced design time is an outcome, a more important advantagesof CAE is higher product quality.

1. Introduction

The achievement of true concurrent engineering, delivering faster time to market.reduced production costs, and increased product quality is the aim of all design and manufacturing operations throughout the world.

The alternative to this practised in 95% of organisations today is sequential engineering with its many individual stages. Pressures to work faster, combined with the availability of computer based solutions for many tasks, has brought the automation of each of these individual stages. The conceptual designer was given a tool to help to create visuals of what he had in mind. The draftsman got a tool to automate the drafting process and help enhance the layout of the design work. The analyst received some number crunching power to help speed through the calculations.

Time scales improved and each of the segments in the process contracted, giving a net faster throughput. However, eventually the system cannot be squeezed any further and this is where concurrent engineering comes in. When you cannot shrink the building blocks any further, the only way to shorten the development cycle is to overlap them.

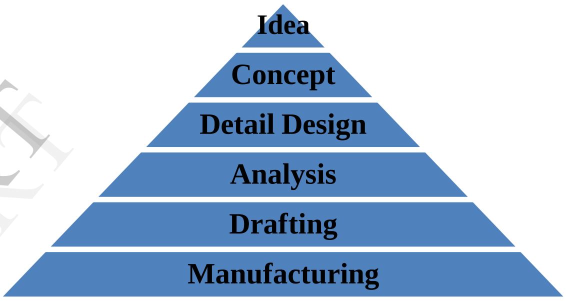

Figure.1 Traditional Sequential Engineering

Solid modelling is the only Computer Aided Design (CAD) approach that completely and unambiguously represents the 3D geometry of parts and assemblies. It is therefore, the only type of design tool capable of fully supporting today's widely diverse range of engineering applications, from analysis to manufacture and thus enables concurrent engineering.

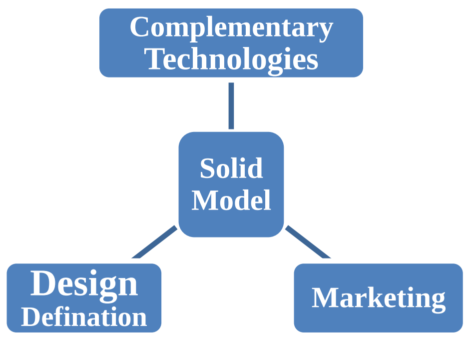

Figure.2 Solid Model as A reference Point for Concurrent Engineering

2. The Solid Model: What Is It?

This paper will consist of many references to the term solid modelling. Therefore, as an introduction. The concept and definition will be discussed briefly. Within the CAD industry there are a number of packages available. This fall into three categories i.e.:
(i) Two dimensional drawing.
(ii)3-D surface/wire frame modellers.
(iii) Three dimensional solid modelling.

The first of these types, two dimensional drawing, was the first CAD technique to develop with well-knownpackages such as Autocad, Easycad. However as computer technology increased and software writing became more sophisticated a new era of three dimensional CAD evolved. This three dimensional CAD initially came into being via the development in finite element analysis (FEA) for the study of behaviour under various load bearing conditions in the aeronautical and automotive industries. Today this has progressed into what is known as three dimensional computer aided design/ computer aided manufacture (CAD/CAM).
Three dimensional surface modelling is a technique used widely in applications such as feature films, adverts and in design. This is a technique whereby the computer operator will model the outer surfaces of the component within the CAD software, which can then be shaded and textured to represent the object on the computer screen.
This can also be manipulated frame by frame to create an animation sequence. This technique is perfectlyadequate for transferring the design intent or visualisation of the components concerned.
The methods involved in creating the surfaces above in many ways are based on exactly the same principles in the construction of the three dimensional solid model.However, a solid model is taken a step further by joining all the outer surface limits together to define an enclosed volume. By defining this enclosed volume other options become available such as cutting one object with another, joining of two volumes, or the intersect volume of two objects.
In this way many of the real actions employed by the traditional model makers of the past can be replicated and controlled more accurately on thecomputer screen. Of course, by being able to define enclosed volume many other advantages are opened up to the CAD operator in the form of three dimensionaldesign. assembly interference checks. weights ofcomponents when the density is inputted to mention but a few. Therefore in solid modelling many more options are available to the designer than by just surface modelling alone.

