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Plastic: Historical Development and an Industrial Survey

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Abstract:-This paper presents an overview of historical development of plastic. Author has visited the plastic Molding Industry and speculated the probable areas where, one can improve the process by adopting the Filed Data Based Modeling Approach. These all prominent aspects are elaborated in forthcoming sections.

Index Terms: - Plastic Molding Industry, FDBM, History of plastic, Injection Molding

1. PANORAMA

If one looks back & thinks about material development process then he could observe that initially human being successfully made the use of a stone as a first material & that age was coined as Stone Age. Then comes Bronze Age, Iron Age & now the Plastic Age. Today plastic is having more influence in our life. The word "Plastic" obtained from the Greek language word "Plastikos"which means any stretchable substance that can be converted or changed into another shape or can be easily molded [7]. We can define plastic as, a polymer (synthetic or natural) of high molecular weight. Plasticity is that property of material by virtue of which those are able to deform without breaking. Now a days, plastics are becoming the most versatile materials and mostly used on a volume basis. Almost most of the products use by the society in daily lives contains plastics. Plastics have covered today's human lifestyle[3] & have a major contribution to all product areas because of some important properties like light in weight, high tensile strength, high impact strength, corrosion resistance property especially for chemicals & salt water applications. Application of plastics also covers utility in electrical insulation as well as sustainability for different temperature ranges [7].

2. HISTORY OF PLASTIC AND RELEVANT MOLDING MACHINE

One has to go back more than hundred years to know the history of plastics. Plastic had originated from rubber. Discovered in1851, ebonite, also known as hard rubber was the first thermosetting material [20]. In 1851 the English scientist Alexander Parkes detected the solid residue after the evaporation of the solvent of photographic collision was a tough elastic & impervious to water [16].Alexander Parkes launched a new material named as Parkesine (1862). Parkesine was obtained by liquefying cellulose nitrate in a minimum of solvent [16]. The mixture was then put on a heated rolling machine from which some of the solvent was then removed. While still in the plastic state the material was then shaped by dies or pressure. An American inventor named John Wesley Hyatt in 1868 developed a plastic material called Celluloid made by combining cellulose nitrate and camphor. Along with his brother Isaiah John Wesley patented the first injection molding machine in 1872[17].Later two German chemists Arthur Eichengrun and Theodore invented the first soluble forms of cellulose acetate in 1903, which was much less flammable than cellulose nitrate. It was available in powder form from which it was readily injection moulded.Arthur Eichengrun developed the first injection molding press in 1919.In1939, Arthur Eichengrun patented the injection molding of plasticized cellulose acetate [14].An American inventor James Watson Hendry, In 1946 built the first extrusion screw injection machine. The rotating screw made the injection speed easier to control and it helped to produce higher quality products. The products like polyethylene, polystyrene, and other materials that had been more expensive in the past, were starting to be produced more cheaply. They also started to replace not only other plastics, but also more traditional materials like wood, metal, leather, and glass [15]. W.H. Willert developed the reciprocating injection molding machine in 1956 [16]. In his machine, the screw moves backwards and forwards during the mold cycle. The screw rotation will stop once the proper mixing will take place. The screw injects the material inside the mould cavity. Many useful new thermoplastics like high-density polyethylenes and polypropylene get invented. In the 1970s. James Watson Hendry worked for construction of gas-assisted plastic injection molding process to overcome the limitation of conventional plastic injection molding process. This made producing complex, hollow products that cooled quickly possible. These results in improved strength as well as surface finish of manufactured plastic parts and helps in reduction of cost, production time, weight, and waste [18]. The Milacron Corporation**,** manufacturer of plastic injection molding machinery had introduced "All Electric" plastic injection molding machine **[19].** Milacron Corporation along with Fanuc Corporation developed the Applied Component Technology (ACT) series of machines in 1985. Today there are plastic injection molding industries producing various components like car parts, tools, toys, décor by using electric injection molding machines. Most anything can be made out of plastic these days.

