INJECTION MOLDING FRACTIONAL MELT INDEX, HIGH DENSITY POLYETHYLENE MATERIALS

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Abstract

When injection molding high density polyethylene (HDPE), typical melt index of the product used ranges from about 2.0 g/10 min. to 100 g/10 min using the standard, ASTM D1238 melt index method for polyethylene (190°C, 2.16 Kg). This paper will discuss advantages and disadvantages of injection molding fractional melt (~0.1 – 0.7 g/10 min), HDPE materials into five-gallon pails. Although processing for this analysis is specific to pails, the theory behind the process could be applied to many injection molded parts. Topics such as processing changes required, differences in impact resistance, shrinkage, and environmental stress crack resistance (ESCR) will be examined.

Introduction

The goal for this project was to determine advantages and disadvantages of using a fractional melt index HDPE for an injection molding application. Many injection molding polyethylene grades are selected due to a high melt index value. This is often the choice given the need to create as many parts as possible in a given amount of time, e.g., higher flow = faster cycle times. However, melt index should not be the governing factor for all injection molding applications. There are injection molding applications that need exceptional impact strength, ESCR, and cold temperature toughness, and for those applications, a fractional melt index, HDPE material should be considered. For this particular experiment, the application chosen was a five-gallon pail. The materials used in this experiment, however can be molded into almost any application if the correct part design and processing parameters are used.

Background and definitions

High density polyethylene grades with a fractional melt index are most often used in the extrusion and thermoforming and/or the blow molding processes. The long molecular chains that decrease the melt index, also give the material "melt strength" useful in these processes [1]. It is this higher molecular weight that also gives the material increased ESCR, impact strength, and cold temperature toughness over a material with similar density, but shorter molecular chains. These advantages may overcome the disadvantage of slower cycle times, depending on the critical properties of the part as required by the end-user.

This experiment involved injection molding five-gallon pails using two injection molding grades of HDPE and six blow molding/extrusion grades of HDPE. To determine cycle time differences, a "successful" part needed to be produced from each material. The successful parts were each made by adjusting the injection speed/pressure and barrel temperatures while keeping hold pressure at 0psi until the part was filled to roughly 99 percent. Once at this point, enough hold pressure was introduced to the part as to not have any visible sinks or flash. Mold temperature and cushion were held constant.

Experimental

Apparatus and materials

All products tested were HDPE materials. Two were "typical," higher melt index materials and six were fractional melt index materials. The densities of these materials varied from 0.945 g/cc to 0.962 g/cc, but most of the products could be grouped into two density ranges, one being ~0.946 g/cc and the other ~0.954 g/cc with one exception being a fractional melt index, homopolymer HDPE. This material was evaluated to determine if long molecular chains can overcome the impact resistance given when using a 6-7 g/10 minutes melt index HDPE material with hexene copolymer. See Table 1 for melt index and density details on the HDPE resins used in this experiment.

A variety of tests were conducted on the products using various machines. To visually demonstrate the differences between molding HDPE materials with a nominal melt index range of 6-7 g/10 minutes versus fractional melt HDPE grades, a 500T Van Dorn injection molding machine was used to mold five-gallon pails under the same conditions. These conditions included transferring injection pressure using time rather than position. All other conditions, including injection/fill pressures, were kept constant. Many manufacturing facilities, however, transfer from injection pressure to hold pressure using screw position rather than time. Due to this difference, pails were also created utilizing screw position to switch from injection to hold pressure (rather than switching on time). Using this processing method, all materials' processing parameters were altered to get a satisfactory part, looking at cycle time differences.

This was done to determine potential variations needed to produce an acceptable, injection molded part and was felt would best mimic what is used in industry.

