INJECTION MOLDING SCRAP REDUCTION: A STUDY IN THE RELATIONSHIPS OF PLASTICS PROCESSING METHODS

By

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ABSTRACT

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To maintain competitiveness and maximize profits in today's marketplace, one of the most important aspects that organizations must focus on is scrap reduction. In the plastics industry Phillips Plastics-Short Run, an injection molding facility, methodically collects data in an effort to better understand and control scrap generation.

The purpose of this research is to analyze the scrap levels associated with variances occurring in the injection molding machines, processes, materials, and operators at the Short Run facility. The results help to identify the possible causes of scrap and will lead to an appropriate solution to support Short Run in reducing scrap.

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Chapter 1

Introduction

In today's business, controlling scrap is one factor that companies focus on in order to remain competitive and maximize benefit. More specifically, in the injection molding area, Phillips Plastics-Short Run is trying to improve scrap control. This can be done through identifying the scrap associated with injection molding machines, plastic processes, materials, and operators. The purpose of this research is to analyze and identify the scrap levels related with those factors to help Short Run in better controlling their scrap rate.

Statement of Problems

This study analyzes scrap produced at Philips Plastics-Short Run, a plastic injection molding facility, to discover the scrap levels associated with machines, processes, materials, and operators to help improve Short Run's scrap control.

Objectives of the Study

The objective of this research was to collect data from Phillips Plastics-Short Run's scrap history log, analyze the scrap data, and identify the scrap levels to help control scrap rates at Short Run.

Purpose

The purpose of this study is to help Short Run, an injection molding facility, to identify a better solution toward the reduction of scrap. This study focuses on analyzing the scrap related with injection molding machines, plastic processes, materials, and operators. The results will help to identify the causes of scrap and will lead to an appropriate solution to support Short Run in reducing scrap.

Limitations

This study analyzes the scrap data from Short Run's scrap history log. The results are based on 100 production samples taken at Short Run. Part mold design is not discussed in this study. The time factor in each process will not be discussed in this study. The post-mold operation scrap and start-up scrap are also not included in this research. This research focuses only on the key parameters related with plastics processing.

Definitions

Amorphous Polymers A family of polymers characterized by the randomness of entangled polymer chains.

Anisotropic Shrinkage A shrinkage that is not the same in all directions. It occurs in fiber filled materials due to the restriction of shrinkage along the fiber length, which tends to be in the flow direction.

Branched Polymer A polymer that has additional monomer chains protruding from its primary chain.

Bubble Air or other gas trapped within the plastic leading to a void in the part.

Burning Showing evidence of thermal decomposition through some discoloration, distortion, or localized destruction of the surface of the plastic.

Calibre The trade name of a polycarbonate material.

Clamping Force The maximum holding force, expressed in tons, that a machine is capable of maintaining.

Contamination Imperfections caused by foreign material molded into the part.

Crystalline Polymers A family of polymers characterized by areas of order in which the molecular chains line up and lay tightly together in an otherwise amorphous mass.

Crystallization Temperature The temperature at which a crystalline resin begins to crystallize upon cooling.

Cycle Time The time that has elapsed between the starting point in one cycle of production and the starting point in the next cycle.

Cycolac The trade name of acrylonitrile-butadience-styrene (ABS) material.

Degradation A reduction in the physical properties of polymers due primarily to breaking of the long chained molecules. It occurs when the resin is heated at too high a temperature, or for too long, and can result in substandard parts.

Delamination The splitting of a plastic material along the plane of its layers. It is a physical separation or loss of bond between laminate plies.

Engineering Thermoplastics A group of thermoplastics generally considered as high performance materials.

Flash Extra plastic attached to a molding along the parting line.

Flow Marks A mark on a molded piece made by the meeting of two flow fronts during molding.

Glass Transition Temperature (Tg) The temperature at which a material turns rubbery upon heating and glassy upon cooling.

Injection Molding A polymer processing method that produces intricate, high performance, precise parts with very little secondary labor operations and with minimal waste.

Melting Point (Tm) The temperature at which the crystalline regions soften and begin to flow.

Molded-In Stress The stress that has been “built into” the part during processing.

Mold Shrinkage The amount of material shrinkage in the mold that must be accommodated for in the tooling design and is reported in inches/inch, mils/inch, or as a percentage.

Molecular Weight The weight of a molecule, calculated as the sum of the atomic weights of its atoms.

Molecule The smallest unit of a substance, able to exist by itself and retain all of the properties of the original substance. Molecules are composed of one or more atoms.

Plasticize A combination of electrical and mechanical heat energy that is used to soften polymer pellets until they flow.

Plastics A material containing one or more organic polymeric substances of large molecular weight.

Polymer A chemical compound formed by many small molecular units joined together to form a large, chain-like molecule.

Polymerization A chemical reaction in which two or more small molecules combine to form large molecules that contain repeating structural units of the original molecules.

Radel The trade name of polyerylsulfone (PES) material.

Resins Any of various materials made from polymers or plastics.

Rheology The study of material flow.

RTP the trade name of a polycarbonate material manufactured by RTP.

Short Shot A part that is not completely filled with plastic.

Shrinkage A volume reduction of polymers that occurs during cooling due to a reduction in space between the molecules.

Sink Marks A depression, or “dimple” due to shrinkage on a part, usually found on the opposite side of where a thick wall section exists, caused by internal stress.

Splay Silver-streaked appearance caused by gasses in the plastic when parts are filled, usually caused by moisture or material degradation.

Thermoplastics A family of polymers characterized by its ability to be reprocessed.

Ultem The trade name of a polyetherimide (PEI) material.

Viscosity The resistance to flow of a plastics material. It is the ratio of shearing stress to rate of a shear.

Void Caused by internal stresses pulling plastic molecules apart.

Warpage Dimensional distortion in a plastic object after molding.

Weld Line The line in a part which results when two flow fronts meet and “knit.”

Chapter 2

Literature Review

Introduction

The analysis of most injection molding problems usually focuses on the molding cycle (Reinhold, 1986). Typically these types of analyses are concerned with three major elements of the molding operation: injection molding machine, mold, and material. The performance of these operating elements is influenced by the three variables controlling the injection molding process: time, pressure, and temperature. They are all interrelated variables. A change in one or more variables in the molding operation can affect the whole process. Molding problems may also occur due to the action of operators (Reinhold, 1986). For example, jobs that require loading inserts, pick-outs, or applying mold release before starting the cycle, are hard to keep on a consistent cycle time. However, through using CAD/CAM, injection molding simulation and prototyping, the problems due to mold design are minimized (Beaumont, Nagel, Sherman, 2002). Cycle time also depends on the response of hydraulic valves and the mechanical system of the injection molding machine. For this reason, this research does not include process time in the analysis. The major operating elements, machines, processes, materials, and operators and their associated problems that cause scrap are presented in this chapter.

Machine

The basic process requirements that each injection molding machine must meet are based on process time, temperature, and pressure (Reinhold, 1987). However, machine characteristics may change with age (Beaumont, Nagel, & Sherman, 2002). Scrap occurs due to inappropriate machine conditions such as a malfunctioning feed system, inconsistent screw stop action, inconsistent screw speed, uneven back pressure adjustment, malfunctioning temperature control system, insufficient plasticizing capacity, inconsistent cycle, clamp pressure not maintained, and so forth (Reinhold, 1986). Inconsistent machine control can cause material degradation, part delamination, burning, flash, short shot, sink marks, flow marks, etc (Reinhold, 1986).

Process

Injection molding is a process by which plastic raw materials are converted into useful products meeting acceptable standards (Beaumont, Nagel, & Sherman, 2002). Each plastic material, based on type and grade, can be correctly processed within a certain range of temperatures and pressures (Whelan, Anthon, Craft, 1978). These are the key parameters of plastic processing. The purpose of this section is to review these key parameters and their associated problems that can lead to scrap.

Melt temperature is the temperature at which a resin changes from a solid to a liquid. At this point, the crystalline regions of a plastic material soften and begin to flow (Reinhold, 1991). Melt temperatures range from 248^{o}F to 662^{o}F (Beaumont, Nagel, & Sherman, 2002) and are controlled by barrel temperature, nozzle temperature, screw speed, back pressure, and residence time.

About 70% of the heat needed to melt the plastic is generated from shear heating that occurs within the plastic itself (Beaumont, Nagel, & Sherman, 2002). Therefore, the melt temperature is difficult to measure and cannot be directly controlled by the thermostats on the control panel. The injection molding machine barrel and nozzle temperatures are maintained by electrical heating elements. These elements provide the remaining 30% of the heat required to maintain a plastic temperature high enough to guarantee plastic flow.

The thermodynamic properties of the molten plastic, such as viscosity, enthalpy, and specific volume, change simultaneously with melt temperature (Johannaber, 1994). Therefore, it is important to try and maintain a constant melt temperature in the molding process. Any change in melt temperature leads to a change in cavity pressure, cycle time, or injection time. The problems associated with inconsistent melt temperatures may cause some common part defects such as splay, burning, flash, flow line, short shot, sink marks, bubbles, etc (Reinhold, 1996).

Mold temperature is the temperature that maintains the cavity surface at a specified temperature to cool a hot plastic to a solid state. Mold temperatures range from 32^{o}F to 302^{o}F, and are dependent on the coolant temperature, flow rate, proximity of the coolant channels to the plastic, and the rate of the heat input from the plastic. The coolant flow rate reaches its maximum if the fluid is in the state of turbulent flow. The flow can be characterized by calculating the Reynold's number for the stream. It is the ratio of inertia forces to viscous forces within the flow field. The Reynold's number is a dimensionless number based on the channel diameter, flow rate, density, and viscosity of the fluid. If this number is greater than 10,000 (Reinhold, 1996), turbulent flow is fully developed and the co-efficient of the heat transfer is maximized (Beaumont, Nagel, & Sherman, 2002). Heat transfer may be satisfactory when the mold is new, but it will decrease as the mold ages due to corrosion and lime deposits. The heat input from the plastic varies from location to location. It depends on the local part thickness and the plastic flow past the location. The mold wall temperature is not uniform, and hence the cooling rate will not be uniform. This can affect the melt viscosity, cavity pressure, or hold pressure (Johannaber, 1994). These problems can cause part defects such as sink marks, void, bubble, warpage, short shot, flow line, surface defects, etc (Reinhold, 1986).

In many plastic injection molding machines, a hydraulic pressure is applied to force the screw forward against the melted plastic. The plastic is forced to flow through the nozzle, the sprue, the runner system, and finally into the cavity to form the part

(Beaumont, Nagel, & Sherman, 2002). This pressure ranges from 7,250 pounds per square inch (PSI) to 36, 260 PSI. Due to the way a plastic fills and solidifies within the mold cavity, pressure is not uniform throughout the part. The highest pressure occurs at the gate; the lowest at the point in the cavity to fill last. The total volume of plastic in the cavity tends to be reduced as it cools and solidifies. Pack and hold pressures are used to provide a compensation flow into the cavity to make up for lost volume as the plastic shrinks with decreasing temperature and while the gate remains open. However, to minimize volumetric shrinkage in the cavity, pressures are minimized to the point where there is enough pressure remaining to provide a compensating flow but not to where it tends to over-pack the material near the gate. Insufficient pressures can cause part brittleness, bubbles, sink marks, cracking, flashing, short shot, etc. (Reinhold, 1986).

Material

Plastic materials consist of two basic groups, thermoplastics and thermosets. Thermoplastic materials are made of the linear or branched polymer units comprised of repeating monomers. They comprise about 94% of the volume of the material used in the plastic industry and can be repeatedly heated, melted, and formed into a product. (Beaumont, Nagel, & Sherman, 2002).