3. DEVELOPMENT OF PLASTIC MOLDING INDUSTRY

In 1978 The Mold flow Corporation [19] launched "Injection Molding Simulation" under the leadership of founder Colin Austin from Australia. Mold flow was the leading company who provided the software which is very useful for engineers working in a plastic domain for optimization of the part designs and molds before "cutting steel". Mold flow, currently situated in Wayland, is intended for raising a quality of the *Design as well as* Manufacturing Process for plastic injection molded components. "Micro Injection Molding" is the prominent field of today's plastic manufacturing industry [19].Various suppliers of Plastic Injection molding machinery have taken initiative to manufacture limited size molding machines, of low clamp tonnages (three tons) and less shot capacities (less than a gram). The new materials science field known as "nanoscience" has also link with plastics [19].Nano composites are reinforced plastics with very finely divided and dispersed nanoclays or nanofibers. These nanocomposites can offer remarkable mechanical performance and properties.

Plastics are used for almost all of the products we use in our daily lives. The food packaging, medical, automotive, electronics, building construction, and textile industries all make extensive use of plastics and elastomers [19]. The developments in new materials and process technologies that have occurred over the past 150 years. Various new developments and discoveries related to plastics are happening all of the time.

4. LITERATURE REVIEW ON PLASTIC MOLDING PROCESSES

Plastics can be manufactured by different methods. The different plastic processing techniques are compression molding, rotational molding, casting, blow molding, extrusion, transfer molding, thermoforming & injection molding.Injecton molding is the most commonly used processing method for plastic components which is used to manufacture thin walled plastic parts for a wide variety of shapes & sizes. In injection moulding the molten plastic injected into a mold. Author had made a literature review on plastic injection molding processes. Through literature review it is observed that different authors had worked on injection molding machine specifically for optimization of injection molding process parameters.

Wong C. T et al [21] carried a work on design of mold necessary for producing a plastic component. Authors prepared a CAD model (Pro-E) for plastic product. Later author used CAM pro-manufacturing to develop machining program. The part was analyzed, examined & simulated using Mould Flow or Part Advisor software before mold design. Authors had made a study on the process by which plastic fills a mould. Authors observed three phases for this process. First was filling phase, second pressurization phase & third was compensating phase. Authors explained the detailed mechanism of all those phases separately. Later authors concentrated on mould design process. For simplicity authors presented a mould designers chart. According to chart initially a CAD model of the part has to be created & converted into STL format. Then the model had opened in Part Advisor. Suitable plastic material & supplier has selected. One has to run the gate locator & after that by creating one or more injection locations go for run the analysis. During this stage one can change the parameters like position of number of injection location, material, mould temperature, melt temperature, injection time & art geometry & go for reanalyze. Using report generators create the report of analysis & that to be made available to concerned peoples. Authors presented a simulation process for a solid model for various parameters like fill time, injection pressure, pressure drop, and air traps etc.With the help of all above information one can avoid the several defects occurring in plastic during actual injection such as, air traps over packing, sink mark, hesitation & assists mould designer to design a faultless mould with minimum modifications & reduced set up time.

P.K. Bharti et al [22] presented a review on current investigation in designing & governing process variables of injection molding. During review authors observed different approaches like artificial neural network, mathematical model, fuzzy logic,tagchi method, case based reasoning, finite element method, genetic algorithms, linear modeling, response surface methodology, gray rational analysis, linear regression analysis, & principle component analysis which author had presented in his paper.

Anand Kr Dwiwedi et al [23] used taguchi technology for optimization of plastic injection molding process variables especially for polypropylene material. Authors considered various process parameters like processing temperature, injection speed, injection pressure, & cooling time. Three levels are considered for each parameter.L9 orthogonal array had selected. Tensile strength had considered as a dependent variable & hence it was measured. S/N ratio had been considered for planned experiments. Authors selected best set of combination parameters. Processing time was observed most significant factor.