Injection molding the pails demonstrated the disadvantages of using fractional melt index HDPE materials in any injection molding application: a cycle time disadvantage. To demonstrate the advantages, 4" x 4" x 0.125" test specimens were molded using a 150T Toshiba injection molding machine. These test specimens were used to demonstrate various impact and ESCR improvements of the fractional melt HDPE materials as well as potential differences in shrinkage rates using two different molding conditions. Instrumented impact was conducted at both room temperature and freezing (75°F and 32°F) using an instrumented impact device with a 0.5" diameter tup. Shrinkage data was measured on a Mitutoyo Coordinate Measuring Machine and ESCR was tested in both the machine and transverse direction of flow on injection molded samples. Typical ESCR samples are compression molded per the ASTM D1693 test method. However, this experiment was produced in order to see the affect of injection molding versus the typical compression molding preparation of ESCR samples.

Results and discussion

The goal of this project was to determine advantages and disadvantages of injection molding fractional melt index, HDPE materials. The disadvantages of injection molding such materials included longer cycle times, higher energy costs, and more extensive use of the injection molding machine's capability. The last two points are not quantified in this study, but are attributed to the higher temperatures and pressures required to get satisfactory parts when molding the fractional melt index HDPE resins. The differences in cycle time are caused directly by differences in molecular chain length of the various materials [1]. The pails produced in Figure 1 show this difference visually. These pails were produced under the same machine settings, using time to switch from injection to hold pressure. Along with a different appearance when using the same processing conditions, the fractional melt index HDPE materials also took significantly longer to mold a complete part. Figure 2 shows pails produced using a typical injection molded HDPE resin alongside a fractional melt index HDPE resin. The cycle time difference between these two materials, which were at the opposite ends of the melt index spectrum in this sample set, was just over 21 percent. The average time difference to mold a satisfactory pail (~99% full with no hold pressure) averaged 14 percent longer and used almost 30 percent more heat in the material. See Figure 3.

Perhaps the greatest advantage of running fractional melt index HDPE materials is the improvement in ESCR. This study showed an exponential increase over the two, "standard" injection molding HDPE grades. The samples collected for this experiment were injection molded rather than compression molded to give a worst-case scenerio. These injection molded samples were also tested in both the machine direction and transverse direction. This data is an indicator of what may happen with other stress-cracking agents. However, it cannot be translated directly into end-use data [2]. Results for ESCR, condition A-10%, F_{50} can be seen in Figure 4.

Improvements were seen in impact resistance, although the results were not as significant as expected until injection molding the typical "high load" melt index materials (Samples F & G). These samples demonstrated a significant impact improvement over the standard injection molding grades of HDPE materials. Other factors that would affect the instrumented impact of the samples but are not discussed in this study would be molecular weight distribution and the production method used to create the resin. The results of the impact analysis can be seen in Figures 5 and 6.

The other factor examined in this experiment was shrinkage. In theory, the shrinkage for a fractional melt index material should be greater due to the longer molecular chains relaxing "more" during the cooling of an injection molded part. This was seen when ran at two separate conditions on the 4" x 4" x 0.125" plaques. Not all of these parts, however, would be deemed acceptable as many were not completely filled. The true test was seen on the pails created using different processing conditions to get a "satisfactory" part. These parts did not show a dramatic difference in shrinkage. The buckets shown in Figure 2 had a top ID of 11.31 inches and 11.34 inches. With additional processing steps, these numbers could have been identical while maintaining a satisfactory part [3].

Conclusions

This study has shown the main advantage to using fractional melt index materials for an injection molded application is the exponential increase seen in ESCR. Higher impact is also a significant advantage, but not at the same level of increase as ESCR. Shrinkage under the same conditions proved to be greater for the higher molecular weight materials, however this difference was diminished when running at conditions used to make satisfactory pails. Fractional melt index HDPE materials should be chosen for an injection molding application over a standard injection molding grade of HDPE when higher ESCR and impact requirements overcome a ~10-20 percent decrease in cycle time and a ~20-40 percent increase in heating/pressure output. Also, the higher the molecular weight, the more demanding it will be to process, but the ESCR and impact benefits will increase [4].

