<u>Design and Compromise</u>

"Achieving the optimum part design"

By: Howard Mullin

The goal in designing a new part/product is to make the best compromise from all the factors available. You need to weigh all the facts and all the needs. The designer determines the quality, pricing and the consistency. The toolmakers and molders are stuck with the design they are handed. They can only try to optimize the situation. This design process is iterative. As you go through each section and make a tentative decision, you need to go back to all the prior sections to see how they have been affected.

- ***<u>PART DESIGN & FUNCTION:</u>*** Most critical is, can it do what is needed? Did you talk to the customers (voice of the customer)? Marketing? Sales? Finance? Production? They all have different needs and wants. And they are all important.

- ***<u>MATERIAL SELECTION:</u>*** Plastic (thermoset or thermoplastic? Amorphous or Crystalline? Rigid or elastomeric?). Metal? Wood? Ceramic? Cloth? Where is it used, Indoors, Outdoors? Chemical exposures? FDA requirements? UL requirements? ISO requirements? NSF requirements, and on and on. There are lots of choices, and more than one material will likely work. The process you pick will also affect the material, and vice versa. See the attached checklist to make sure you have considered all the factors

- ***<u>PROCESS REQUIREMENTS:</u>*** How will you make it? Injection molding? Overmold, 2 shot? Structural foam? Die Casting? Investment Casting? Sand Casting? Gravity Casting? Aluminum Extrusion? Plastic extrusion? MIM (Metal Injection Molding)? Blow molding? RIM (Reaction Injection Molding)? Stamping (4 slide, progressive, deep draw)? Laser cut or NCT and bend? Machining? Each process will require a different adjustment to the ideal functional design.

- ***<u>TOOLING DESIGN & FUNCTION:</u>*** Most processes require tooling. And the part design needs to be adjusted for the tooling requirements. Also, the desired life of the tool can affect the design requirements of the tool and the part design.

- ***<u>SECONDARY OPERATIONS, AUTOMATION & ASSEMBLY</u>***: (Ultrasonic, heat, dielectric, and mechanical) FINISHING (pad print, silk screen, hot stamp, painting, plating) Everything you sequentially do with this part will come back to affect the part design. They all need to be considered before you start any tooling.

- ***<u>QUALITY CONTROL & CONSISTENCY:</u>*** The part needs to be readily inspected and measured. We need to go through steps of Validation and verification. The easier you make this process, the more likely it will be checked on a regular basis

- ***<u>END OF LIFE & ENVIRONMENTAL CONCERNS:</u>*** This is becoming more and more of a critical concept. And it does affect the part design, and the materials chosen to make the part from. The parts can affect the environment, just as the environment can affect the part.

- ***<u>Be careful where you get help and information:</u>*** If you go to an Architect with a problem, you will likely be given a building as a solution. You will get different "help" from Processing Engineers, Assembly Managers, Toolmakers, Material suppliers, etc.

COMMON ISSUES IN INJECTION MOLDING

There are some very common issues that re-occur in many parts, so we need to be concerned about the following:

INTERNAL RADII: All plastics are "notch sensitive". Any internal corner can create a stress riser, even if we have almost no internal stresses, this is a highly likely cause for an impact failure.
Solution: Add radiused corners at all internal corners. No problem, except, larger radii will effectively increase the wall section, and could result in a sink issue. There are several guidelines about the optimum radius at the inside corners, and they hold true, up to the point of causing sink.

GATING: The two weakest places on an injection molded part are the gate locations and the weld line. The gate is the place of highest fill pressure, and hence the highest internal stresses are there. The gate location and type can also influence flatness and warp, weld lines, needed secondary operations after molding, molecular orientation of the polymer (and more).

WELD LINE: The plastic flow will separate when flowing around a core in the mold (hole, window, etc.). When it gets to the far side of the hole, the material has to meld (weld) back together.
There are many reasons this area is weaker: The plastic is cooling as it flows, so the fronts of the material may not fully melt back together. There can be trapped air at the weld lines and this prevents the material from melting together (you can actually get "dieseling", or burning, when you compress trapped air). Also, any of the fillers, or reinforcing agents (such as glass fiber, for instance) do not cross the weld line. They only come up to the weld line. At best, your weld line is only about 95% of the strength of the unfilled material.