Thermoplastics include amorphous polymers and semi-crystalline polymers. Amorphous resins have a wide processing temperature window. An amorphous polymer chain is randomly entangled. Typical amorphous polymers are polystyrene, acrylonitrile-butadience-styrene (ABS), polyethersulfone, etc. Crystalline resins, on the other hand, have a narrow processing temperature window. Their molecular chains lie side by side in a highly oriented fashion. Well-known examples of crystalline polymers are polypropylene, acetal, and polytetrafluoroethylene (Brydson, 1999)

Thermoset materials react chemically during processing to form a cross linked structure. They cannot be melted and reprocessed (Reinhold, 1991). Polyimides, polyesters, and epoxies are examples of thermoset materials.

The transition between solid and liquid phases is a primary concern when processing plastics. In crystalline materials, the change from solid to liquid is abrupt and easily discernible. In an amorphous polymer, the material softens over a wide temperature range. In polymer science, there is a point called the glass transition point (Tg). At temperatures below this point, plastic is stiff, stable, and behaves like a solid. In environments at temperatures above the Tg, the polymer will behave as a viscous liquid (Reinhold, 1991).

Within a material, there are two forms of energy (Reinhold, 1991) used to maintain the physical structure. One is potential energy, which is a measure of the forces of attraction between the molecules. The other is kinetic energy, the energy of motion tending to separate the molecules. As more energy is put into the system, it turns into a liquid. That is where the potential and kinetic energies are equal.

Thermoplastic materials are made of strong covalent bonds (primary bonds) along polymer molecules and weaker secondary bonds (Van der Waals' forces) between polymer molecules (Beaumont, Nagel, & Sherman, 2002). A covalent bond exists when two atoms share the electrons in their outer shells in order to be stable. It has a disassociation energy of 83 Kcal/mole. The Van der Waals' forces are electrostatic in nature and have a disassociation energy of 2-5 Kcal/mole. This is the energy that attracts molecules (cohesive energy), and is also the energy required to move a molecule a large distance from its neighbor (Reinhold, 1991).

If the temperature of a plastic rises, the distance between the molecules increases. Because the Van der Waals’ forces decrease with the sixth power of the distance, the molecules and their segments become more mobile. As these forces decrease in an exponential manner, there is a relatively narrow range in which the polymer changes from solid to a liquid. Therefore, polymer properties are quite temperature-dependent (Reinhold, 1991). For this reason, it is important to know the processing temperature range for each plastic material in order to make good parts.

During the injection molding process, a polymer mass is heated to a point at which it melts. In this molten phase, the material can flow and is forced into a cold mold where it will take the shape of the cavity (Beaumont, Nagel, & Sherman, 2002). However, a resistance to the flow of plastic material, exists due to viscosity (Brydson, 1999), which is determined by shear stress divided by shear rate. Shear stress is a measure of the resistance to flow of the molecules sliding over each other (Reinhold, 1991). Shear rate is the rate of velocity change of a flowing material.

For a specific polymer, the viscosity is dependent on temperature, molecular weight, and shear rate (Brydson, 1999). The higher the temperature, the lower the viscosity. The higher the molecular weight, the greater the entanglements and the greater the melt viscosity. To maintain the same volume of material in the cavity, shot after shot, it is necessary to maintain the consistency of pressure and viscosity. However, the characteristics of materials are very complex (Beaumont, Nagel, & Sherman, 2002) and most of them are non-constant. Non-constant viscosity is affected by the molecular weight distribution of a polymer. This is a factor that makes it difficult for a process engineer to create an optimum process.

State-of-the-art tools such as material databases and injection molding simulation software are available to aid in the prevention of common problems. However, the non-constant and complexity in characteristics of plastic material, combined with the process conditions in manufacturing, still result in unacceptable parts. Common part defects include contamination, burning, bubbles, splay, sink marks, voids, short shot, and warpage (Reinhold, 1986).

Operator

Reinhold wrote, “If the problem appears, disappears, or changes with the operators, look for the differences in actions of operators.” (1986, p 665) Operator actions are the methods by which operators perform their jobs, and these actions can be related to machine performance. This research reviews the operator experience-performance relationship and uses it as a tool for analyzing the relationship between operator and scrap levels. The only factor relating to operators that this research focuses on is work experience based on the time spent on the job.

Most literature on work experience has focused on time (79.5%) or job level of specificity (68.2%), (Kolz, McFarland, & Silverman, 1998). Job experience was defined as a number of years an employee had worked in the same job for the same company. This is the most commonly used definition of job experience. However, the jobs consisted of a limited number of activities and rarely deviated from their routine; the number of years on the job was highly related to the number of times each work task was performed. This agreed with the results showing that the number of times a person performs a job task is more strongly correlated with work performance than the time spent on the job. Data on the number of years on the job is readily available. Therefore, it is a more practical measure of experience rather than counting the number of times a task is performed. For this reason, the years on the job are likely to continue to be an important measure of experience.

Work experience can be measured based on time, amount, or type (Kolz, McFarland, 1998). In a time-based mode, experience is measured by the time spent in a particular job, company, or given occupation. In an amount-based measure, the experience of an operator can be measured as the number of times he/she performs a particular task. Some studies measure an individual’s work experience based on type. This measurement mode defined experience as the degree of similarity between a person’s previous job and current job. The more similar the previous job is to the current one, the more relevant work experience the person is presumed to bring to the current job.

Work experience has also been measured at the task, job, or organizational level of specificity (Kolz, McFarland, 1998). At a task level of specificity, work experience is measured as the number of times an individual performed a task. At a job level, experience is measured by the amount of time an individual spent on a job. At the organizational level of specificity, experience is measured as the time a person spent in an organization.

The results showed the strongest relationship between experience and performance was when work experience was measured at an amount or task level of specificity. The meta-analysis also reveals that the relationship between work experience and job performance was positive regardless of the work experience measure used (Quiñones, Ford, & Teachout, 1995). In other research, conducted by Hofman, Jacob, & Baratta, It was concluded that individuals may rate an employee’s performance relating to his/her level of experience (1993). In addition, a meta-analysis by McDaniel, Schmidt, & Hunter (1998) found a mean corrected correlation of 32% between work experience and job performance across a number of occupations.

In the injection molding process, there are cases where the operators need to manually operate the injection molding machines. For example, an operator has to open the machine door to take the part out of the mold. They need to put in inserts, pick-outs, or apply mold release before starting the next cycle. Such actions by operators may result in changing the cycle time, residence time, temperature, and viscosity of the plastic material. These problems will result in several part defects such as splay, burning, short shot, sink marks, surface defects, and so forth (Reinhold, 1986).

Chapter 3

Methodology

This chapter will present the methods and procedures used to identify the scrap levels associated with each major factor: machine, process, material, and operator. The information is based on scrap data collected from the scrap history log at the Phillips Plastics-Short Run facility. Data was organized and used to calculate average scrap levels related to each factor for this analysis. Results will be discussed to address the causes of the problems that lead to scrap.

Research Design

The data from hundreds of production jobs was collected randomly from September through November 2003. However, to assure that a good statistical sampling of data was gathered, at least three jobs for each machine were collected. To guarantee consistency when gathering data, each production job was run through all shifts. The data collected includes material type and key process parameters: melt temperature, mold temperature, and pressure. Information about machine age and size or tonnage for all 32 injection molding machines was collected. Operator data for the facility's first, second, and third shifts was obtained according to their years of experience.

Data Collection

With permission from the plant and production managers, maintenance coordinator, and supervisors of all three shifts at Phillips Plastics-Short Run facility, data was collected from Short Run's scrap history logs for September to November, 2003. The data included: operator initial and shift run, total good part, total scrap, and scrap caused by common problems like contamination, partial fill, void/bubbles, sink marks, burning, and splay. The material type, process key parameter, melt temperature, mold temperature, and pressure were also included with the data (Appendix A). In addition, age and tonnage from all injection molding machines on the floor were collected (Appendix B). The list of operators and their years of experience was also collected (Appendix C).

For this study the data was collected randomly from one hundred production jobs. However, to assure that a good statistical sampling of data was taken, at least three production samples were collected from each machine in an effort to include every machine in this research. Although limited data can be gathered from a real world business, the information collected satisfied basic statistical and research requirements.

Analysis

The data collected was organized and grouped in a manner that addressed each of the major factors covered in this research: machine, process, material, and operator. Then the scrap was organized and analyzed based on the appropriate requirements of each factor to yield their scrap levels.

Machine

To analyze the scrap related with the injection molding machines, the percentage scrap related with each machine was calculated. Then the machines were organized into four groups based on their tonnage and age at their associated scrap level. Group one consisted of machines two years old or less. Group two included machines from three to four years of age. Group three included machines from five to eight years of age. Finally, group four included the oldest machines, which consisted of eleven to fourteen years of operation. The average scrap percentage related with these groups was calculated for an overview of the scrap level trends associated with the age of machines.

To analyze the scrap level related with the machine tonnage, machines were organized into following five groups:

- Group one: 20-40-ton machines.
- Group two: 55-80-ton machines.
- Group three: 110-150-ton machines.
- Group four: 200-300-ton machines.
- Group five: only one machine of 400 tons.

The average scrap level, in percentage, was calculated and yielded the scrap trend associated with the machine tonnage from low to high.

Process

This area of research focused only on the analysis of key process parameters in the injection molding process conditions. These parameters include melt temperature, mold temperature, and pressure.

Melt Temperature

The melt temperature of the process in this research is classified into three levels: under 500^{o}F, 500-600^{o}F, and over 600^{o}F. The scrap levels associated with each range of temperature were calculated to identify trends.

Mold Temperature

The mold temperatures are presented at three levels: under 100^{o}F, 100-200^{o}F, and over 200^{o}F. The scrap levels related with the mold temperatures were calculated for each range to identify trends.

Pressure

The pressures were organized into three ranges: pressures under 10,000 PSI, 10,000-20,000 PSI, and over 20,000 PSI. Good and scrap part rates associated with each range of pressure were calculated to get the average scrap percentage. The results identify a trend of scrap levels associated with the process pressure.

Materials

The majority of materials used in the one hundred production samples collected for this research consisted of the following materials: Calibre, Radel, Ultem, Cycolac, and RTP. Other materials used with less frequency in the production run were Lexan, Bayblend, LNP, Lustran, Cycoloy, Zytel, Santoprene, etc. Only the first five materials are analyzed for this study. The data related with each of these five materials was organized to yield their specific scrap levels. The scrap rate related to common defects, such as contamination, partial fill, void/bubbles, burn/streaks, sink marks, and splay, was also calculated to identify relationships between these material defects.

Operator

To analyze the scrap associated by operator; this research organized operators on each production line based on their years of experience. Operators were divided into three groups: less than one year of experience, one to two years of experience, and over two years of experience. The scrap percentages for each operator were calculated, and then identified for each group. The results show a relationship exists between scrap levels and operator experience. The average scrap levels associated with operators on each production line and shift were also calculated and analyzed.

Chapter 4

Results

This chapter presents a detailed overview of the scrap levels associated with machine, process, material, and operator. The scrap levels are related to the tonnage or age of injection molding machines. The scrap percentages are also related to plastic process key parameters: melt temperature, mold temperature, and pressure. The scrap levels associated with the five most common materials, used by Phillips Plastics-Short Run facility, were used for this research. And the scrap associated with operators, on each shift and production line, was based on their years of experience. These results, based on the analysis of actual scrap data, can be used by Phillips Plastics-Short Run to quickly predict the levels of scrap that may occur at each work station. Therefore, they will be able to better control the generation of scrap at their work stations.

