International Journal of Applied Research in Mechanical Engineering

Volume 2 | Issue 1 Article 7

July 2012

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CONFIGURING SPRUE CONDUIT EXPANSION IN PLASTIC INJECTION MOULD DESIGN

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Abstract- Plastic injection mould design methodology and criteria to configure sprue bush for augmenting functionality are briefly compiled. Hereto prevalent sprue conduit design criteria is systematically consolidated and its sensitivity to machine, moulding and material influences are quantitatively ghettoised as expansion ratio on the basis of ubiquitous empirical relationships. This generic, simple, inexpensive preventive criterion exemplifies sprue bush conduit geometry design to inject melt specifically for a particular combination. Further for design meticulousness its sensitivity is also briefly deliberated over a feasible range to achieve best performance.

Received on 19 April 2013, Peer reviewed and accepted on 2 June 2013 and Published online on July 2013

Keywords *- Sprue bush, Melt Conduit, Expansion ratio*

I. INTRODUCTION

Plastic injection moulding is a continuous process to precisely contrive identical parts with complex topography across stringiest tolerance ranges [1], possessing reliable properties and are highly production efficient at affordable cost from a rigid mould [2]. Contemporary developments in injection moulding technology performance, efficiency, quality, etc, are impeded severely because barely few operational parameters are detectable and moderatable [3], perhaps most parameters are presumed to regulate intrinsically within moulding cycle. Clearly, from a control theoretic perspective, injection-moulding process is neither observable nor controllable [4]. Thus reckoning more on mould design to exemplify functionality [5]; despite maturity in designing moulds from global interaction resoluteness perspective design criteria are still deficient, while obscuring mould analysis inhibit judgement. Quite often designing moulds has to deal high complexity, which necessitates exhaustive simulative analysis, deliberate modifications and multifarious trails interactively and iteratively, owing to these uncertainty is obvious [6]. Injection pressure delivered from moulding machine must progressively suffice nozzle, sprue, runner, gate and moulding impression gap energy transformations. According to dimensional analysis of mould function, in-mould pressure head recovery from kinetic injection velocity would be prominent performance metric. Conscientiously injection mould components constituting feed system is where performance hearth is for critical insight [7]. Obviously, for efficient mouldability meticulous in-feed conduit pressure recovery criteria is essential, so a rational approach seems to first embrace fundamental injection mechanics criteria. Perhaps appreciating melt injection dynamics and then solving them to design prudent feed system conduit geometrical features might enhance overall confidence [32]. Off feed system significant fraction of in-mould pressure head recovery occurs in sprue bush conduit, hence sprue conduit efficiency will significantly influence overall mould performance quotient, and so is conspicuous element for design perfection [8].

II. SPRUE BUSH DESIGN CONFIGURATION

Operationally sprue bush is plastic melt conduit from upstream nozzle tip to downstream runner and/or gating system on the parting plane for onward injection into moulding impression gap. Occasionally a portion of primary runner is machined on its base linking sprue well to main runner conduit, wherein to retain alignment anti-rotation locking feature design is necessary. Rarely sprue bushes are also designed to deflate unwanted dross and precipitates proceeding into moulding impression gap by adopting cyclonic separation along sprue melt interface boundary by using micro porous powder metallurgy materials. Functionally sprue bush has to mechanically and thermally engage cold mould to hot barrel with minimum energy loss [9] as well as recover necessary in-mould packing pressure energy from nozzle's kinetic injection energy. So it is oriented parallel to injection barrel and exclusively assembled into mould [10] by slip-fitting through top plate (H7h6) and transition-fitting (H7k6) into cavity plate, as well as to receive very little cooling.

The degree of molecular structure orientation in moulding depends on residual stress variance on it's surface consequent to injected melt front pattern. To accomplish almost uniform melt injection pattern despite discrete periodic fluctuations warrant a conduit design criteria conceding injection dynamics, which is never given due consideration [11] and is the prime focus of this research effort.

In injection moulding dominating viscous effects inject laminar streams at creep Reynolds number (Re) ranges, so melt layers pushed against peripheral boundary walls experience relatively large and almost uniform pressure build up with least shearing. Thus forming stagnation region with substantial hesitation along plastic melt-to-sprue wall interface, secluding thin boundary layer [12].