VENTING: We all learned that only one type of matter can occupy a space, at one time. If we want to fill a cavity with plastic, we need to get the air removed. This can be done by properly placed vent locations, which will ensure we are getting air removed at the last places to fill, as well as all along the fill path. We can even make the venting positive (vacuum venting). Improper venting severely limits the processing window and can affect the overall strength of the part.

RIBS: When ribs intersect a wall, they give us a locally thicker area, this can be a cause of sink. A general rule of thumb is to make sure the ribs (including radii on internal corners) are ***no more than 50% of the wall it intersects.***

BOSSES: Bosses have center core pins surrounded by plastic. The pins cannot always carry the heat away as fast as the surrounding steel, so the pin heats up. This can create sink marks. There are lots of little tricks to help alleviate the potential sink marks.

SINK MARKS & SHRINKAGE: All plastic materials get smaller in volume when they solidify (transition from liquid to solid). The amount of shrinkage depends upon:

1. ***The material***; Amorphous (shrink less) or Crystalline, Reinforcements (glass fibers, minerals used in the plastic):
    - Flow or Cross flow directions. Flow direction usually has lower shrinkage than cross flow.
    - Wall sections; thicker parts have more shrink.
    - Mold Temperatures.

2. When you start to get sinks in a part, the plastic no longer contacts the mold surface. You create a vacuum between the plastic part and the mold cooling surfaces. The rule of thumb is to run the mold as warm as possible to still get the heat transfer needed and achieve the desired cycle. This allows for better packing of the part.

3. ***Plastics are very good heat insulators***. As parts get thicker, the cooling time goes up logarithmically. The longer a plastic stays hot, the more shrinkage it will exhibit. If the design rules are "stretched", the processer usually needs to increase packing and holding pressures, increase speeds, and cool down the material stock temperature and mold temperature (creating a compromise for surface uniformity and weld lines).

   All of this creates higher internal stresses.

HIGH INTERNAL STRESSES

Ok, you have gotten past the initial set of compromises. You have a pretty good idea of part design and have been through the first iterations of compromise. My main remaining concern is internal stress levels.
What is the definition of a "good "plastic part? It needs to look good, meet tolerances, and have LOW INTERNAL STRESS.

High internal stress gives you the following:

- Lower impact strengths
- Lower heat distortion resistance
- Lower chemical resistance
- Low dimensional stability, and warp
- Lower environmental stress cracking resistance
- Worse low temperature properties

Not one of these makes a better part.

So, what causes high internal stresses, and how do we prevent them?
In general, the harder we have to pack out an injection molded part (higher pressures, and longer holding times), the more internal stresses we build into the part.

Why do we build these high internal stresses into the part?
Most of the time, we do so to make up for bad part design. And the most common culprit is sink.

Because of the importance, I will repeat myself: ***Plastics get smaller in volume when they cool from liquid to solid.*** This is referred to as shrinkage. Every material has a shrinkage range. The longer the material stays hot in the mold, the more shrinkage occurs. When you have details, such as ribs, bosses, improper thickness transitions (try to keep a transition distance of at least 5 times the change in thickness), they create a localized thicker area. This area takes longer to cool, so you get more shrinkage in the thicker area. This will give you a "sink". This sink can be measureable (often at the intersection of a rib to a wall), or just slight enough to cause a surface gloss difference (often at the parting line where you have a thinner wall section for the interlocks).

Customers don't like sinks or the gloss changes (even though they have caused them by their design). Molders try to accommodate by increasing injection and holding pressures and adjusting mold temperatures. They can minimize the sinks with these tricks, but at the expense of increasing the internal stress levels.

Please note the attached Checklist. This lists many of the factors you need to consider and balance, in order to make a good plastic part:

This paper was intended to be a simplified overview of the many factors required in designing a good plastic part. There are a lot more details available from the many design guides from the raw material suppliers. Many of the articles/ brochures that I have found useful over the years, have been put on our web site.

The Link is at the end of the checklist.