The scrap rates associated with machine age are shown in Figure 1. The scrap rates related with using the newest machine (1-2 yrs) were quite high. The scrap rates were lowest using the 2-4 year old machines. Scrap level related with using the machines over 5 years of operating age were similar, at above 5%. Except for the machines under 2 years of age, scrap level tends to increase as machines get older.

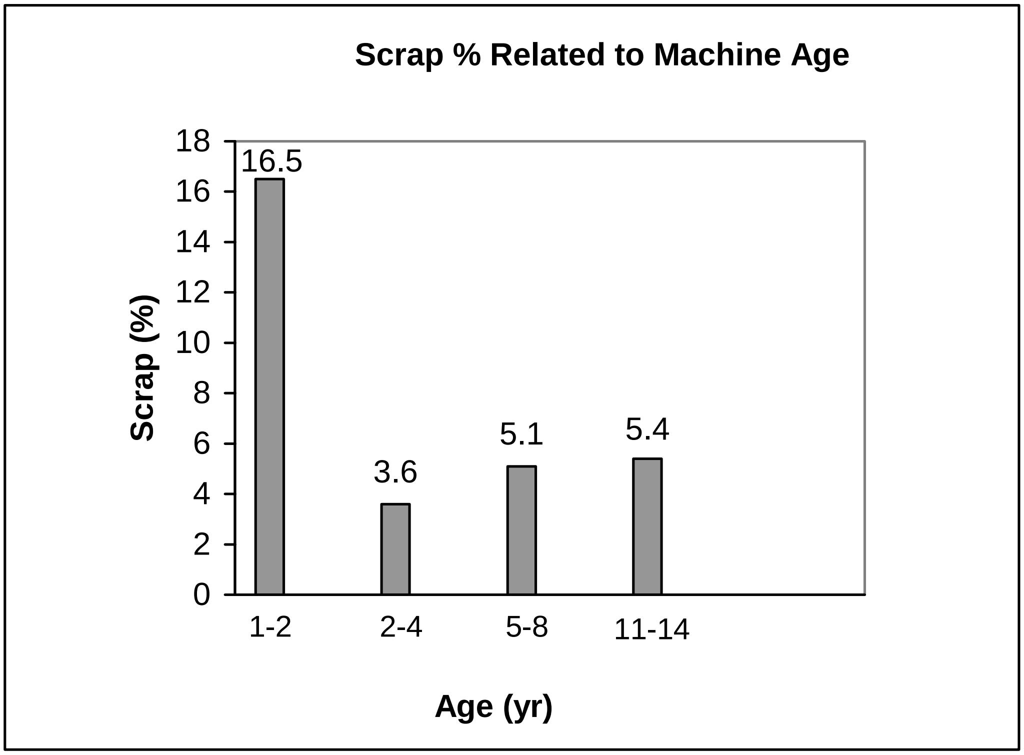

Figure 1 Scrap Percentage Related to Machine Age

The results show in figure 2 that the scrap level increases as the tonnage of the machine increases. The machines less than 40 tons in size resulted in the lowest level of scrap. Machines from 55-80 tons in size resulted in 5.9% of scrap. Machines 110-150 tons in size resulted in a scrap level of 5.8%. Machines 200-300 tons in size resulted in a 7% scrap level. Only one 400-ton machine operates on the shop floor. The scrap related with it was high, up to 34%. However, just one machine at that clamp force does not result in a good statistical sampling. In general the trend of scrap increases as the machines' tonnage gets higher.

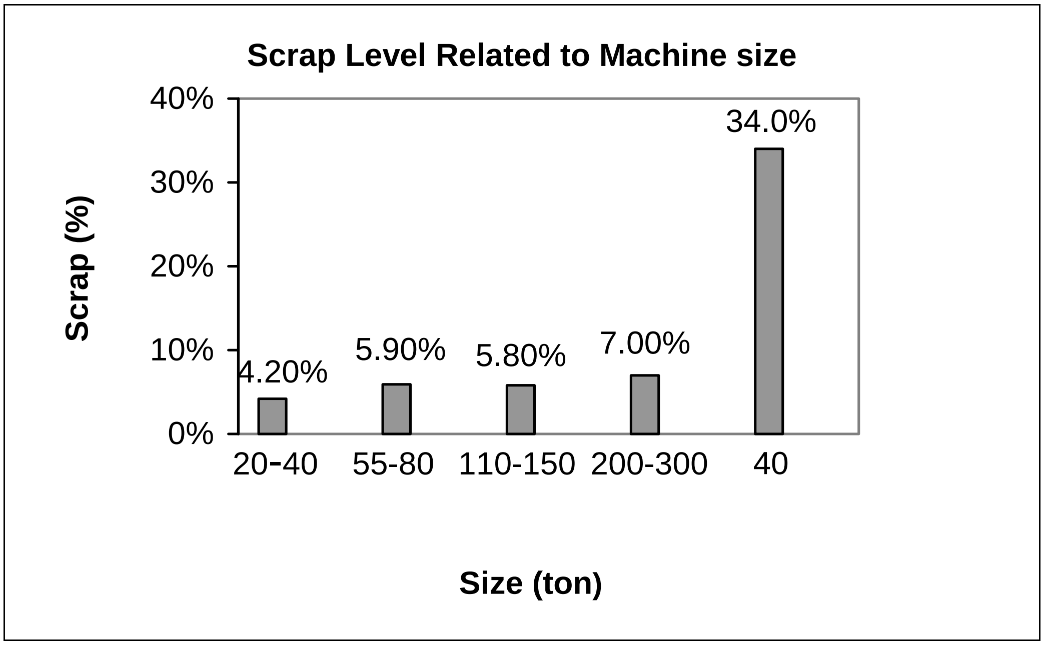

Figure 2 Scrap Percentage Related to Machine size

Figure 3 shows the scrap levels associated with the melt temperature. In the range of melt temperatures under 500^{o}F, the scrap level was 0.8%. The scrap jumped to a higher level of 3.9% with the melt temperatures between 500-600^{o}F. And with the melt temperature over 600^{o}F, the scrap again increased to a level of 5.3%. In the common range for melt temperature (under 500^{o}F), the scrap was at an acceptable level. At higher temperatures, the scrap levels increased. The apparent trend is that the higher the melt temperature, the higher the scrap level.

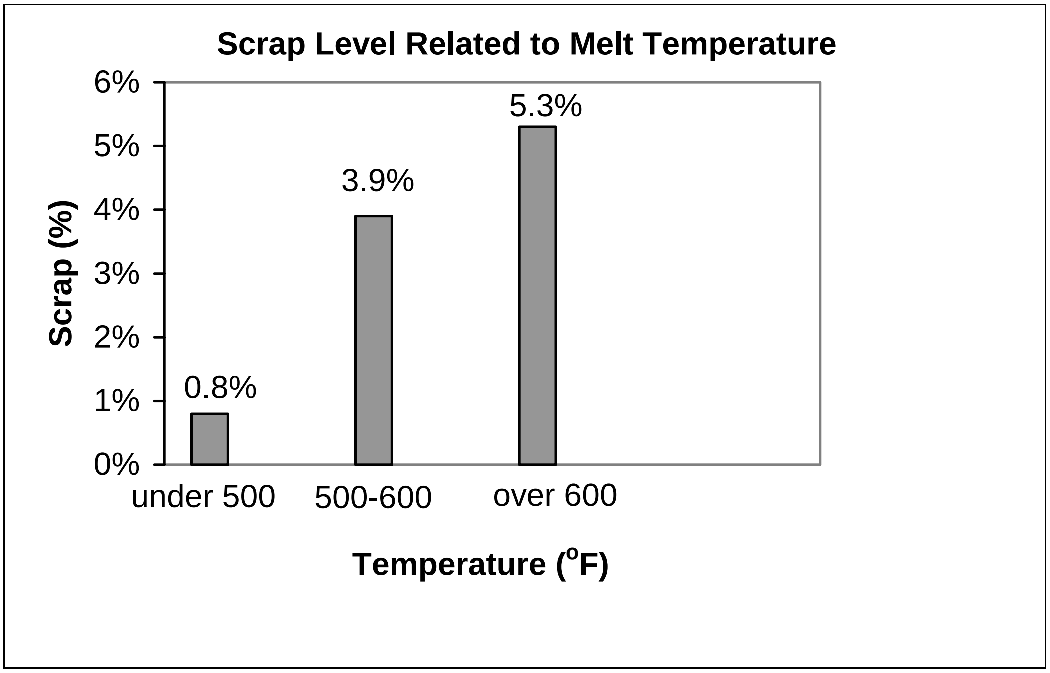

Figure 3 Scrap Levels Associated to Melt Temperature

Figure 4 presents the average scrap percentage results associated with mold temperatures. At lower mold temperatures (under 100°F), the scrap level reaches a very high level of 8.6%. The scrap percentage reduces to about half (at 4.7%) in the mid-range of mold temperatures (100 °F -200°F). At higher mold temperatures (200°F and up) the scrap level was 2.9%. Therefore, it is apparent that the higher the mold temperature, the lower the scrap level.

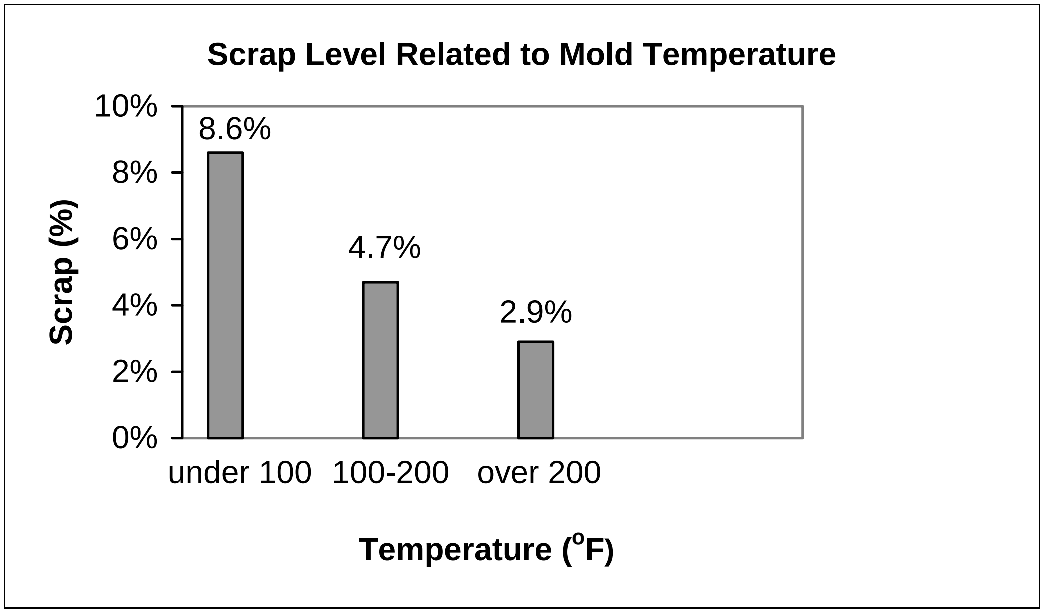

Figure 4 Scrap Levels Related to Mold Temperature

As Figure 5 shows, at the lower range of pressures (under 10,000 PSI), the scrap level was very high at 9.3%. At the mid-range of pressures (10,000-20,000 PSI), the scrap was lower at 3.7%. The process at higher pressures, 20,000 PSI or higher, resulted in a scrap level of 4.8%. In general, the scrap level was lowest at pressures of 10,000PSI to 20,000PSI. The processes that require higher pressures produce higher level of scrap. However, at a lower pressure (under 10,000 PSI) the scrap level also becomes very high.