Sokkalingam Rajalingam et al [24] studied traditional method of determination of injection molding process parameters. Authors suggested response surface methodology for determination of optimal process parameters. Authors presented the literature survey where response surface methodology was used for optimization of process parameters. Authors explained the concept of response surface methodology in their paper.

Neeraj Singh Chauhan [25] presented a study on injection molding process for DVD manufacturing with an aim of reducing cycle time. The machine parameters considered includes mould open/close time, cooling time, holding time & robot take out time. Authors performed a design of experiment with all above factors. All the data are analyzed using minitab software. Finally author concluded that the effective travel distance & speed of mould results in reduction of cycle time.

F. Shi et al [26] presented a hybrid technique in a soft computing for optimization of injection molding operation. Authors focused study on various operating parameters like mould temperature, melt temperature, injection time & injection pressure. The hybrid technique includes a genetic algorithm, a multilayer neural network & numerical simulation software. Authors described genetic algorithm & multilayer neural network as a soft computing approach to determine optimum parameters. Authors developed an approximate analysis model with a BPNN to solve the optimization model.

Sajjan Kumar Lal et al [27] observed different defecs like warpage, shrinkage, flash, and shrink marks in plastic parts those are produced by injection moulding process. Authors used DOE technique by taguchi method to determine optimal injection molding process variables for minimum shrinkage while molding which results into change in dimensions of plastic part. The effects of various variables like refilling pressure, injection pressure, cooling time & melting temperature on shrinkage of Low Density Polyethylene presented in this paper. At the end Authors concluded that the refilling pressure of 85 mpa, melting temperature of 190^0C, cooling time of 11sec & injection pressure of 55 mpa gave minimum shrinkage of LDPE.

Y. P. Tidke et al [28] presented the review on experimentation of practical utilization of taguchi method in the optimization of processing variables for injection molding. Authors presented various causes for the effect defects in the pat through fish bone diagram. Authors presented stepwise procedure in taguchi parameter design. Authors mentioned various injection molding parameters like melting temperature, injection speed, cooling time, injection pressure in their work.L9 orthogonal array had considered. Authors concluded that the parameters like melting temperature, packing pressure & packing time were the most affecting parameters for quality of product (warpage).

Mr. Ravi B Chikmeti et al [29] presented a literature survey on reduction of warpage of plastic components. Authors used a taguchi optimization technique. Authors observed warpage as a major issue in injection molded component which results in deviation in the shape of the product from the shape of the mould cavity. Authors explained different steps in taguchi method. As per review presented by authors various independent variables considered are melting temperature, holding pressure, injection speed, holding time, injection pressure & cooling time for dependent variable shrinkage. Authors observed the melting temperature as most significant parameter for shrinkage.

Sanjay N.Lahoti et al [30] presented an experimental work for determining the effect of injection molding process parameters like mould temperature, melt temperature, injection pressure, holding pressure, cool time on the quality of molded parts for two separate materials ABS & PP(Polypropylene). Authors used taguchi method for the work.L27 orthogonal array with three levels of each parameter had considered.ABS & PP as a plastic material had selected. Further Authors used ANOVA technique for data analysis. Authors observed that cooling time had a significant effect on cycle time for ABS material & injection pressure at 95% level of confidence. Injection pressure had a significant effect on cycle time for PP material i.e. a small variation will have greater influence.

S.Selvaraj et al [31] focused on warpage measurement of injection moulded plastic components through image processing technique. Authors prepared a set up with fixed digital camera on top flat plate to capture the image of specimen which was kept on the bottom plate.Thermocoal was used for white background. Image had processed in photoshop.Further authors used MATLAB as an image processing tool for measurement of warpage.Authors also suggested that the method can also be extended to determine other defects like shrinkage, blow holes etc.If warpage is above acceptable limit, the suitable process parameters of injection molding machine such as mould temperature, injection pressure, injection speed, filling time & cooling time can be adjusted.