Acknowledgments

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References

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3. Rosato, Dominick V and Rosato, Donald V (editors), "Injection Molding Handbook," Van Nostrand Reinhold, New York (1986), pp. 561-563

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Key Words

Injection molding, HDPE, fractional melt, polyethylene, ESCR, cold temperature toughness, impact strength.

TABLE 1

Resin	Density (g/cc)	Melt Index (g/10 minutes)
Nominal	ASTM D1505	ASTM D1238
A	0.945	6.0
B	0.953	6.6
C	0.955	0.35
D	0.954	0.40
E	0.946	0.31
F	0.948	~0.05 or 10 HLMI
G	0.955	~0.10 or 21 HLMI
H	0.945	0.7

Figure 1
Pails Molded Using Resins B (on left) and G. Same Processing Conditions Used. Injection Pressure Transferred Using Time.

Figure 2
Pails Molded Using Resins B (on left) and G. Different Processing Conditions Used. Injection Pressure Transferred Using Screw Position.

Figure 3
Percentage Increase When Injection Molding Fractional Melt HDPE vs. 6-7 g/10 min Melt Index HDPE

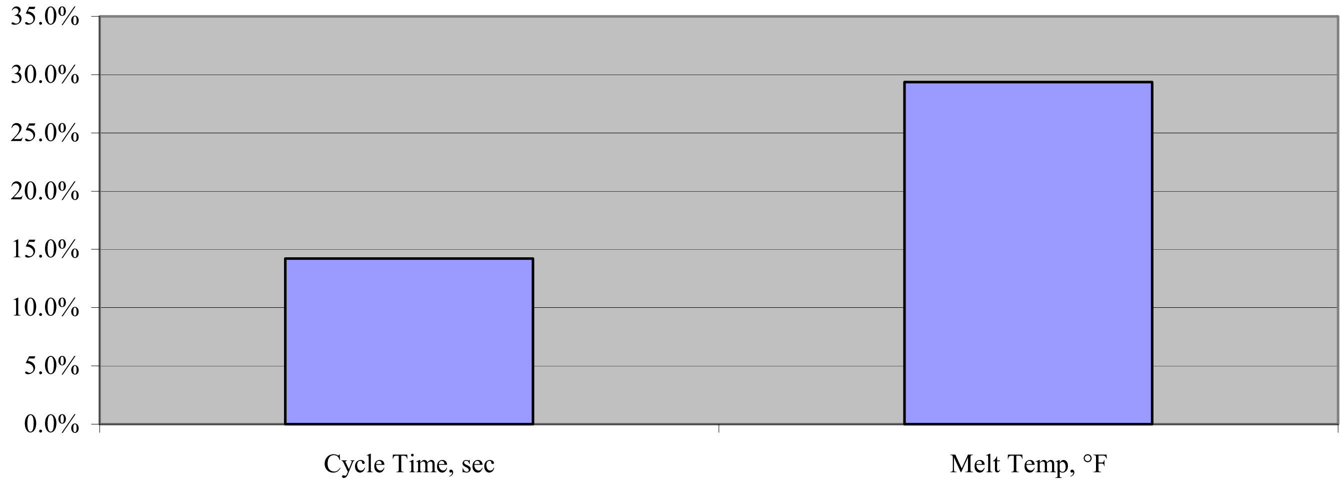


Figure 4
ESCR, Condition A-10%, F50, Hours to Failure

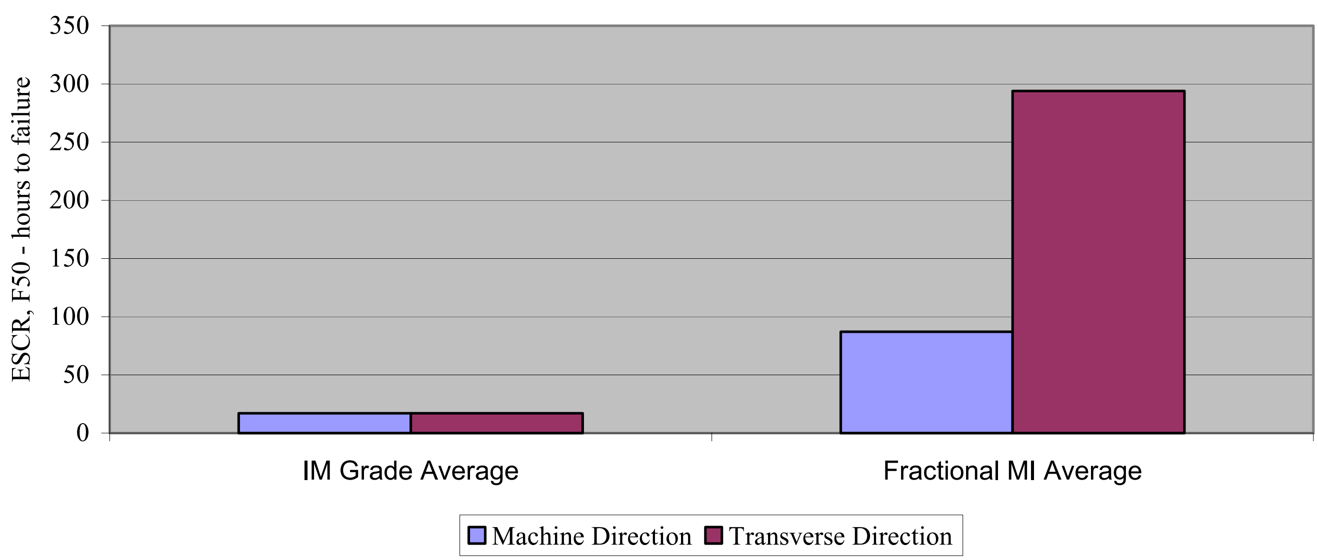


Figure 5

Instrumented Impact vs. Melt Index

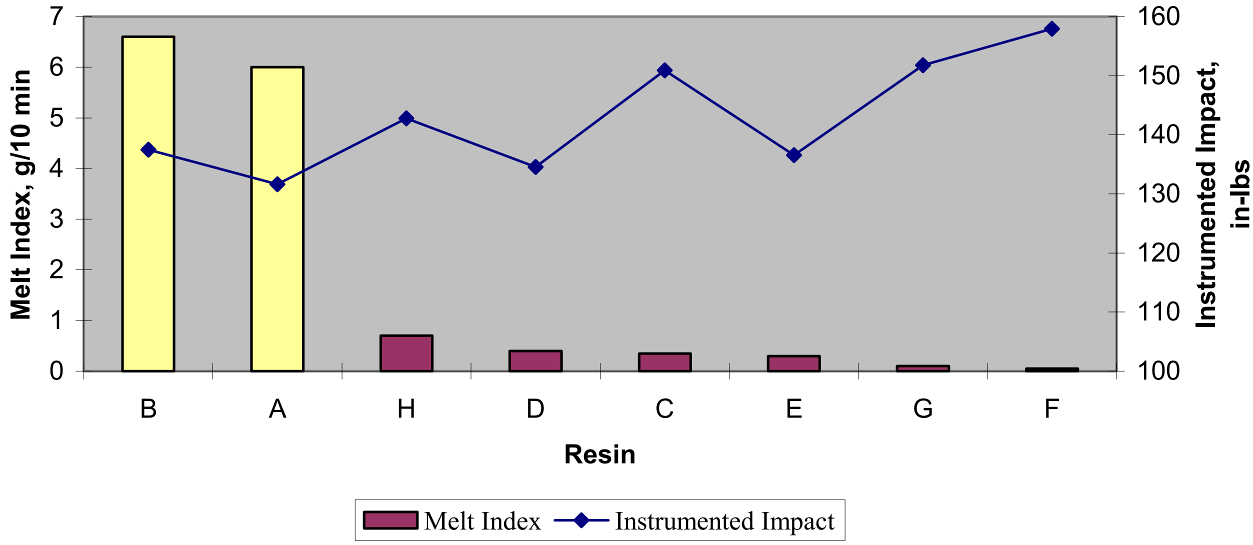
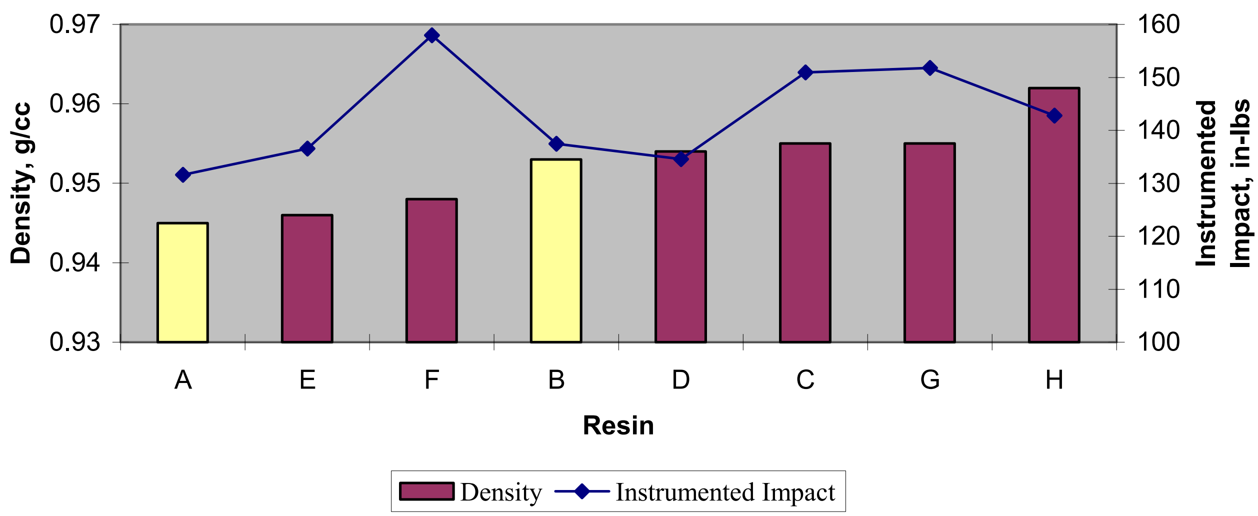