The five most commonly used materials for this research were Calibre, Radel, Ultem, Cycolac, and RTP. Calibre was the most commonly used material in the data collected for this research. Table 1 show that the over all scrap level associated with using this material was 3%. The contamination level related with this material resulted in the highest specific scrap level. The scrap level due to burning, void/bubble, and splay were also monitored. Scrap levels due to partial fill were very low using this material, and scrap due to sink marks was nonexistent. Generally, Short Run should pay very close attention to contamination of material, then consider scrap due to burning, void/bubble, and splay when using this material.

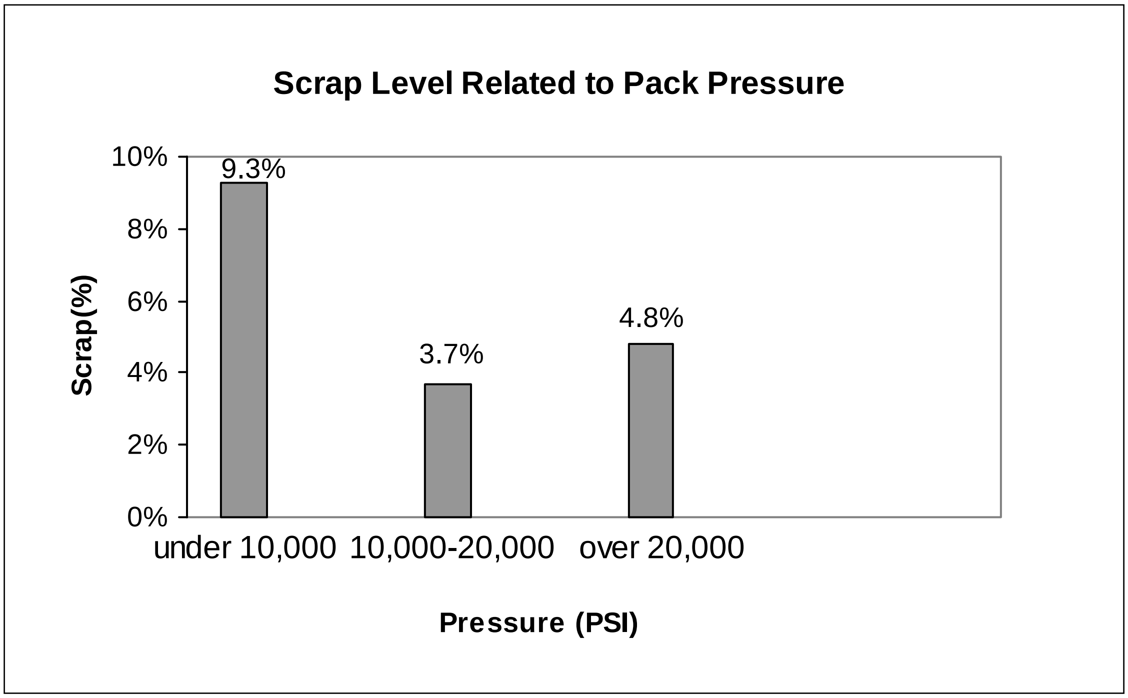

Figure 5 Scrap Level Related to Pack Pressure

Total Parts	Contamination	Partial	Void/Bubble	Burn/Streak	Sink	Splay	Scrap Rates
203,707	1844	52	256	318	0	203	3.0%

Table 1 Scrap Level Related to Calibre

Radel was the second most commonly used material at the Short Run facility, as identified by this study. The over all scrap level related with the use of this material was

4.6%. Splay resulted in the most scrap. Scrap due to contamination was the second most important issue when using this material.

Total Parts	Contamination	Partial	Void/Bubble	Burn/Streak	Sink	Splay	Scrap Rates
8,387	59	14	7	1	0	138	4.6%

Table 2 Scrap Level Related to Radel

Ultem was another material used often by Short Run. The study shows that the over all scrap level related with using this material was 5.3%. Most scrap problems occurred due to splay. The next problem occurred due to contamination scrap level. Void/Bubble and burn/streak scrap levels were much lower than splay and contamination scrap levels. For this material, scrap levels due to sink marks and partial fill were very low. Therefore, splay and contamination should be closely monitored when using Ultem.

Total Parts	Contamination	Partial	Void/Bubble	Burn/Streak	Sink	Splay	Scrap Rates
102,519	245	26	97	63	18	840	5.3%

Table 3 Scrap Level Related to Ultem

Table 4 shows that the over all scrap level associated with using Cycolac was 2.5%. The most common scrap problem presented with using this material proved to be splay. Contamination was far less a problem, but nevertheless also needs to be considered. Similar to Ultem, when Cycolac was used, the splay scrap levels were highest.

Total Parts	Contamination	Partial	Void/Bubble	Burn/Streak	Sink	Splay	Scrap Rates
39,056	72	15	3	2	3	420	2.5%

Table 4 Scrap Level Related to Cycolac

The over all scrap level related with using RTP is presented in Table 5, and was found to be 9.3%. The table also shows the biggest problem was scrap due to contamination. Sink marks and partial fill scrap levels should also be considered. Splay, bubble, and burning scrap levels were rarely problematic when using this material. Therefore, most scrap reduction efforts should be focused on contamination during the use of RTP.

Total Parts	Contamination	Partial	Void/Bubble	Burn/Streak	Sink	Splay	Scrap Rates
13,184	454	178	0	13	193	5	9.3%

Table 5 Scrap Level Related to RTP

Figure 6 shows the scrap percentage related with three lines of 1st shift production at Short Run. The scrap level on A-line was found to be 2.9%. On B-line, the scrap percentage jumped to a higher level of 4.6%. And on C-line, the scrap level resulted in a rate of 3.5%. These scrap rates resulted in an average scrap rate of 3.7% for the first shift.

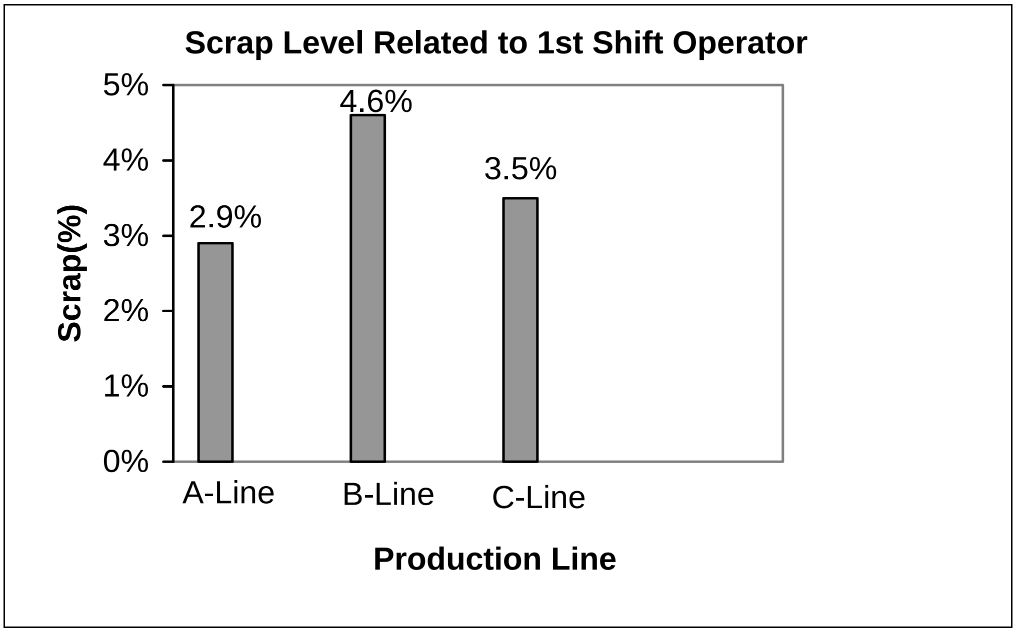

Figure 6 Scrap Levels Related to 1st Shift Operators

The result in figure 7 show that the scrap percentages for 2nd shift as related to operators were: 6.8% (A-line), 9.6% (B-line), and 7.5% (C-line). B-line, again garnered the highest percentage of scrap level. The next lower scrap level was C-line, and at yet a lower scrap level was the A-line. On average, the scrap level on 2nd shift was 8%.

The results for 3rd shift, shown in figure 8, at Short Run were: 4.7%, 8%, and 4.2% associated with A, B, and C-lines, respectively. The highest level of scrap still occurred with the B-line. However, A and C-lines were extremely close to each other, at 4.7% and 4.2%, respectively. The results also show an average scrap percentage of 5.6% for 3rd shift.

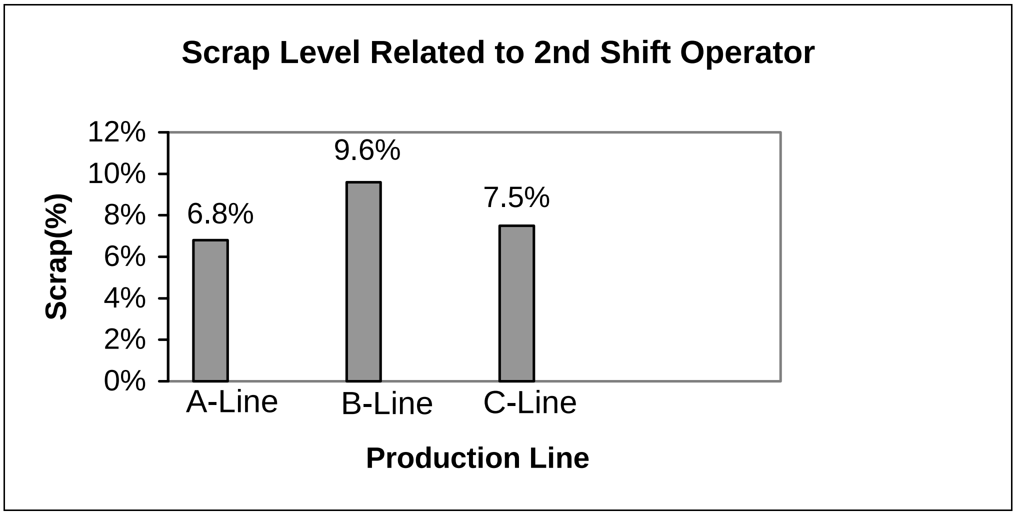

Figure 7 Scrap Levels Related to 2nd Shift Operators

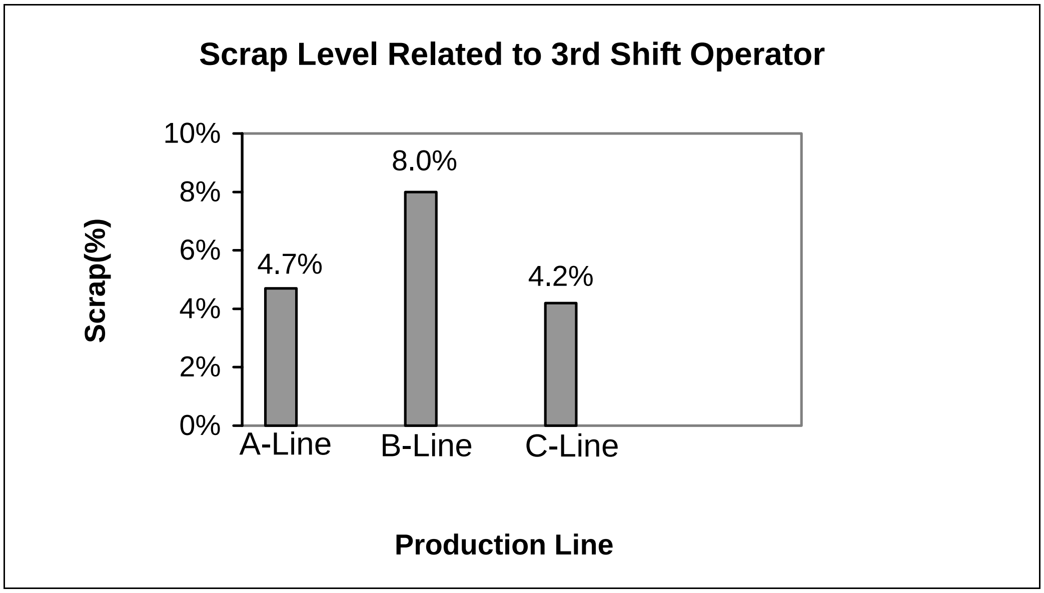

Figure 8 Scrap Levels Related to 3rd Shift Operators

The average scrap level for each production line on all three shift is shown in figure 9. It can be seen that the average percentage scrap level for the A-lines on all shifts was 3.7%. The B-lines reached an 8% average and the C-lines yielded a 5.6% scrap level associated with all three shifts. Generally, Figure 9 shows the highest scrap level occurs for B-line, lowest on A-line, and C-line falls in between.