N.A.Shuaib et al [32] presented a study to find the factors that leads to warpage of thin as well as shallow injection molded part. Authors used simulation & taguchi experimental method as well as ANOVA technique for the same. Authors identified five factors like packing pressure, filling time; mold temperature, melt temperature, & the packing time. Four levels with L16 orthogonal array had been considered. Authors observed that the packing time had the most significant factor observed for warpage of the plastic component. Authors also provided optimum values for each process parameter.

Harshal P. Kale et al [33] experimentally determined the optimal injection molding parameters for minimum shrinkage. Authors used the design of experiments techniques by taguchi method. Authors used HDPE material having a natural colour polymer with good process ability. Signal to Noise ratio was considered. Authors considered various injection molding parameters such as cooling time melt temperature, injection pressure, & packing pressure with three levels of each. A plastic disc of 3mm thickness & 100mm diameter was produced using HDPE of grade 080M60 material.L27 orthogonal array was selected for this study. ANOVA method was used to find out the influence of all above mentioned parameters parameters on shrinkage of HDPE material. Melt temperature was observed as most influencing parameter.

P. Pachauri et al [34] made a research on optimization of metal injection moulding parameters. Various parameters considered by author for optimization were injection pressure, injection temperature, mould temperature, holding pressure, injection speed, powder loading, holding time & cooling time against response variable impact toughness. Authors presented a Metal Injection Moulding technology in their research work. This process consists of four main steps: mixing, injection moulding, debinding & sintering. During mixing the powder is mixed with a binder to form a homogeneous feedstock. The binder provides necessary flowability & formability for moulding. During injection moulding a green part with the desired shape formed by the feedstock flow into a mould under pressure. The binder is then removed by debinding step & debound part is sintered to desired shape to achieve required mechanical properties. Authors conducted the experiments by using Taguchi L27 orthogonal array & ANOVA was used for data analysis. Authors used S316L powder with a mixture of polyethylene glycol, polymethyl methacrylate & stearic acid as a binder. Experimental results were converted into S/N values for optimization of parameters. Finally authors presented optimum values of each parameter for maximum impact toughness.

M. V. Kavade1 et al [35] carried a research work for optimization of process parameters of injection molding phenomena with an objective to enhance productivity. Authors used the polypropylene as a moulding material. Various input parameters considered by authors were injection pressure, injection speed, barrel temperature, holding pressure, holding time, coolant flow rate & cooling time against response variable weight of part in grams. Authors used taguchi L18 array for experimentation work. ANOVA was used for data analysis. Finally authors observed that the reduction in cycle time was 4 sec which was 32.4 sec previously & productivity was enhanced by 12.5%.

Ng Chin Fei et al [36] had taken review of the research on practical use of taguchi method in the optimization of processing parameters for injection molding. The review throwned light on taguchi method & integration of taguchi method on various approaches like numerical simulation, grey relational analysis, principal component analysis, artificial neural network & genetic algorithm. Initially authors presented the standalone taguchi method in which authors presented various injection molding processing parameters like injection time, holding time, cooling time, mould open & close time, screw returning time, injection pressure, holding pressure, back pressure, melt temperature, mould temperature, ambient temperature & many more in the form of fish bone diagram. Later authors explained the integration of various approaches with taguchi method one by one.

Kingsun Lee et al [37] presented a research on LED lampshades manufactured by injection molding process. Further authors used a FEA technique to study the impact of LED lampshades shrinkage. Authors used Taguchi method for experimentation. Authors started the work with survey of literature of related work. Authors considered various controlling parameters like mould temperature, melt temperature, pack pressure, pack time & cooling time etc.Four levels of each parameters were considered.L16 orthogonal array was considered. Polycarbonate resin material was used for experimentation. ANOVA tool was used for data analysis. The minimm shrinkage obtained was within 0.03mm.

5. STUDY OF PLASTIC MOLDING PROCESSES

Author has visited different plastic molding industries to study the different processes & operations carried out to get plastic product. These processes are (a) Inspection and Pouring of Raw Material i.e. Plastic granules (b) Mould setting (c) Machine operation (e) Finishing of final Product and (d) inspection of final product. These all processes are detailed out sequentially as below.