Figure 6

Instrumented Impact vs. Density



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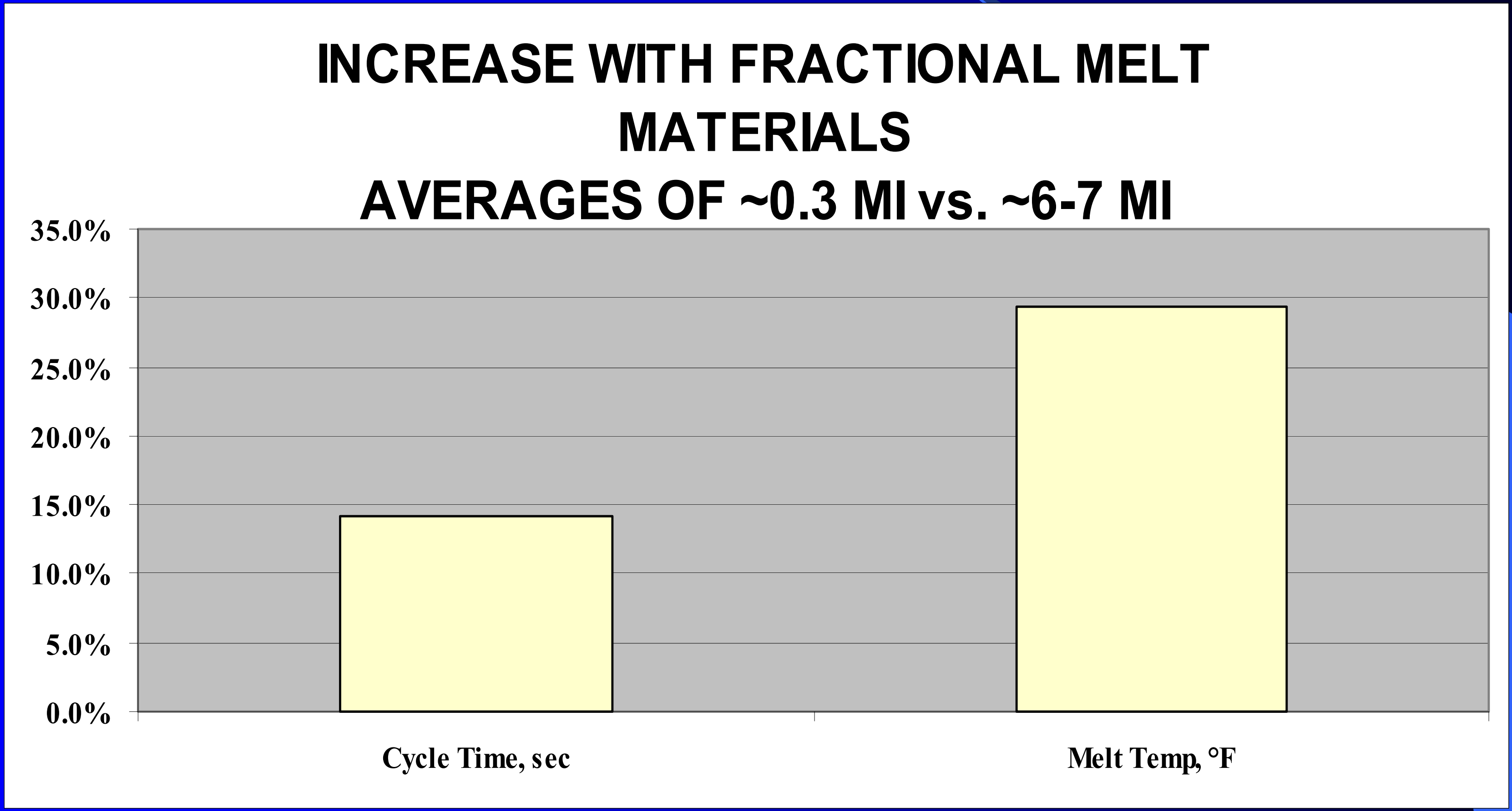
WHY?!?!?

- Longer cycle times, more taxing on machine limitations… Where's the profit?
- Obvious disadvantages, not-so-obvious advantages.
- Let's discuss the end-user's needs (advantages) versus the processor's hurdles (disadvantages).

Disadvantages / Processor Hurdles

Disadvantages / Processor Hurdles



Disadvantages / Processor Hurdles

- Another theoretical disadvantage is increased shrinkage for fractional melt HDPE materials vs. standard IM HDPE materials.
- Longer molecular chains will want to relax more, creating more shrinkage.
- This may be the case, but it was not experienced in this project.