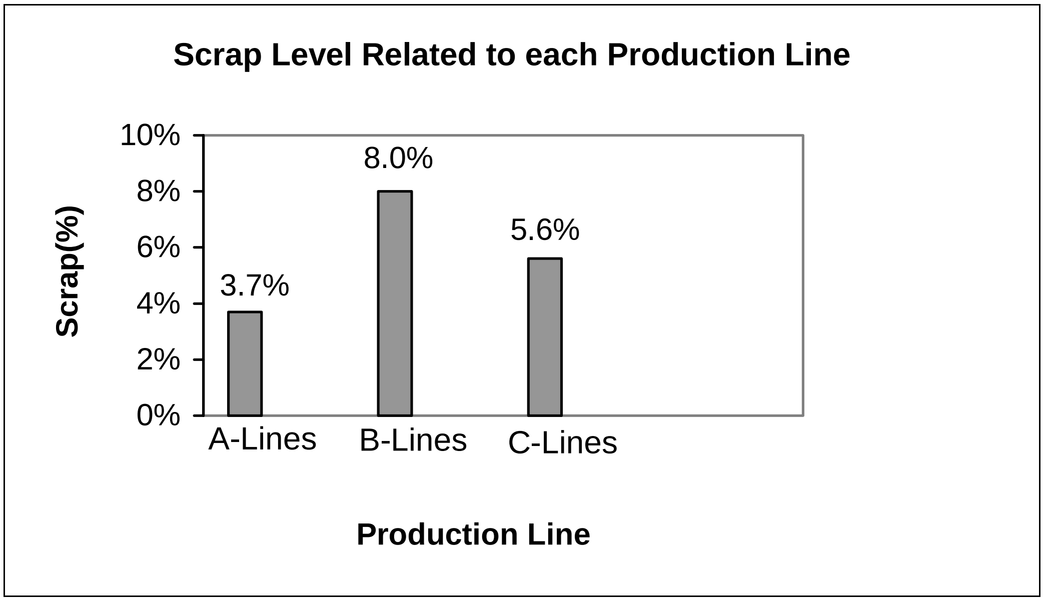

Figure 9 Scrap Levels Related with Each Production Line

Data gathered on operator experience for A-Line 1st shift is shown in figure 10. This data was organized into three groups based on their years of experience:

- Group 1: includes the operators that had less than a year experience.
- Group 2: includes the operators that had 1 to 2 years of experience.
- Group 3: includes the operators that had over 2 years of experience.

Figure 10 shows only two groups because there were no operators with less than one year of experience. The group of operators having from 1 to 2 years experience resulted in a scrap level of 3.2%. The other group having over 2 years of experience was associated with a scrap level of 2.1%. Figure 10 provides evidence that operators with more than 2 years of experience generated less scrap.

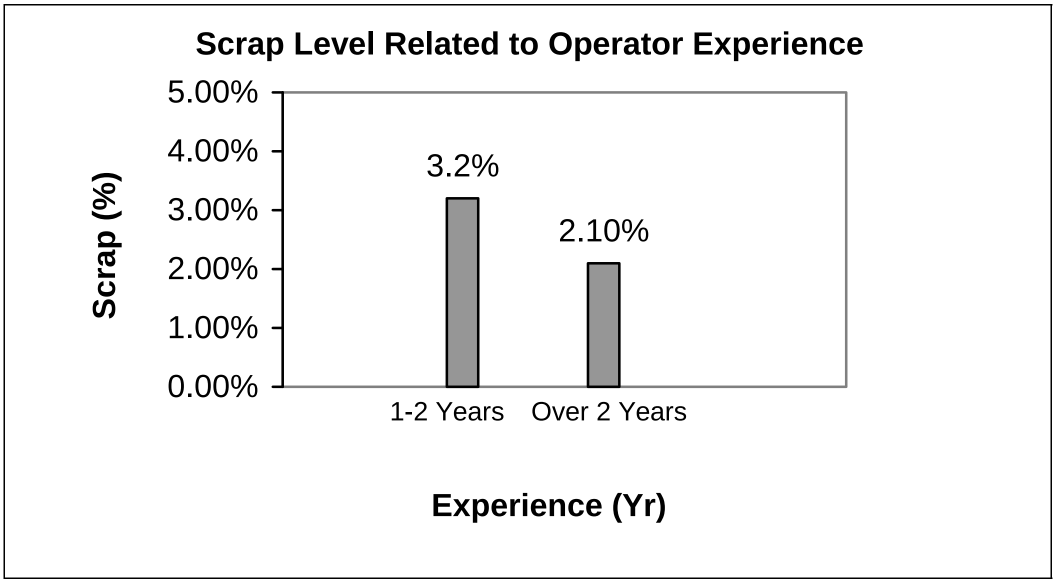

Figure 10 Scrap Levels Related to 1st Shift's A-Line Based on Experience

Figure 11 shows the scrap levels related to three operator groups for 1st shift B-line. This study was organized into the following groups:

- Group 1: operators that had less than 1 year of experience resulted in 3% scrap.
- Group 2: operators that had from 1- 2 years of experience resulted in 3.4% scrap.
- Group 3: operators that had over 2 years of experience resulted in 4.4% scrap.

Surprisingly, Figure 11 shows that the more experienced operator generated the higher scrap level. The fact that a more experienced operator generated the highest scrap level was an unexpected trend.

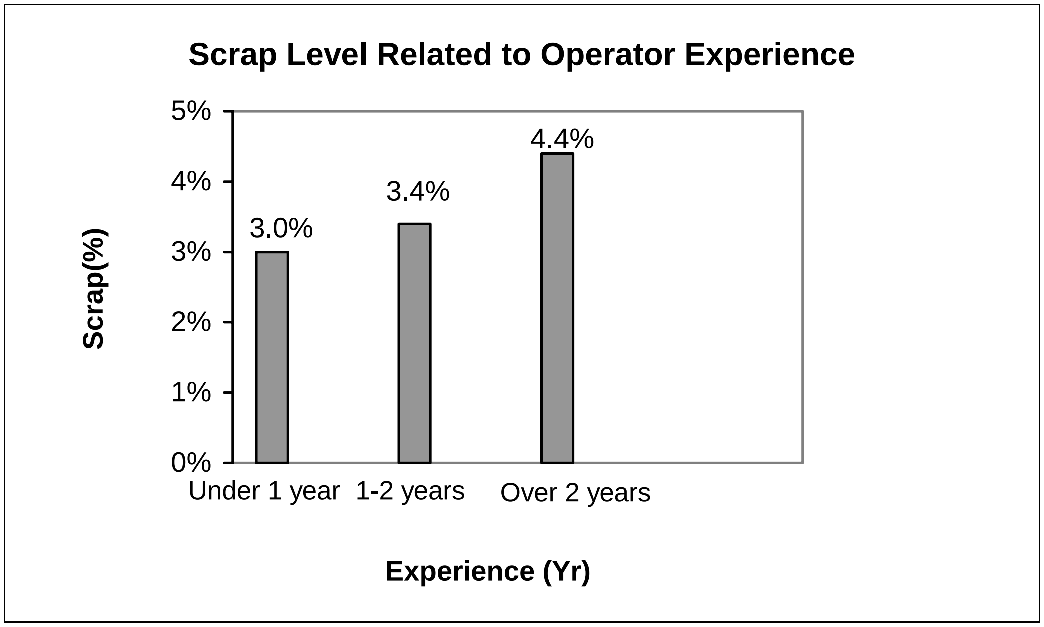

Figure 11 Scrap Levels of 1st Shift's B-Line Operators Based on Experience

Figure 12 shows the relationship between operator experience and scrap levels for 1st shift C-line. This data was organized into the following groups:

- Group 1: operators that had under 1 year of experience resulted in 5.2% scrap.
- Group 2: operators that had 1-2 years of experience resulted in 3.7% scrap.
- Group 3: operators that had over 2 years of experience resulted in 2.0% scrap.

The results presented in Figure 12 show that the higher the operator's experience, the lower the scrap level. Based on the operator capabilities due to experience, this is an expected trend in the generation of scrap.

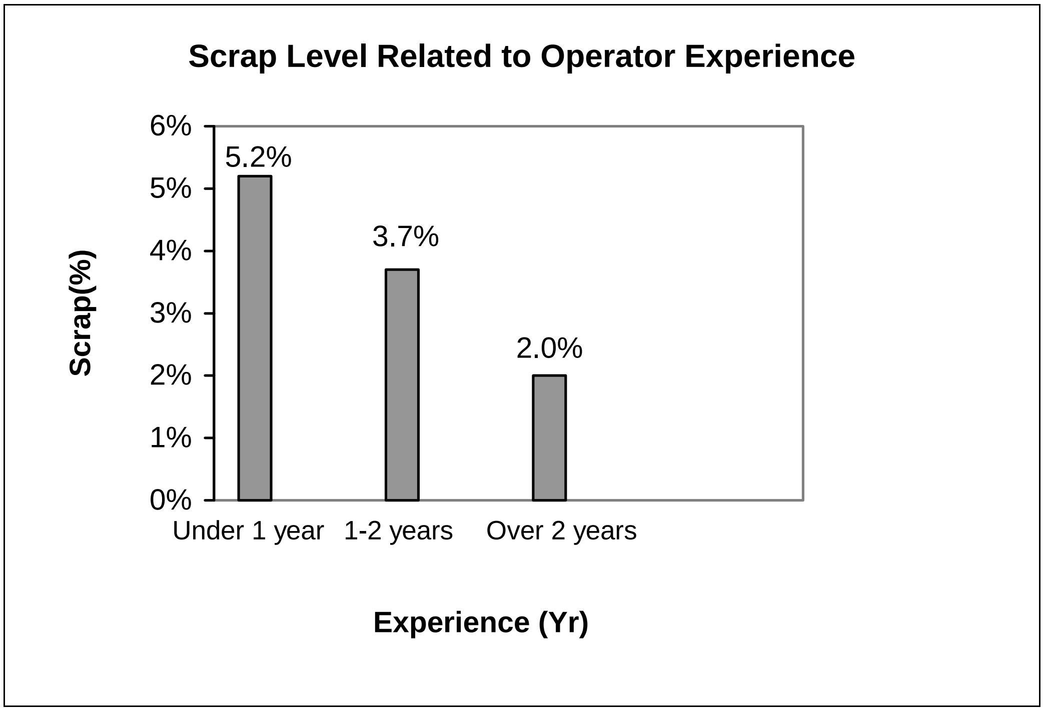

Figure 12 Scrap Levels of 1st Shift's C-Line Operators Based on Experience

Figure 13 presents the scrap levels related to 2nd shift A-line, based on operator experience. The data was organized in the following groups:

- Group 1: operators that had under 1 year of experience resulted in 9.4% scrap.
- Group 2: operators that had 1-2 years of experience resulted in 7.2% scrap.
- Group 3: operators that had over 2 years of experience resulted 1.3% scrap

The trend shows a good relationship between operator's experience and their scrap levels. As expected, the more experienced operators produced less scrap.