Initially the raw material in the form of granules (pellets) is received & inspected. Then comes mould setting. During mould setting mould has to be lifted by using a crane & carry towards injection Molding machine. Then the Mould is fitted on an injection Molding machine. It is observed that mould size varies according to the capacity of machine. Generally two to three persons are engaged in setting and it requires approximately 45 minutes.

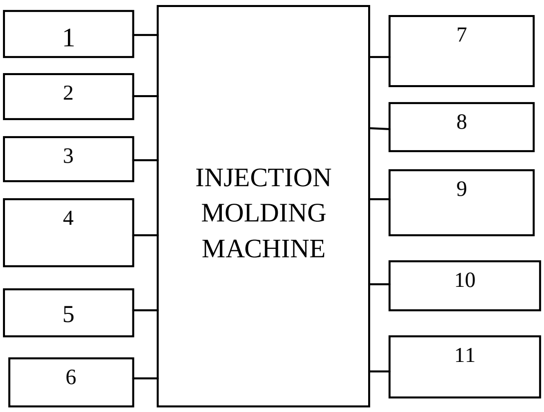

Fig1:-Block diagram of Injection Molding Unit

Where, 1=Electric Motor, 2=Hydraulic cylinder, 3=Hooper, 4=Barrel with heaters on periphery, 5=Reciprocating screw, 6=Check Valve, 7=Control Panel, 8=Mould in two halves, 9=Cooling Water Channel, 10=Ejector Pin Mechanism, 11=Workstation for Manual Operation.

Once mould setting is completed, the parameters related to injection Molding process like injection pressure, injection time, preheating temperature different barrel temperatures, melt temperature, cooling time, hold on time, part releasing time, cycle time etc have been set as per the requirement. Afterwards raw material in the form of granules is poured into hopper in which heaters are provided for preheating of the granules, in order to remove moisture contents. This is done to avoid the defects in the final product. In some industries the preheating furnaces are provided separately. The granules from hopper are then flowed downwards inside the barrel by virtue of gravity.

Inside the barrel, a reciprocating screw is provided. The electric heaters are provided on the outer periphery of the barrel for the purpose of heating. The function of reciprocating screw is to carry the raw material forward & this happens due to reciprocating as well as rotary motion of screw. The screw also ensures mixing & homogenization of the polymer & minimizes the required heating time of the process by mechanical shearing of the material & friction phenomenon. The material feeds forward through a check valve and collects at the front of the screw into a volume known as a shot. When sufficient material has assembled, the material is forced at high pressure and velocity into the mold cavity. To prevent fluctuations in pressure, the injection molding process generally takes a transfer position corresponding to a 95–98% full cavity where the screw shifts from a constant velocity to a constant pressure control. Once the screw approaches the transfer position the packing pressure is applied. Packing pressure ensures complete filling of mold with shrinkage compensation. The packing pressure is applied till the solidification of gate. The gate solidifies first due to small size. Material entry is restricted to flow inside the cavity after gate solidification. The screw reciprocates and collects material for the next cycle. Parallely the material within the mould cools & ejected outside the mould cavity. This cooling duration is reduced by providing cooling channels inside the mould for circulating water or oil from an external temperature controller.