3. Concept of Design

"Enlightened trial and error succeeds overthe planningof flawless intellects" This statement may seem somewhat paradoxical whentaken into context of the modem design philosophy of'right first time' but as will beillustrated in the sectionfollowing computer aided solid modelling fosters thusanthem and leads us substantially down the road towardsexactly that goal.

i. Right first time:

The importance of a right first time approach to productdefinition can be demonstrated by a comparison betweenJapanese and British approaches. Thus by expending more effort in definition the overalltime to market may be reduced and post launchdifficulties minimised

	JAPAN	BRITAIN
DEFINITION	66%	17%
DESIGN	24%	33%
REDESIGN	10%	50%

Figure.3 Comparison between British and Japanese product development approaches

ii. Importance of Cost

Clearly this improved focus on definition, demonstratedthat changes may be made much earlier when the cost ofchange is significantly reduced.

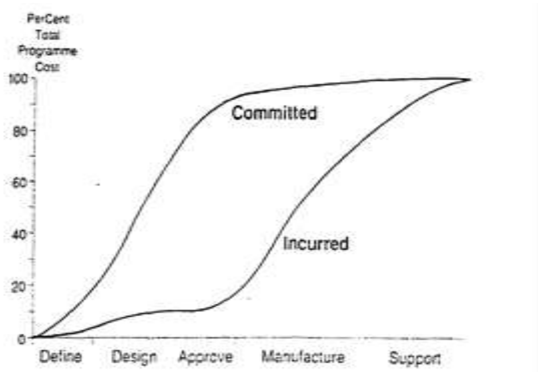

Figure.4 Profile of Costs committed and cost incurred over the design cycle

Figure 4 shows that although 80%of the costs arecommitted by the end of the design stage, actual spend isonly around l0%, thus iterating towards a more precisesolution at this stage is much more inexpensive both interms of cost and time. How effective this simulatedsolution will be depend upon how realistic theassumptions taken during the design definition stage arc.Increasingly these simulations are being modelled oncomputers in which user friendly design tools calculateextremely complex equations that replicate real life or touse a much coined phrase create a 'virtual reality'. This is were the solid model application comes into thereckoning. The solid model acts as a reference point or'virtual product' for many post modelling simulationactivities that define the design of the product to a much greater extent. There are many such simulationtechniques, the most relevant to the plastics injectionmoulding industry arc FEA, flow analysis, assemblychecks. Anexplanation of each of these methods is shownbelow.

a. Finite element analysis:

Finite element analysis (FEA) was developed for the automotive and aerospace industries in the late 1960's in order to be able to analyse stresses in load bearing parts. FEA uses a mesh which divides the interior volume of an object being analysed into discrete units by creating brick like building blocks. This mesh is broken up into nodes, usually three nodes (creating triangular elements). By studying load behaviour on each individual node at a point in time, an overall load pattern can be developed for the entire volume of the object. The outputs of these results are in graphical. Pictorial and numerical forms. These results will simulate.

i) Stress.
ii) Strain.
iii) Distortion, warping, stretch.

The advantage of this technology is it allows the designer to simulate the component in actual use and therefore design specifically to strengthen the areas under greatest load. Many combinations of design can be tested especially in plastics, to allow the designer to reduce the amount of material used, i.e. thin the wallsections of component, but still allow the part towithstand the load functions that are required, (design optimisation) and thus decrease the cost of moulding theitem.

b. Flow analysis

Flow analysis also uses the finite element mesh to simulate the flow of a molten polymer into an injection mould tool and thereby flag the problems encountered during this process. This enables the designer to obtain vital information on flow within the injection moulding tool and simulate the consequences of a design and design changes before the tooling is manufactured altered.

There are many reasons why plastics moulding aredifficult. All polymers feature large and complex molecules in which size, entanglement and orientation contribute to the behaviour of the material. When formed and in service they are greatly affected by time and temperature effects. This complex range of attributes means that the mathematics and physics involved in a full description of the process are more than can be feasibly be handled in a regular industrial designcontext, unless computer technology is utilised. With the introduction of flow analysis simulation, designers are now able to formulate the successful design of runner and gating positions to eliminate the trial and error approaches of the past problems associated with too large a runner and gate system. Thisis of course dependant on the accuracy of the material databases available to the designer which describe the viscosity and characteristics of the polymer used. The first mould- flow simulation program was developed in 1978 and was called 'Moldflow', Moldflow programs make specific predictions about pressures, temperatures, shear rates, and cooling times throughout the component and feed system. These predictions are quite specific to proprietary polymer grades and process conditions. Results are obtained from the model in tabular formshowing values of injection time, pressure required to fill and the melt temperature at the end of fill. By examining the upper and lower ranges of pressures, shear stresses and temperatures that fall within reasonable limits, the designer can judge the range of processing conditions in which they can work. This data can then be used by the finite element model to achieve an overall filling pattern. The user can then visualise the filling of the part on the computer screen and also pinpoint more accurately weld line and gas entrapment positions.