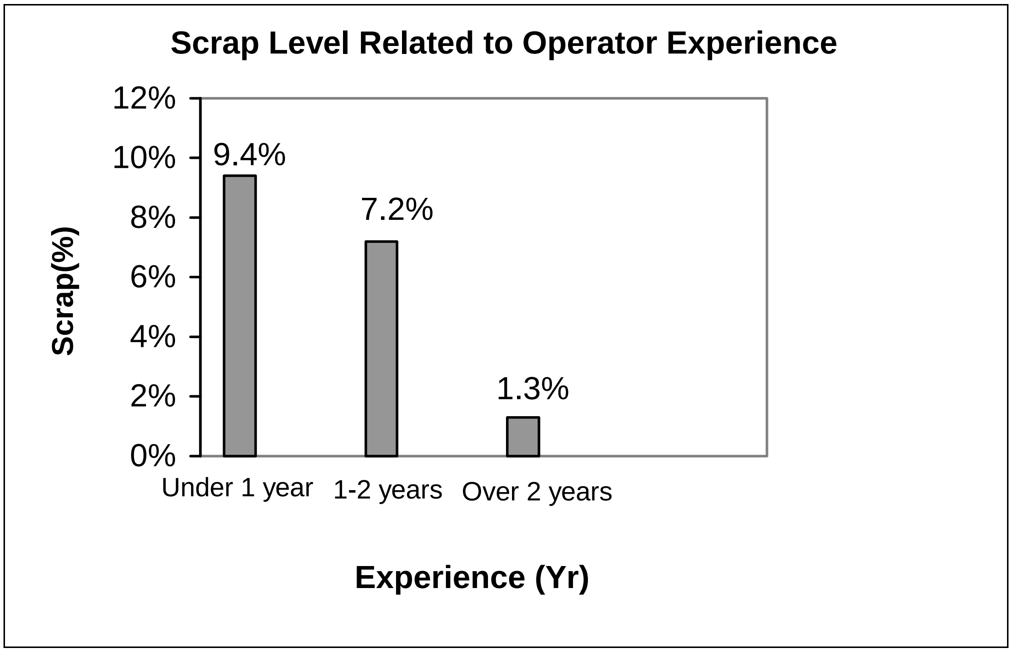

Figure 13 Scrap Levels of 2nd Shift's A-Line Operators Based on Experience

Figure 14 presents two groups of operators for 2nd shift B-line and their related scrap percentage, based on their experience. In this particular case, there was no group of operators with 1 to 2 years of experience. The results show a scrap level of 6.3% for the group of operators having less than 1 year of experience. The group of operators having over two years of experience generated scrap at a 11.3% level. Once again, the trend here is that the higher experienced operators produced more scrap. This trend is counter intuitive to what was expected, scrap levels should decrease as operator experience increases.

Figure 15 presents the scrap levels associated with two groups of operator for 2nd shift C-line. One group had from 1 to 2 years experience. The scrap level for this group resulted in an 11.2% scrap level. The other group consisted of operators with over 2 years of experience. The scrap level for this group resulted in a 6.6%. Figure 15 also shows an expected trend. The 2nd shift C-line operators with the most experience generated the least scrap.

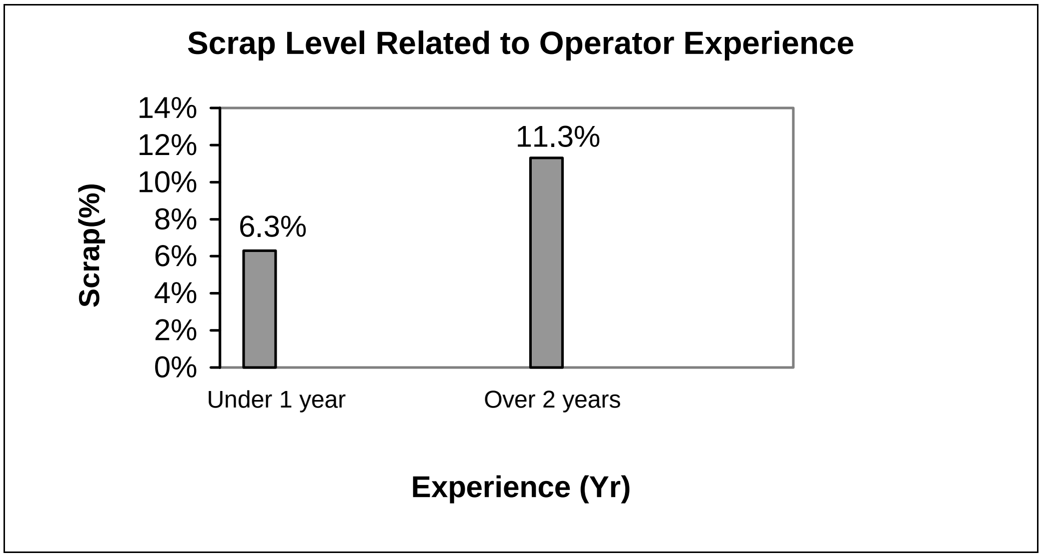

Figure 14 Scrap Levels of 2nd Shift's B-Line Operators Based on Experience

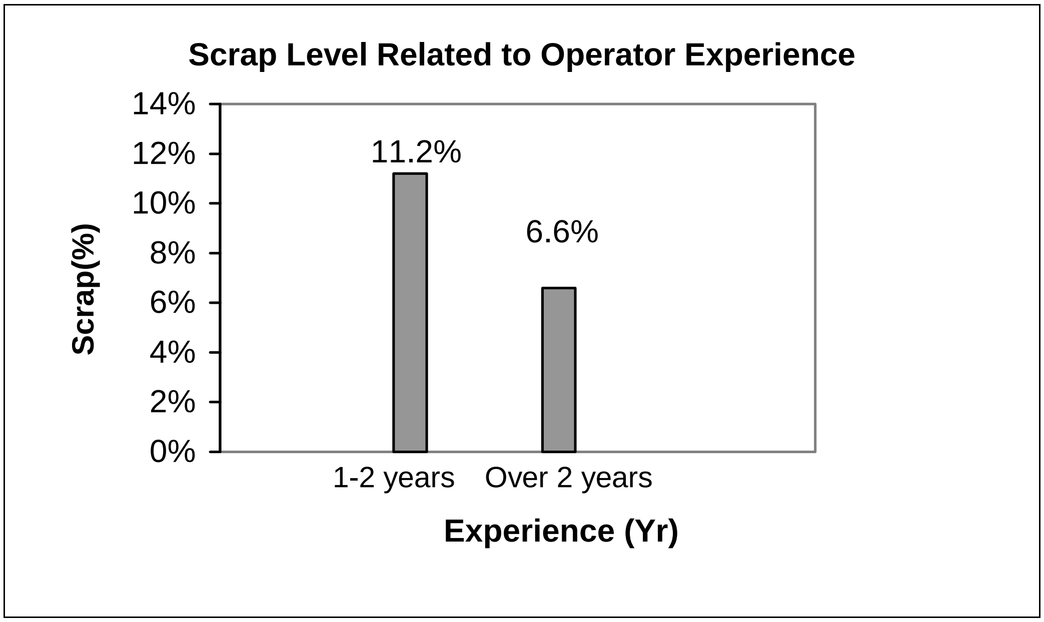

Figure 15 Scrap Levels of 2nd Shift's C-Line Operators Based on Experience

Figure 16 shows the scrap levels related with the operators on 3rd shift A-line. The data was organized by operator experience into the three following groups:

- Group 1: operators that had under 1 year of experience resulted in 2.2% scrap.
- Group 2: operators that had 1-2 years of experience resulted in 5.7% scrap.
- Group 3: operators that had over 2 years of experience resulted 5.2% scrap

These results are inconsistent in regards to the expected relation between operator experience and scrap levels. The group of operators having the least experience resulted in the lowest level of scrap. The group having 1-2 years of experience resulted in the highest level. The group of operators having over 2 years of experience resulted in a slightly lower scrap level. In general, the trend witnessed here is that the more experienced operators made more scrap.

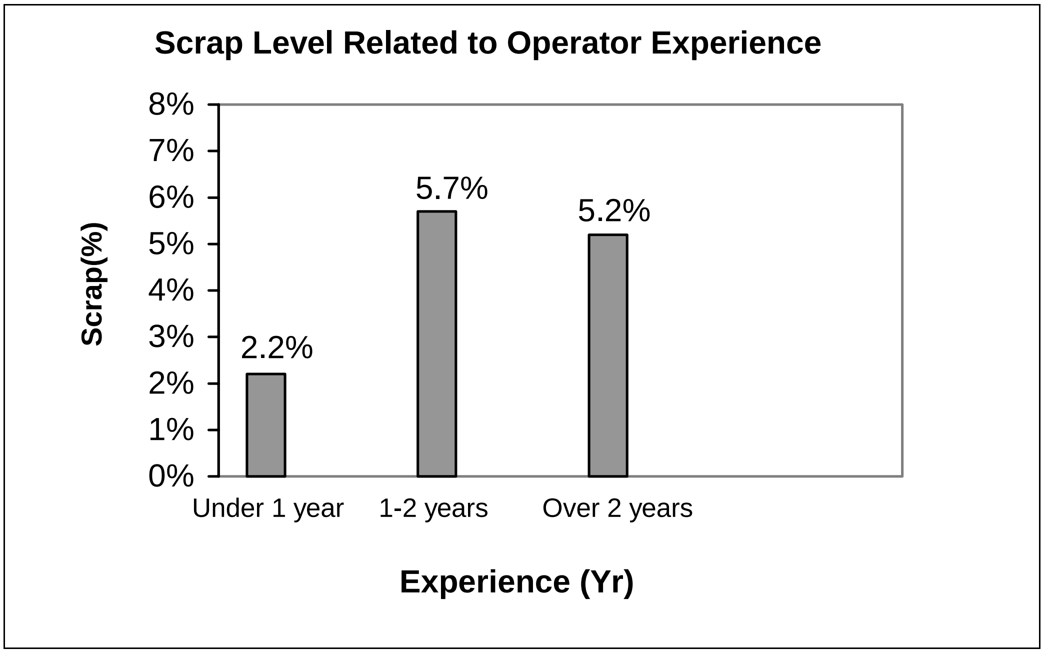

Figure 16 Scrap Levels of 3rd Shift's A-Line Operators Based on Experience

Figure 17 illustrates the relationship between operators and their related scrap levels for 3rd shift B-line. An irregular trend can be witnessed here. The least and most experienced groups generated similar levels of scrap, 11.0% and 10.4% respectively. The group of operators that had 1-2 years of experience resulted in the scrap percentage of 4.3%. Again, these results do not show a consistent relationship between operator's experience and scrap.