Flattened boundary layer simultaneously freezes below its glass transition state up to an equilibrium thickness, relative to local melt injection rate as well as accompanying diathermic heat transaction rates. Resulting melt frozen layer thickness generally stagnates at,

(a) zero velocity region, depending on melt residence time

(b) congealed temperature region depending on melt to sprue material thermal property differences like thermal conductivity, specific heat, glass transition temperature, etc,

(c) high viscid region relative to injection shock plane melt viscosity

Consequently intermediate nominal layers experience low relative pressure and large shear rates, hence fresh melt erupts at the core along the nominal injection direction as convection proceeds. This combination of poor shear heating and sluggish melt slip continuously drag core layers towards conduit wall (perimeter), despite intermediate laminates shearing faster resulting in 3D nonlinear velocity profile at the flow front i.e, initial melt front advance flattens abutting over and along cold sprue conduit interface boundary. Generally this phenomenon is attributed as fountain flow effect [13].

Rapid shear rates necessitate precise and accurate sprue-conduit region design with minimum frozen layer thickness [14 and 15]. Normally frozen layer is thicker at exit and relatively thinner at the entrance. Existing polymer molecular structure kinetics based thermo-rheological models solely characterise polymer behaviour above melting point, but extrapolating them in congealed ranges below glass transition temperature to ascertain melt state would be erroneous.

Therefore, frozen layer thickness estimation and profile criteria are still contentious [16]. Consequently, solidified interface boundary layer effectively shrink conduit orifice escalating demand for either additional pressure or cycle time extension to inject desired shot volume through narrow conduit. Nevertheless frozen layer thickness neglection would introduce considerable injection velocity-computation error. As melt streams diffuse through expanding conduit along injection direction in compliance to law of mass conservation nominal velocity decreases. As well as incompliance to law of energy conservation, nominal melt temperature decreases due to heat dissipation into colder sprue walls.

Also incompliance to law of momentum conservation necessary in-mould pressure is recovered at the expense of injection velocity. But alike real transport circumstances melt convection is irreversible, so the actual in-mould pressure recovery will be always less than corresponding driving injection barrel pressure.

Sprue bushes are subjected to cyclic (harmonic) temperature and pressure fatigue as well as processing erosion. So corresponding failure criterion dictates chosen material to have sufficient strength. Accordingly sprue bushes are manufactured from nickel chrome steels (BS 970:817M40) or BIS T110W2Cr1 or DIN ISO 10072 (DIN 16752) 1.2826 with 740 N/mm2 and should always be hardened [17], tempered, precision ground, nitrided keeping surface hardness 55□2 HRc and core hardness at 40-45 HRc and lapped to achieve desired surface finish.

A. Sprue Bush Design Methodology

Sprue bush design perfection is crucial to inject, distribute melt and eject moulded part [17], its configured features significantly influence impression contrivability [18].

Exterior head, shank and base sections integrate to form internal conduit geometry as represented in Figure 1 that has to be very specifically configured for available machine specifications, desired moulding features and chosen polymer characteristics.

Sprue conduit design should maintain continuity, balance mechanics and equilibrate energy transactions to sustain required melt state for ideal contrivance.

(a) Head: Sprue head is a positive feature possessing negative inlet orifice region to receive melt as well as accommodate abutting nozzle tip

(b) Shank: Sprue shank is a transition feature with tubular cross-section forming internal conical conduit between head and base

(c) Base: Sprue base with exit orifice region delivers melt into sprue well harmonising feed system continuance along the parting plane.