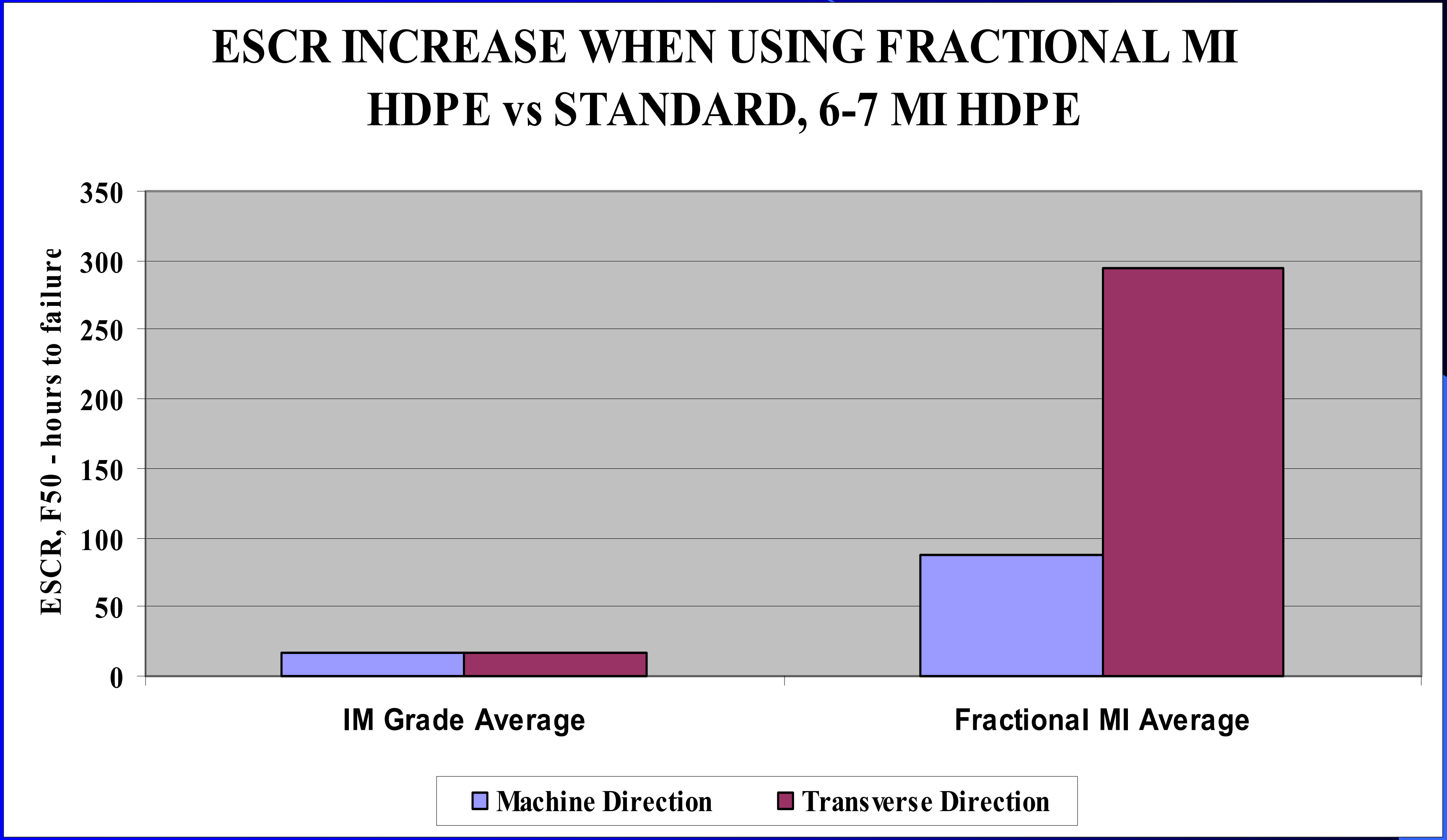
Disadvantages / Processor Hurdles Summary

- Cycle times ~ 14% longer
- ~30% more heat needed in the material
- Higher pressures required from the machine
- Shrinkage could be a factor

- Advantages for the part would need to overcome these issues for it to be viable