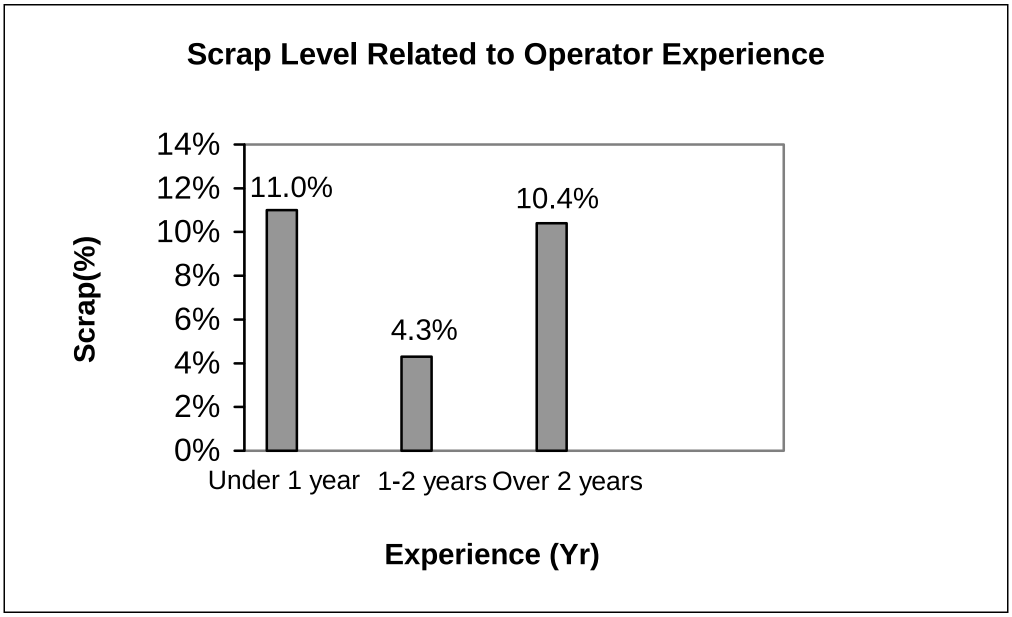

Figure 17 Scrap Levels of 3rd Shift's B-Line Operators Based on Experience

Figure 18 presents the scrap levels related with three groups of operators on 3rd shift C-line. Based on their experience, this data is summarized below:

- 4.6% scrap level for the group with under a year of experience
- 3.0% scrap level for the group with 1-2 years of experience
- 10.8% scrap level for the group that has over 2 years of experience

The first two groups depict an expected trend about the relationship between operator's experience and scrap percentage. However, as seen previously, the highest scrap level of 10.8% was generated by the most experienced operators. This result again is counter intuitive to what is expected in the generation of scrap and based on operator experience.

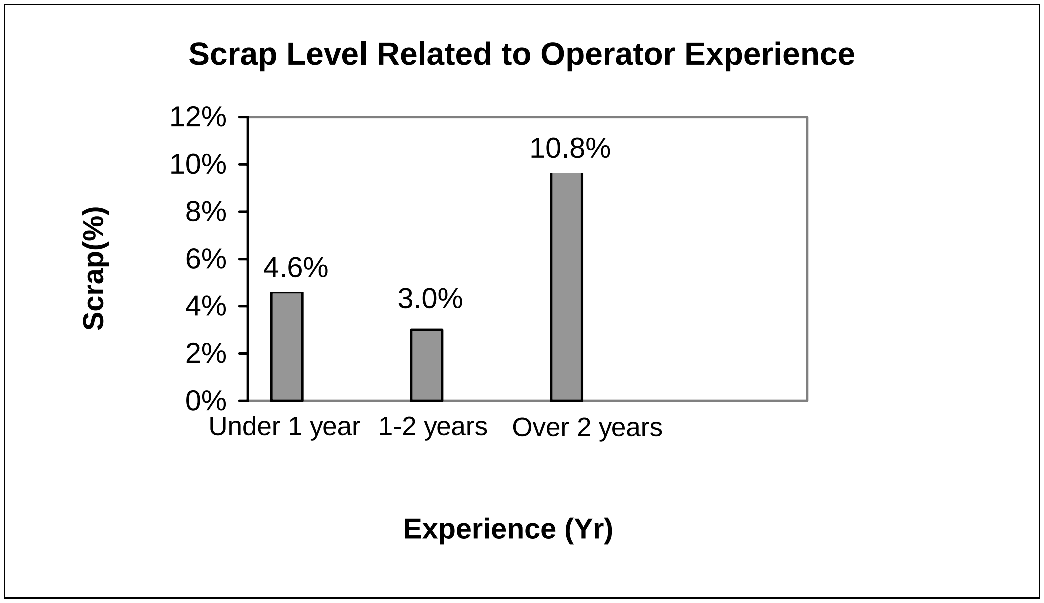

Figure 18 Scrap Levels of 3rd Shift's C-Line Operators Based on Experience

Validity

The research presented here is based on real data gathered from a Phillips Plastics-Short Run facility. The data was organized and analyzed based on the statistical process control that has been applied in the real-world manufacturing operations at the Short Run facility. Due to the fact that this Short Run facility continually monitors their scrap levels, it is possible to have a high level of confidence in the data gathered.

This research can be used by Short Run production to better understand why scrap levels vary for production jobs run with the specific process parameters identified in this work. Short Run production personnel, such as machine operators, mold technicians, and supervisors, will be able to use this work to minimize the generation of scrap. Every production job will be prepared in a way that will reduce the problems by acknowledgement of the related scrap levels with the type of injection machine, process, material, and operator involved in each production job at specific work stations.

Discussion

This section of the research discusses the reasons for the varying scrap levels seen in production related to the machine, process, material, and operator. By understanding the root causes of the problem, Short Run can determine more predictable ways in using these production resources, ultimately resulting in a better control of scrap generation.

Machines

The findings of this research indicated that the scrap levels vary based on machine age and tonnage. The data gathered supports the concept that the longer a machine is in operation, the less efficient it becomes. The machine response time becomes inconsistent with age. Therefore, the machine itself changes the processing conditions, resulting in an increase of scrap. At Short Run, an injection molding facility, scrap increased from a rate of 3.6% to 5.4% with machines that had been in operation from 2 to 14 years. An unexpected result identified when evaluating the production data was that newer machines (1-2 years old) resulted in a very high scrap level of 16.5%. These newer injection molding machines included a vertical machine and a 400-ton machine. Most of the time, these machines must run in a semi-automatic function mode. The reason for the higher scrap levels associated with using these machines was due to the way operators operate the machines. Differing operator actions made it difficult to keep the cycle times consistent. This inconsistency in cycle time was the reason for processing condition changes, resulting in an increase of scrap generation.

Another factor identified in this research that lead to scrap generation involved machine size or tonnage. This factor is an indicator of the machine’s strength. Jobs requiring a stronger machine are usually complicated in shape, mold design, and part design. The polymer flow pattern of larger parts is usually quite complex, requiring higher processing pressures to fill mold cavities and greater machine strength. Due to the complexity of these larger parts, they must be made in a semi-automatic function mode because of the necessity of loading the pick-outs, inserts, etc. For these reasons it was difficult for the operators running these jobs to keep cycle times consistent. When one or a combination of these machine factors existed in production, the scrap level may have risen. Based on the recently discussed items it is possible to make a rationalization as to the reason that the use of larger machines can often lead to increased levels of scrap generation.

Process

This portion of the research focuses on analyzing the key process parameters of melt temperature, mold temperature, and pressure. Though process time can lead to other issues of concern, it is easy to control. Problems can occur based on how machines respond to each change in setting. If the machine does not respond well, possibly due to its age, the time setting may not work resulting in molding problems.

Melt Temperature

The research findings shows that the higher the melt temperature, the higher the scrap level. Most of the melt temperature induced problems can be related to melt temperatures higher than 500^{o}F, especially when the temperature was higher than 600 ^{o}F. This occurs because most thermoplastics require that the processing temperatures be less than 500^{o}F. Melt temperatures higher than 500^{o}F are considered to be excessively high temperatures. With the higher temperatures, the covalent bonds of the resin molecules are more likely to degrade in molded materials. Therefore, the chances of splay, burning, or shrinkage problems occurring may be higher than when processing at lower temperatures. It is for this reason that higher melt temperatures typically lead to higher scrap levels.

Mold Temperature

The research findings show that when higher mold temperatures were used the resulting scrap level was lower. Scrap levels were lowered because the use of higher mold temperatures lead to a reduction in material shear rate. Therefore, the in-mold material flows occur more smoothly. Problems such as short-shot, surface finish, over-sizing, etc, may be reduced by increasing mold temperatures.

Pressure

Machine pressures between 10,000 PSI to 20,000 PSI are applied for processing of most thermoplastics. Most parts require pressures in this range to guarantee adequate in-mold material flow. Pressures should be great enough to keep the cavity filled but not so much that over-packing occurs. If a particular process requires a higher pressure (over 20,000 PSI) to meet the requirements of a complex flow pattern, it usually causes higher material shear rates or more material crystallization around the gate. These problems can cause part splay, crack, or warpage. For this reason higher machine pressures typically lead to higher scrap rates. The results also show a trend towards high scrap levels (9.3%) related to using machine pressures that are less than 10,000 PSI. Too low a machine pressure usually leads to slower material fill rates and improperly filled or packed parts. Not enough plastic is added during the mold fill process to compensate for part shrinkage when too low a pressure is used. This can be the reason of material short shot, shrinkage, or sink marks.

Materials

In a real-world plastics manufacturing facility, like Short Run, quite a few material types are used to produce plastic parts. In an attempt to keep the analyses performed for this research manageable, this study covers the five most commonly used materials at Short Run. These materials consist of Calibre, Radel, Ultem, Cycolac, and RTP. The scrap levels associated with each of these five materials, listed from worst to least, were as followed:

- RTP at 9.3% scrap
- Ultem at 5.3% scrap
- Radel at 4.6% scrap
- Calibre at 3.0% scrap
- Cycolac at 2.5% scrap

Cycolac

It is easy to understand why the use of Cycolac as a material resulted in a low scrap level of 2.5%. By examining the data collected, it can be seen that the processing of Cycolac required a temperature range from 400 ^{o}F to 500 ^{o}F. As discussed earlier in the literature review section, this is a common processing temperature range that is applicable for most plastic materials.

The mold temperature required for processing this material ranged from 50 ^{o}F to 150 ^{o}F. Most of the productions runs, based on the data collected for this research, were completed using a mold temperature of about100 ^{o}F. This was another advantage of using this type of material. The pressures applied for processing this material ranged from 5,500 PSI to 21,000 PSI. For most of the productions runs pressure ranged from about 10,000 PSI to 15,000 PSI. This range of processing pressures is common for pack and hold pressures used to process most plastic materials. In general, the key parameters used to control the processing of Cycolac, melt temperature, mold temperature, and pressure, were within common process conditions. Therefore, the 2.5% of scrap associated with processing Cycolac can be explained by looking at its key processing parameters. Because Cycolac is hygroscopic it is susceptible to the occurrence of splay, contamination, or short shot when used to produce parts, and ultimately is the primary reason for producing degraded and undesired parts.