The benefits to the designer include being able to prove how many gates are needed, find the best pressure conditions, prove how thin the component can be whilst still remaining mouldable, obtain the best stress balance within the component, avoid excessive stress balance within the component, avoid excessive shear stress values and predict weld line and gas entrapment areas.Other flow defects such as race tracking, hesitation and underflow can also be identified and corrected.

c. Assembly analysis

The assembly analysis software is used to build previously created parts together on screen. Assemblies'arc used to visualise the complete assembly of created parts. to calculate interferences and analyse tolerances. to calculate weight and also to animate configurations of the assembly.

This tool is very useful in the design of complex assemblies where interference is not always apparent e.g. in linkages, or rotational components. The designer can also change the design of parts and incorporate these changes very quickly into the whole assembly to see their effect. Relationships (or constraints) may also be applied to models to

allow the changes in one part of the assembly to be reflected in a mating part automatically therefore eliminating repeatability and mistakes in forgetting to change mating parts, especially in largeassemblies.
Results are displayed graphically on the computer screen with points of interference flagged. Animations also allow the designer to get a better grasp of the assembly helping them in turn to optimise the design. Other benefits include the function of producing a bill of materials and assembly drawings automatically and the storing of standardised parts in a library which can beused again in other designs. These libraries are available to all members of the design team.

4. Complementary Technologies

The increasing need to respond rapidly to changes in marketable products requires that the design cycle encompassing 'concept to component' is continually being time compressed. As stated previously there is no doubt that concurrent engineering has a key role to play in this area. However, in addition to the implementation of the concurrent engineering approach the successful company must embrace complementary technology with enthusiasm. There are many such Complementary technologies at available. Those of particular relevance to the plastics injection moulding industry arc rapid prototyping and rapid tooling.

i. Rapid prototyping

The technique of rapid prototyping was first initiated in 1988 when. its pioneers,3D Systems, shipped the firstproduction units. The technique is simple in concept but made possible by the computer software. And sophisticated electronics now associated with lasers. The process of SLA starts with the sectioning of CAD model of the proposed component into a series of horizontal slices similar to contour lines on a map. The data is then passed from a computer to a laser which accurately draws each slice in order onto the surface of a bath of photosensitive resin;which is instantaneously cured to the solid by the laser spot. The first slice is supported on a table just below the resin surface and as the laser touches the resin it cures to a solid on the table support. The table is gradually lowered to enable the next layer of the model to be constructed on top of the previous slice this process continues until the model is completely constructed.
There are no restrictions on the complexity of models and they can be hollow or contain undercuts since uncured liquid resin can be subsequently poured out from any section which is not part of the component. Many other rapid prototyping technologies are now available i.e:

a. Fused Deposition Modelling (FDM)

FDM (Fused Deposition Modelling) is a layer additive manufacturing process that uses production-grade thermoplastic materials to produce both prototype and end-use parts. Solid Concepts offers a number of thermoplastic FDM materials that can be used for direct digital manufacturing including ABS, PC-ISO polycarbonate and Ultem-9085 for high-temperature applications.
A Rapid Prototype model is built up through the extrusion of a molten polymer such as ABS or Nylon. Like theStereo-lithography route the CAD model is split up into two-dimensional slices and is built by the nozzle of the FDM machine following a two dimensional CNC path. The table of the machine then lowers and the nest layeris built upon the last when it has solidified, until a completed object is obtained. This method can be visualised if you imagine squeezing icing onto the top of a cake into a pattern. The costs of this method are approximately the same as STL.

b. Laminate Object Manufacturing (LOW)

Again similar to STL, the model is built up in layers,from sections created throughout the part by the CADsoftware. These layers are built out of a roll of treatedpaper which is cut and fused by a laser beam. Theresulting model has the appearance and feel of a woodenmodel.

c. Selective laser sintering (SLS)

Selective Laser Sintering (SLS) is an additive rapid manufacturing process that builds three dimensional parts by using a laser to selectively sinter (heat and fuse) a powdered material. The process begins with a 3D CAD file which is mathematically sliced into 2D cross-sections. The SLS prototype or part is built a layer at a time until completed.In many ways this technology is an amalgamation of the STLand FDM methods of prototyping. A laser beam cures a polymer powder again in 2-Dimensional layers, building up each row until the model is completed.