MATERIAL CHECKLIST

EXPECTED PART LIFE ____________
USE OF PART ____________
LIABILITY IF FAILURE ____________

ELECTRICALS
SURFACE + VOLUME RESISTANCE ____________
DIELECTICE STRENGTH – SHORT TERM ____________
DIELECTICE CONSTANT_____HERTZ_____ ____________
DISSIPATION FACTOR _____HERTZ_____ ____________
ARC RESISTANCE ____________
ANTI-STATIC PROPERTIES ____________
SHIELDING ____________
ELECTRICAL GROUNDINGS ____________

MECHANICALS
COMPRESSIVE MODULUS ____________
HOURS UNDER LOAD ____________
TENSILE STRENGTH ____________
TENSILE/FLEXURAL MODULUS ____________
ELONGATION ____________
CREEP RESISTANCE ____________
ABRASION/SCRATCH RESISTANCE ____________
TEAR STRENGTH ____________
FATIGUE RESISTANCE ____________
VIBRATION TESTS ____________
HINGE CAPABILITY (MOLDED IN/COINED) ____________
SHEAR STRENGTH ____________
COEFFICIENT OF FRICTION (STATIC/DYNAMIC) ____________
HOOP STRENGTH (BURST PRESSURE) ____________
IMPACT (IZOD/DROP) ____________

TEMPERATURE
HIGHEST USE TEMPERATURE (LOADED/STATIC) ____________
LOWEST USE TEMPERATURE (LOADED/STATIC) ____________
HOURS AT HIGHEST TEMPERATURE-- LTHA ____________
COEFFICIENT OF EXPANSION ____________
THERMAL CONDUCTIVITY ____________

MOISTURE
ENVIRONMENTAL HUMIDITY ____________
WATER ABSORPTION ____________
WATER ADSORPTION ____________
HYDROLYSIS RESISTANCE ____________

FLAMABILITY
UL 94 /746 CLASSIFICATION ____________
UL HEAT DISTORTION ____________

OUTDOOR EXPOSURE
U.V. (LIFE) ____________

PACKAGING CONSIDERATIONS
BARRIER PROPERTIES ____________
H2O (WALL THICKNESS) ____________
CO2 ____________
NITROGEN ____________
ETHYLENE OXIDE ____________
GAS ____________

OTHER
BIO-DEGRADATION ____________
BACTERIAL/FUNGI RESISTANCE ____________
OUTGASSING (Electronics+Painting Foams) ____________
SPECIFIC GRAVITY (BASIC MATERIAL) ____________
SPECIFIC GRAVITY (FOAM) ____________
RADIATION OPACITY ____________
SURFACE FEEL (Tacky, Dry, Slippery, Smooth, Rough)__________
SOUND DAMPENING ____________

OPTICS
CLEAR, OPAQUE, TRANSLUCENT (THICKNESS)______________
BIREFRINGENCE ____________
DIFFUSIVITY ____________
REFRACTIVE INDEX (ND) ____________
HAZE (AT WHAT THICKNESS) ____________
TRANSMISSION (AT WHAT THICKNESS/WAVE LENGTH) ____________
CRITICAL ANGLE (IE) ____________
REFLECTIVITY ____________
FINISH (SCRATCH / DIG) ____________

APPEARANCE CHARACTERISTICS
COLOR (PIGMENT/DYE/PEARLSCENT/FLUORSCENT/PHOSPHORESCENT) ____________
FINISH (SPE=SI NUMBER/OPTICAL/TEXTURED/(MOLD TECH/EDM BLASTED)/RMS) ____________
SURFACE UNIFORMITY ____________

SECONDARY OPERATIONS
DECORATING ____________
MOLD SPRAY ALLOWED ____________
SILK SCREEN ____________
HOT STAMP ____________
LABELS ____________
PAINT ____________
PLATE (Vacuum, Electro, Electroless) ____________
FLAME SPRAY ____________
ELECTROSTATIC COATING ____________
FLUIDIZE BED COAT ____________
BLAST/HONE ____________
MECHANICAL ____________
DRILLING, TAPPING, CUTTING ____________
ULTRASONICS, VIBRATORY+SPIN WELDING, DIELECTRIC ____________
HEAT STAKING ____________
ADHESIVES (HOT MELTS, PRESSURE SENSITIVE, SOLVENT) ____________
SCREWS (SELF TAP, CAPSERTS) ____________
INSERTS (EXPANSION, PRESS IN, ULTRASONIC) ____________
SNAP FITS ____________
INTERFERENCE FITS ____________
STRESS RELIEF / HEAT OR RADIATION CROSS LINKING / POST MOLD ORIENTING) ____________