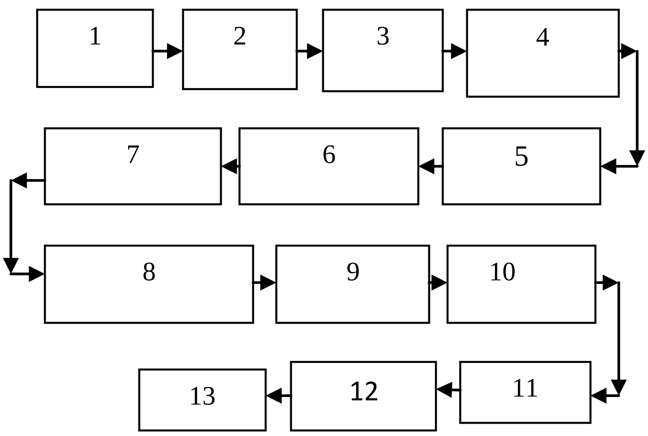

Fig2:-Block diagram of Injection molding process

Where, 1=Pouring of plastic granules inside hooper, 2=Preheating of plastic granules inside hooper, 3=Gravity flow of granules from hooper to barrel, 4=Reciprocating action of Screw inside barrel, 5=Plasticizing of Granules through shear & heat conduction, 6= Feeding, compression & metering are three zones of reciprocating screw, 7= The heated thermoplastic is conveyed by screw to its front side, 8= The molten thermoplastic is injected into the mould through the nozzle under high pressure, 9= Cooling & Solidification period, 10= Mould opens & component ejected outside, 11= Degating & Deflashing of component 12=Visual Inspection of plastic component,13= Final Inspection

Moulds are then opened once required temperature has been achieved or after completion of the cycle time. An operator removes the component from the mould or component gets pushed with the help of ejector pin mechanism outside the mould cavity. The finishing operation is then performed by the operator. He also checks the quality of surface by visual inspection & takes preventive action wherever required.

During visit authors have identified possible areas, where one can focus for the improvement in the existing plastic Molding process. These areas are detailed out as below.

5.1 Product Defects

The common defects observed in final components are listed as below (1) Rib bend (2) Scratches damage (3) Weak Welding (4) Colour Mark (5) Short Mould (6) Sink Mark (7) Oil Mark (8) Deflashing (9) Black Spot (10) Silver Mark (11) Ejector Pin Mark (12) Hole Crack(13) Burn Mark (14) Air bubble (15) Flash (16) Partition bend (17) Gauge fitment issue (18) Water Mark (19) White Mark. Out of all above mentioned defects the silver mark & white mark defects are having more frequency of occurrence which results in rejection of a component.

5.2 Human Comfort Condition

As the plastic Molding industries deal with the temperature parameter, it is observed that as the working place temperature slightly increases this in turn affects the humidity of the working place. The imbalance of humidity causes discomfort to the worker. At the other hand the posture acquired by the worker during production process seems to be inadequate. All these above problems affect the production process & needs to come out with appropriate solution.

5.3 Concept of Solutions Over Existing Problems

A Field Data Based Modeling Approach proposed by Dr.J.P.Modak [1][2][4][8] gives a favorable solution for this specific cause. In fact, FDBM simulates the process or activity pertaining to field or industry. In other word it derives the relationship between causes and effects of the process or activity or phenomenon. Sometimes causes are coined as independent variables and effects are coined as dependent variables. In this research work, the plastic injection molding process is taken as the activity or phenomenon. For this phenomenon following some dependent variables have been identified. 1. Productivity 2.Human Energy 3.Input Quality 4. Electrical Energy consumed. These dependent variables are dependent on independent variables Listed below. 1. Mould volume 2.Mould elasticity 3.Mould surface finish 4. Motor speed 5.Motor Torque 6.Meltng time 7.Hydraulic Back Pressure 8.Injection speed 9.Injection Pressure 10. Injection time 11.Packing time 12.Packing pressure 13.Hold on pressure 14.Hold on time 15.cooling water temperature 16.Mould Temperature 17.Environmenal variables such as temperature, humidity etc 18.Human anthropometric data & 19. Workstation parameters etc.

If one come out with the quantitative relationship between these dependent & independent variables then those would be field data based model. These models will predictive type. It means one could understand the effect of one variable on dependent variable so that he could optimize the model for the best desired output. In all in a field data based modeling one has a clear cut idea about the variables where he has to focus to improve the productivity. Therefore author is gathering a data related to the plastic processing industry and will form a mathematical model to predict the production rate of such an industry which will be the adjunct future proposal for this paper.

5.4 Future Scope

By using gathered field data related to plastic processing industry, author will form a mathematical model to predict the production rate of such an industry which will be the adjunct future proposal for this paper.

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