d. Solid ground curing (SGC)

This method uses photocopying technology to put a mask on wax, which is then subjected to an ultra-violet beam which then cures the wax at the unmasked areas. Again this process is repeated layer upon layer until the overall object is complete.

e. Jetting

Printer ink jet technology is being developed into creating stereo-lithography models. Instead of applying ink to paper, the cartridge will apply an epoxy onto a table which will then lower and allow a second layer to apply onto the first and repeated until a model is completed.

ii. Computer Numerical Control Machining (CNC)

CNC technology uses the surfaces created within the 3- Dimensional CAD model to apply 3D X, Y, Zpoints and paths for a cutter to follow. These paths can have a fine or rough resolution according to the level of accuracy the user requires. This method of prototyping is different from the others in the sense that the model is not created in layers, but the exact shape is machined out of the medium.
Probably the most important benefit is that rapid prototype technology enables a designer to have a resin model of a complex component in hand within 12 hoursof the completion of the 3D solid model. However,thiscomponent is more than a designers 'toy' to show himhe has put his correct thread in the nighthole in an accessible position. This is most important to confidence in the design but of equal importance rapid prototyping enables control of aspects of the design cycle such as:

a. Fitment

Often the greatest restriction to a design is the space envelope into which the designed component must be located. Although fragile, the prototype is often durable enough to test limited functionality e.g. screwing a part into the thread of a prototype model.

b. Analysis

Analysis from CADmodels by simulation using the virtual product plays an essential role in the design. However, although continually improving there still remains uncertainty in matching it with empirical reality. Rapid prototypes have been utilised to perform analysis using some of the latest stress analysis techniques.

c. Functionality

Although the rapid prototype model cannot obviously be used for heavy load beaning tests due to its fragility what it can be used for are functional tests under limited loadse.g. air flow tests, interactive assembly tests etc. This is a very powerful tool for the designers and assemblers. The use of rapid prototyping will significantly shorten the design development time and avoid unforeseen downstream problems associated with the introduction of new components.

d. Rapid tooling:

One of the most time consuming part of the development cycle is the wait for the completion of tooling and fixtures. CAD has helped in providing a numerically controlled (NC) machining route I e the cutter paths for the construction of electrodes for cavity manufacture can be directly set using information from a solid model, this also having the advantage of leaving no interpretation. Thus 'what you see is what you get', a very important factor when dealing with complex surfaces However,even with this aid a 17-18 weekmanufacturing lead time for injection mould tool is commonplace. It is now envisaged that the rapid prototype model can be used in the development of tooling lead to a much decreased lead time, this development is usually given the title of rapid tooling
.

e. Soft tooling:

Many techniques for fast tooling have been used for small volume prototypes, now that rapid prototyping models could be readily available, techniques that use a model are becoming extremely attractive offering time and cost savings.
Probably the most used of these methods is that of combining the rapid prototype model with vacuum casting to produce a soft tool capable of producing up to 20 prototype models in a polyurethane resin which when mixed correctly, approximates many of today's engineering plastics. The technique itself is simple. A semi-soft silicone resin is cast round the rapid prototype model. The model is removed and the polyurethane resin is cast in the mould.

f. Production tooling:

However, as the required quantities rise then there is a requirement to introduce better tooling, particularly, if that tooling can produce in the correct material, in the required production process and ultimately, in the production volumes. There has been much work done recently to develop techniques to produce tooling from rapid prototypes in a matter of days rather than weeks and months.
There are a number of techniques for decreasing the time to produce rapid tooling capable of production volume durability some of these are outlined below:

(1) Metal spray:
Rapid prototype models can be metal sprayed to produce a metal pattern surface that is then backed with resin for support and placed in a bolster. The spraying of metal on a model to produce a tool surface has been around for many years but has suffered from doubts about its durability. Investigations have been carried out using metal spray on rapid prototype models and adopted much improved spraying technology to provide confidence in the metal surfaces for tools. This produces a surface with the durability close to that of the base metal used in the spray. The metal skin is then backed with a special ceramic composite and the tool used in a bolster.

(2) Nickel plate:

Electro-plated nickel skin taken from a rapid prototype model can be backed with ceramic similar to the previous tooling technique.