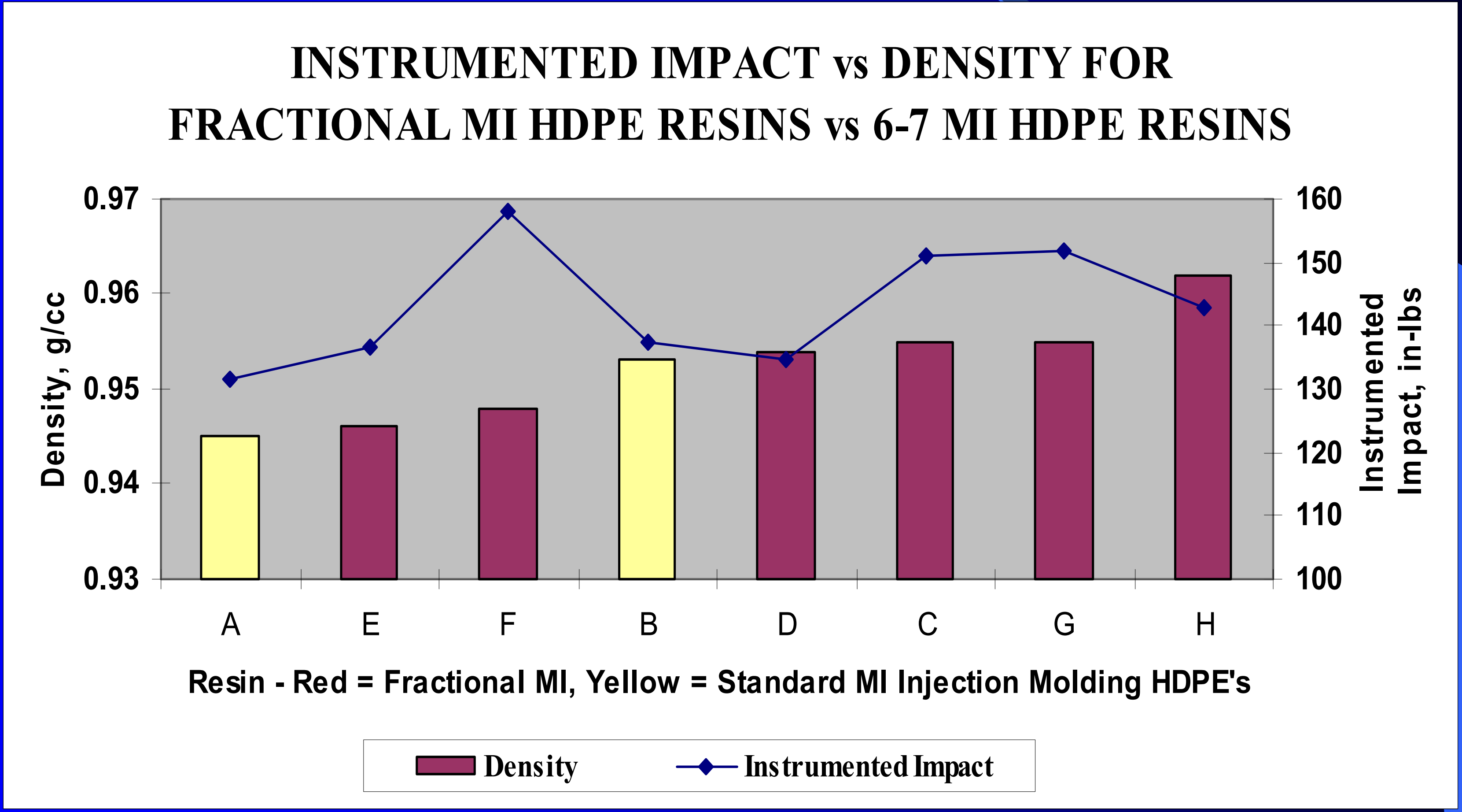
Advantages / End-User Needs

Advantages / End-User Needs



Advantages / End-User Needs

- Previous experience has shown impact improvements to be significant.
- Other factors affecting impact are density, molecular weight distribution, and production method.



Advantages / End-User Needs Summary

- ESCR exponentially improved
- Impact improvements were apparent most with the HLMI materials at ~14%
- These advantages may overcome the disadvantages for several different applications…

Potential Real World Applications

- Parts where higher ESCR is a must:
  - Liquid detergent lids, caps, or spouts
  - Automotive lids, caps, or spouts
  - Injection molded packages containing a chemical surfactant, especially when in a water mixture.
  - ESCR doesn't equal chemical resistance

Potential Real World Applications

- Parts where higher impact is a must:
  - Injection molded packages that need cold temperature toughness, such as frozen food applications or parts shipped to a cold climate.
  - Parts where regulatory or other issues warrant a higher cost product to get a higher impact.

THANK YOU FOR YOUR TIME!
ANY QUESTIONS?