MOLDING CONSIDERATIONS
ENCAPSULATION ____________
MATERIAL SHRINKAGE+SHRINKAGE RANGE____________
TOLERANCES ____________
SINK, VOIDS ____________
POST MOLD SHRINKAGE & CRYSTALLIZATION____________
ORIENTATION ____________
MOLDED IN STRESSES (FOAM) ____________
SHEAR SENSITIVITY ____________
VISCOSITY AND FLOW LENGTH ____________
HEAT STABILITY ____________
MOLD SPRAY ____________
REGRIND ALLOWED (PROPERTY CHANGES DUE TO CROSSLINKING OR VIS BREAKING) ____________

CHEMICAL ____________________
MOISTURE ____________________

CHEMICALS
EXPOSURE TIME/TEMPERATURE ____________________
LOAD WHEN EXPOSED ____________________
STRESS CRACKING RESISTANCE ____________________
ACIDS (STRONG/WEAK) ____________________
ORGANIC SOLVENTS ____________________
ALKALAIS (STRONG/WEAK) ____________________
GREASES / OILS / LUBRICANTS ____________________
PERSPIRATION, BODY FLUIDS ____________________
OTHER PLASTICS ____________________
FOODS (FDA) ____________________
MEDICINES (ALCOHOLS/BLOOD) ____________________
COSMETICS ____________________
PAINTS/COATINGS/ADHESIVES/ CLEANING ____________________
DEIOIZED H2O ____________________
POTABLE WATER (NSF) ____________________
GREY WATER (SEWAGE) ____________________
Consider both the effect of the environment on the plastic and vice versa
STERILIZATION ____________________
GAS (ETO) / RADIATION / CHEMICAL ____________________
STEAM (TEMPERATURE / PRESSURE / TIME ____________________
RoHS, REACH, NSF,FDA , EPA ____________________
EN (ISO), EPA, ASTM, WEEE Specifications ____________________
ENVIRONMENTAL STRESS CRACKING ____________________

PART DESIGN CONSIDERATIONS

WALL THICKNESS/UNIFORMITY ____________________
SINK/VOID POTENTIAL (CORING) ____________________
RADII ON CORNERS ____________________
DRAFT ____________________
REINFORCING RIBS ____________________
GATING (SIZE, LOCATION) ____________________
WELD LINES (STRENGTH) ____________________
PARTING LINE ____________________
EJECTION (PINS, BLADES, SLEEVES, PLATES) ____________________
SIDE ACTIONS (A-SIDE, MECH, HYDRAULIC, EJECTORS) ____________________
HAND LOADED INSERTS ____________________
STRESS RELIEVING/POST MOLD CROSSLINKING OR ORIENTING ____________________
HOW IS PART USED? ____________________
WHAT HAPPENS IF IT FAILS? ____________________
EXPECTED FAILURE OR REJECT MODE? ____________________
WILL PROPERTY CHANGES, DUE TO AGING, CAUSE PROBLEMS? ____________________

FIXTURES NEEDED
COOLING ____________________
TRIM ____________________
Q.C. ____________________

Q.C. & INSPECTION REQUIREMENTS
DIMENSIONS ____________________
LINEAR ____________________
HOLE DIAMETER ____________________
CONCENTRICITY OR T.I.R. ____________________
FLATNESS (BOW/WARP) ____________________
PERPENDICULARITY ____________________
CRITICAL/CONTROL DIMENSION & TOLERANCE FIT AND FUNCTION REQUIREMENTS ____________________
(INITIAL DIMENSIONS VS. PART TO PART UNIFORMITY)______________

APPEARANCE
GATE TRIM ____________________
SINKS ____________________
VOIDS/BUBBLES ____________________
FLASH ____________________
PARTING LINE MATCH ____________________
CLARITY ____________________
SCRATCHES ____________________
UNIFORMITY OF SURFACE ____________________
FINGER PRINTS ____________________
MOLD SPRAY ____________________
FLOW LINES (PIGMENT ORIENTATION) ____________________
WELD LINES ____________________