Calibre

Calibre is the most commonly used production material at Short Run. A scrap level of 3.0% was seen with the use of Calibre. The most common problems to occur when using this material consisted of contamination, burning, splay, and voids/bubbles. These issues can be explained by taking a look at material processing parameters. The melt temperature used to process this material ranged from 530^{o}F to 600^{o}F. Mold temperatures ranged from 70^{o}F to 190^{o}F. Pressures ranged from 11,000 PSI to 25,000 PSI. In comparing these processing parameters to those used for Cycolac, it can be seen that the values for all three parameters had increased slightly. These results imply that the use of a higher mold temperature resulted in a lower scrap level. Therefore, it can be seen that the mold temperature-scrap relation is not an issue when processing Calibre. However, the melt temperatures and pressures required for processing Calibre can be related to the generation of scrap. The higher that the melt temperature or pressures are the higher the resulting scrap levels. Again, by closely examining the process parameters used to produce Calibre parts, it is possible to explain the low scrap level of 3%.

Radel

The use of Radel in producing parts resulted in a scrap level of 4.6%. The most common reason for scrap generation was the occurrence of splay. The next most common reason for problems occurred due to contamination and short shot. It is easy to understand why the scrap levels related to using this material were higher than the scrap levels that occurred when using Cycolac or Calibre. By examining the process melt temperature, ranging in value from 670^{o}F to 740^{o}F, required for producing Radel parts, it is possible to gain insight into the reasons for an increase in scrap generation. It can be seen that fairly high temperatures were used to produce Radel parts, causing the material in the barrel to easily degrade or burn. For this reason, an increase in the occurrence of splay or contamination was seen with the use of Radel, resulting in higher scrap levels.

A similar situation to that seen with the processing of Radel also applied to the processing of Ultem. The processing of this material resulted in a 5.3% scrap level. Ultem processing also required the use of higher temperatures, ranging in value from 680^{o}F to 740^{o}F. However, the pressures used to process Utem ranged in values from 7,500 PSI to 28,000 PSI. This resulted in the use of a greater pressure range than that used to process Radel. The use of a greater pressure range led to higher in-mold flow rates (Reinhold, 1991). A phenomenon such as this can lead to part defects such as splay or contamination. These results tend to support the premise that higher pressures result in higher scrap levels.

RTP

The highest scrap level as seen in the collection of data for this research resulted in the use of a material called RTP. When processing RTP, a polycarbonate material, the recorded melt temperatures ranged from 490^{o}F to 530^{o}F. The mold temperatures used to process RTP ranged from 70^{o}F to 180^{o}F and the pressures ranged from 4,000 PSI to 17,000 PSI. If the processing of this material is compared to that of Cycolac or Calibre, it can be seen that the processing parameters are identical. Since this is the case, why does the processing of RTP result in a very high scrap level, consisting mostly of defects due to contamination, sink marks, and short shot? Based on the literature review performed for this research, the processing temperature of RTP or polycarbonate, ranges from a value of 446^{o}F to 572^{o}F. At processing temperatures just above this range, the material degrades quite rapidly (Brydson, 1999). The melt viscosity of this material is very high. During processing, this material's flow path ratios fall in the range of 30:1 to 70:1. These ratios are substantially less than many of the more general-purpose thermoplastics such as polypropylene at 175:1 to 350:1, ABS at 80:1 to 150:1, and Nylon 6/6 at 180:1 to 350:1.

The characteristics of RTP just discussed can be used to try and explain the cause of part defects like contamination, sink marks, or short shot. The high scrap level could be related to the injection machines used to produce RTP products. Based on the data collected for this research, most of the time these products were molded using injection molding machines sized in the range from 200 ton to 400 ton. These are considered high clamp-force machines at the Short Run facility. These injection molding machines are typically used to produce complicated part designs with complex flow patterns. Due to the difficulty in moving material through these molds, several types of part defects can occur. Another reason for high scrap levels could be due to the operator's actions. Again because of the complexity of some part designs, machine operators often have a difficult time in identifying the correct processing parameters. This difficulty in setting processing parameters results in inconsistent cycle times or longer material residence times. These problems can be the reasons for higher scrap when RTP is used.

Operators

The scrap level associated with each production shift can be explained by relating them with operators' experience. Most operators working on the A and B lines of 1st shift have over two years of machine operation experience. These experienced operators are uniformly distributed throughout the lines. The 1st shift generated a total scrap level of 2.9%. This trend is similar to that predicted by the reading discussed in the literature review; the more experienced an operator is the less scrap generated. The scrap level of 4.6% associated with 2nd shift was higher than the 3.5% scrap level associated with 3rd shift. This phenomenon cannot be explained based solely on the experience of each operator because the operators on 2nd shift and 3rd shift were uniformly distributed with similar years of experience. Also with each shift on the same production line, the same machines, processes, and materials were used. The highest scrap level, which was seen on 2nd shift, can be hypothesized as being a function of something other than operator experience. By applying practical reasoning to identifying the causes of this problem, it appears that this higher scrap level could have been caused by outside non-machine related variables such as time of day, operator alertness, or non-machine related responsibilities. These conditions may have an extreme affect on the performance of a 2nd shift machine operator.

The scrap levels associated to the A-line, B-line, and C-line can be explained based on machine use and the operators' actions. All A-line injection machines are smaller in size, from 20 to 40 tons. Most of these machines are relatively new and modern. The production jobs run on these machines are typically operated in an auto-function mode, hence consistent cycle times are possible. Also, since these are small machines, they are used to produce small parts. Due to the smaller sized parts, the flow patterns are simple and result in less part fill type problems. For these reasons the A-line scraps levels are low for all three shifts.

Most B-line scrap generation levels can be explained based on machine age and use. Almost half of the B-line machines are 8 to 14 years old, fairly close to the end of their life cycle. In addition, the B-line also consists of a vertical injection molding machine that requires all jobs be operated in a semi-automatic mode. Problems typically encountered in using this machine can usually be correlated back to the operator. Many of the jobs produced on the B-line also require that inserts and pick-outs be loaded into the mold prior to starting a cycle. Therefore, operator experience is a key factor when problems arise in the B-line.

The C-line scrap level of 5% was better than B-line's scrap level at 7.4%. This difference in scrap levels can also be explained based on machine age and use. Except for one 12-year-old machine, most of the machines on C-line are relatively new. These newer machines are more dependable and require less operator interaction during operation. For these reasons the C-line had a better scrap level rate on all shifts than the B-line.

The scrap levels associated with the production of the 1st, 2nd, and 3rd shifts of A-line were 2.9%, 6.8%, and 4.7%, respectively. Because 1st shift of A-line had more experienced operators than the 2nd and 3rd shifts, operator inexperience was a reasonable cause for the higher scrap levels seen on the later shifts.

B-line 1st, 2nd, and 3rd shift scrap levels were 4.6%, 9.6%, and 8.0%, respectively. Some of the differences in scrap levels between shifts can be explained due to the more experienced operators working on 1st shift, most having more than two years of experience, and ultimately resulting in the lowest scrap level. The 2nd shift B-line scrap level was higher than that of the 3rd shift. Again, this phenomenon cannot be explained based solely on operator experience. Both shifts consist of a similarly uniform distribution of experienced operators. Since these shifts consist of the same production lines, machines, processes, and materials, the variation in scrap levels between the B-line 2nd and 3rd shifts may be caused by non process related variables, as presented earlier in this section.

The scrap levels associated with all of C-line shifts, in chronological order, were 3.5%, 7.5%, and 4.2%. The distribution of operator experience was identical for all shifts. Therefore, it appears once again that operator experience was not a factor in the scrap level variances seen between all of the C-line shifts. These variances in all probability occurred due to non-process dependent variables, as presented earlier.

Chapter 5

Conclusion

The generation of scrap is an important problem that must be addressed by today's businesses. It needs to be controlled for the purpose of lowering costs in an attempt to gain a competitive advantage in business. Despite several methods currently used to control scrap generation, a simple way that can help Phillips Plastics-Short Run control scrap generation is to understand the scrap levels as they relate to injection molding machines, processes, materials, and machine operators. By understanding the effects of these process parameters it becomes possible for a production facility to gain insight into the generation of scrap due to the production conditions for each workstation as it applies to each job. In this way production facilities can control scrap levels by making a better informed decisions in the selection of injection machine, process, material, and operator required to produce a particular job, ultimately minimizing scrap levels.

This research presented scrap level data associated to the major processing parameters: injection machine, process, material, and operator. The analysis performed in this work was subdivided further by examining the scrap levels associated to several production lines and work shifts. Understanding the reasons for variance in production lines, shifts, or operators can help Short Run plan for the rise in scrap levels for specific production jobs. Therefore, it will become possible for Short Run to better adjust production conditions to minimize scrap generation.

This research analyzes the scrap generated from 100 samples jobs collected at Phillips Plastics Short Run facility. Most of the research results can be explained based on an understanding of process parameters in regards to injection machine, process, material, or operator assigned to the production job. Some results, such as the differences seen between scrap levels from 2nd shift and 3rd shift, and A, B, and C-lines, requires further study.

Recommendations

Generally, this research identifies the causes for most problems related with the scrap rates that occur at the Phillips Plastics-Short Run facility based on injection machines, processes, materials, and operators. Some findings could be refined and researched further.

The 100 samples collected for use in this research only satisfy basic statistical analysis requirements, but yield acceptable results for use in this research. For more accuracy, future research should be performed by collecting more data samples.

Future research should also involve gathering data about mold design. Bad mold design is another common cause of scrap generation. Including this data in the research analysis may yield more comprehensive results and help better explain research findings.

Collection of process time variables, such as fill time, pack/holding time, cooling time, and cycle time, was outside the scope of this research. However, inconsistency in process time is a common cause of part defects. Including process time in future research analysis can provide more comprehensive explanations in regards to scrap generation.

Several production jobs required the implementation of secondary operations to complete part fabrication. These additional operations can lead to an increase in the amount of part defects. For a more comprehensive study, research should also include more specific information in regards to this data.

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Appendix A

Scrap Reduction Research Datasheet

Job #: ________________
Collection Date: __________________

Press #: ________________
Item #: _________________
Production Order #: ______________
Dates of Production: ________________

Material: ________________________
Melt Temps: _____________________
Mold Temps: ____________________
Pressure: ________________________

Contamination																				
Partials																				
Voids/Bubbles																				
Sink																				
Splay																				
Good																				
Scrap Total																				
Shift																				
Initials																				

Supervisor’s Signature: ____________________________________

Production Manager’s Signature: __________________________________

Appendix B

Press Investigation
For
Scrap Reduction Research

Press #	Tonnage	Estimated Age	Press #	Tonnage	Estimated Age
A-1			B-5		
A-3			B-6		
A-4			B-8		
A-5			B-9		
A-6			B-10		
A-7			C-1		
A-8			C-2		
A-9			C-3		
A-10			C-4		
A-11			C-5		
A-12			C-6		
A-13			C-7		
A-14			C-8		
A-15			C-9		
A-16			C-10		
B-1					
B-2					
B-3					
B-4					

Supervisor's Signature: ______________________________

Production Manager's Signature: ____________________________

Appendix C

Operator Data
For
Scrap Reduction Research

Initials	Year(s) of Experience (estimated) Under 1 yr 1-2 yrs Over 2 yrs

Supervisor’s Signature: ________________________________

Production Manager’s Signature: _____________________________