(3) EDM electrodes:

As explained earlier the tooling industry machines EDM electrodes from the CAD information and these are subsequently used to produce cavities in the tooling metal. A major time saving over machining of EDMelectrodes can now be achieved by producing electrodes. From the rapid prototyping models. Tooling by this development is relatively unchanged and could be immediately applied by tool manufacturers.

5. Marketing

The marketing advantages of solid modelling aretremendous. The customer can visualise the product before any expenditure on costly hardware has been made and can critically evaluate and improve the product if need be. As well as this the image is usable within desk top publishing packages and thus with the high degree of photo realism available today marketing of a product can take place before manufacture of the product has actually been initiated This is a very important benefit as advanced orders can be generated and production levels can be high from the start thus economies of scale advantages can be evident straight away.
The production of a prototype model allows all packaging design to be carried out in parallel therefore reducing the time to market further. Packaging design may also be carried out on screen using the solid model.

6. Conclusion

There are basically three words that summarise the advantages i.e.:
(1) Concurrency.
(2) Rapid.
(3) Control.
The solid model is a concurrent engineeringsupporter, it is the only CAD solution that fully supports the concept. The model if used correctly can act as a central reference point for all the activities involved in new product development from marketing to design and as such product development times will decrease as sequential engineering is eradicated.
The complementary technologies that have come about since the inception of the solid modelling technique e.g. rapid prototyping and rapid tooling have meant that segments of the product development process have become vastly shortened, these areas, especially tooling, have in injection moulding traditionally taken a large proportion of the development time. Thus, as well as the shortening of the development process through concurrency it can also be greatly shortened by using these technologies.
The use of concurrency and complementary technologies is becoming increasingly important if a firm is to stay competitive. As product life cycles continually shorten the successful firm will be the one that can get the product to the market quickly and thus reap maximum revenue from it, the window of opportunity does not remain open for long.
The third major advantages of the solid model are that of control. Downstream design simulation such as FEA. flow analysis and assembly checks have meant that the definition of design has been improved immensely and the number of iterations towards the ‘right’ design are decreased and thus cost and time savings are made, this means that the world class manufacturing ethos of ‘right first time’ is now a reachable goal. This increase in control also fosters another world class manufacturing anthem, ‘total quality management’ and the road to ‘zero defects’ the designer is in control. if the design is defined fully and the virtual product is correct in every way then in theory, no interpretation should be made and quality should not be an issue.
The solid modelling technique has revolutionised the design of products and if given the opportunity and implemented correctly could act as a very useful weapon in an increasingly competitive industry.

7. References

1. Hartley J, and Mortimer J., 1991, "SimultaneousEngineering", Industrial Newsletters. Dunstable, UK.
2. McKinnon *S,* 1992, Building on a solid foundation,Manufacturing Breakthrough, NodDec,.
3. Dastagiri.M., MaruthiPrasad.MAnnamacahrya , Application of Axiomatic Design in Injection Molding Process, 978-1-4244-9082-0/10/$26.00 ©2010 IEEE[P. No.222-228]
4. Xiaoli Li, Bin Hu, and Ruxu Du, Predicting the Parts Weight in Plastic Injection Molding Using Least Squares Support Vector Regression, ieee transactions on systems, man, and cybernetics—part c: applications and reviews, vol. 38, no. 6, november 2008[P. No. 827-833]
5. Chi-Huang Lu, Ching-Chih Tsai, Multivariable Self-Tuning Temperature Control for Plastic Injection Molding Process, [P. No.702-709]
6. C.G. Li, Yuguang Wu, Evolutionary optimization of plastic injection mould cooling system layout design, 2010 International Conference on Intelligent System Design and Engineering Application, 2010 IEEE[P. No.693-696]
7. Zhou Chun-ying, Wang Li-tao, Injection Mold Design based on Plastic Advisor Analysis Software in Pro/E, 2011 International Conference on Multimedia and Signal Processing, 2011 IEEE,[P. No. 205-208]
8. B. Bona, L. Giacomello, C. Greco, A. Malandra, Position Control of a Plastic Injection Moulding via Feedback Linearization Machine, Proceedings 01 the 31st Conferenceon Declslon and ControlTusaon, Arizona - December 1992[P. No. 2591-2593]
9. Sked G, 1992, A compliment to design, ManufacturinP Breakthrough, NovDec, 3 39-343.
Smith G.f., and Tromans G., 1996, Rapid tooling in the polper design cycle, Institute of Materials conference Droceedinns, Athlone.