SPRUE (CONVENTIONAL/HOT) SIZE ____________________
SPRUE PULLER (Z OR UNDERCUT) ____________________
COLD SLUG WELL - (SIZE) ____________________
RUNNER BAR (MATERIAL/HARDNESS) ____________________
BACK-UP PLATES (1 7/8" MIN) OR INSERTS (MATERIAL HARDNESS) ____________________
(BLIND-THRU) POCKETS ____________________
Material hardness finish surface-treatment special Mfg.
CAVITY INSERTS____
CORE IINSERTS____

(H-12, S-7, P-20, ALUMINUM, BE/CU, O-1, A-10, M-2, P-4)

All hardened inserts are to be stress relieved (double drawn). When Feasible, stress relieve inserts after EDMing.

GATES – (Round Edge, Trapezoidal Edge, Rectangular Edge, Half Round Edge, Tapered – ½ Edge, Tapered-Full Edge, Sub Gate, Thru Ej. Pin, Pin Point, Diaphram, Flash, Fan, Ring, Pool, Tab.
SIZE________ LAND ________

EJECTION – (PINS- DME – std., Pins-High Speed, Sleeves-Std/Special, Blades, Plate, Double Action, Hot-side, Cammed Ejectors, Kicking Ejectors, Spring Loaded, Multiple (via Springs & Jiffy Locks), Guided Ej. Plate (Required with All Sleeves & Pins under .062")

PARTING LINE (Regular/Stepped)____________________________

SIDE ACTIONS (With Positive Return & Full Locking) – (A-Side/B-Side, Angle Pin, Hydraulic, Air, Cam, Cammed Ejectors, Kicking Ejectors, Interlocking, Automatic Unscrewing, Collapsing Cores, Stilson Core, Hand Loaded – Core/Slide, Molded In Inserts (All HL or Molded In Inserts must fit in only one side of the mold, in only one Direction, and in only one location.

SAFETIES
BERMER RETURN ____________________
DME RETURN ____________________
MICROSWITCHES ____________________
SPRING LOADED EJECTION ____________________
OTHER ____________________

COOLING
BASE ONLY ____________________
(ALL PLATES) ____________________
INTO EACH CAVITY & CORE ____________________
(INDIVIDUAL CONTROL) ____________________
FOUNTAINS ____________________
BAFFLED INNER CORES ____________________
HEAT SINKS ____________________
HEAT PIPES ____________________
RUNNERS - TYPE ____________________
SIZE ___________(2ND)__________(3RD)__________
STREAMLINE/CONVENTIONAL/LAYOUT ____________________

VENTING
VACUUM POPPETS ____________________
VENT WELLS ____________________
P/L EDGE VENTS ____________________
THRU CORE/EJECTORS ____________________
VACUUM EVACUATION ____________________
SPARE PARTS ____________________

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1100 Industrial Rd. #11-B
PH: 800-600-2010
www.controlplastics.com
sales@controlplastics.com

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BLACK SPECKS ____________________
BURNS ____________________
SPLAY/BLUSH ____________________
EJECTOR MARKS ____________________
AQL LEVEL ____________________
SPECIAL TESTS ____________________

PACKAGING
LAYERED (DIVIDERS) ____________________
BULK ____________________
TISSUE WRAP ____________________
SEPARATE P.E. BAG ____________________
FOAM PACK ____________________
STACKED ____________________
EGG CRATE ____________________
SPECIAL TRAYS ____________________
PARTS PER BOX ____________________
PARTS PER BAG ____________________

TOOLING CHECKLIST
NUMBER OF CAVITIES ____________________
MATERIAL (PLASTIC) ____________________
SHRINKAGE (FLOW, CROSS, FLOW) ____________________
TOOL LIFE ____________________
PRESS SIZE ____________________
SHOT SIZE ____________________
ESTIMATED CYCLE (PARTS/HOUR) ____________________
MOLD TYPE (STANDARD, HOT RUNNER, 4 PLATE, INSULATED RUNNER
____
MOLD SIZE (MINIMUM OF 2" AROUND CAVITIES) ____________________
BASE MATERIAL (DME #1,2,3, ALUMINUM, H-13 ____________________