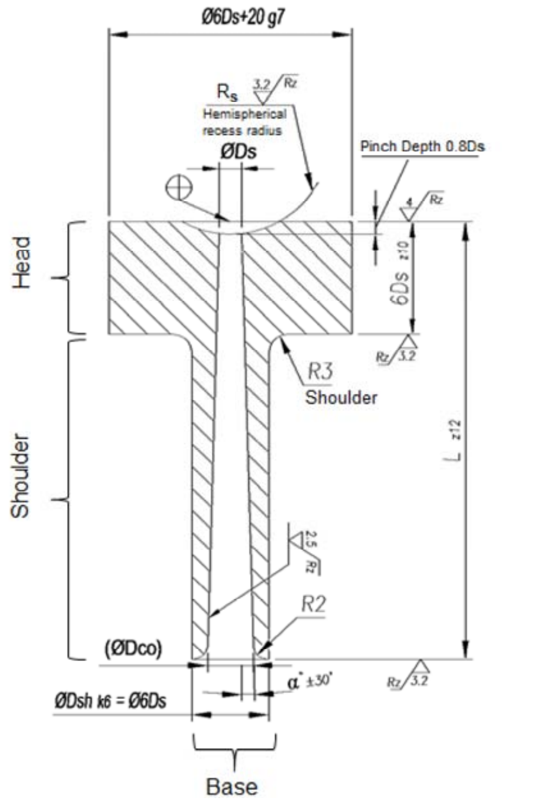

Figure 1 Schematic representation of typical sprue bush

a. Sprue Head

(i) Shoulder Design: During barrel advancement or mould engagement axial thrust by moulding machine injection sliding unit typically range from 100□50 kN for general utility components and 250□50 kN for high-pressure injection or even higher for engineering components. So large diameter collar head configuration is designed with sufficient butting shoulder area enough to bear nozzle tip sealing pressure i.e, restrain in-mould displacement. Similarly upon barrel retrieval, locating ring prevents out of mould assembly displacement, due to injection mechanics as well as engagement gap leakage welding. Also big enough to accommodate clamping screw heads arrayed on a circular PCD to bear axial ringing torque. Structurally collar head height and shoulder butting area are designed to bear repeated (fatigue) high mechanical load impacts of mixed stresses (shear, compression and tension) and resist deformations [19]. Consequent to repeated barrel engagement and disengagement within each cycle, sprue head recess will be imperilled to severe wear possibilities. Hence from maintenance and serviceability perspective sprue bushes have to be designed for replacebility.

(ii) Stress Concentration: Rigid sprue bush experiences an indeterminate stress concentration at shank and head juncture much higher than those approximated by elementary equations and perhaps accurate magnitude calculations demand theory of elasticity perspective.

(iii) **Thickness Design:** From a design perspective, sprue-bush wall thickness exceeds 10% of nominal conduit diameter $\left(\overline{D}\right)$ and internal melt pressure exceeds $\left(\frac{1}{6}\right)$ of allowable stress, so it has to be considered as a thick shell [20].

(iv) **Pressure Drop:** Sprue conduit entrance-pressure loss (P_c) is another practical issue expressed as $P_c = c.\tau^m$, where c and m are empirical constants determined from popular Bagley curves for the chosen polymer and τ is shear stress.

b. Sprue Conduit Design

Off the entire feed system diverging sprue conduit inlet orifice witnesses' swiftest volumetric shear rate i.e, maximum shear rate with major heat and mass transformations occurring at the shock plane [21]. Narrow sprue conduit size will decrease solidification time, which will enhance productivity [22]. Nevertheless smaller nozzle orifice compel processors to inject melt at higher temperature, so sprue-bush conduit should be designed to achieve highest melt injection rates for the available pressure gradience. Prime objective of sprue conduit design is to mitigate melt / gas entrapment, abrupt streaming and pressure / temperature variance, vortexing, undue turbulence, discontinuous splashing of streams, self-tumbling, etc, and relative to dynamic rheological characteristics fully contrive the impression with continuous injectability. Eventually aid mould elements contrive parts that are (1) wholly filled (2) superior surface finish (3) undistorted (4) denser (minimum voids, pores and bubbles) (5) flexible (6) superior weldmesh (7) dimensionally precise (8) uniformly shrunk [23].

(i) Sprue bush length (L) has to flush with (cavity + bottom) plate thickness, so at component level an excess metal stock (zIT12) is provided to compensate finish grinding after final assembly. Thermal expansion causes the sprue bush length to "grow" far enough past the parting line leading to flashing. Also the nozzle contact forces push it over the moving side of the mould, trying to open it. So for non-sprue-gated parts, moulders should ensure sprue bushing length while it is hot [24].

(ii) Consequent to conduit convergence and divergence on either side of interface shock plane, greatest restriction to inject melt occurs at the interface between nozzle exit and sprue inlet orifice. So to achieve ideal throttle action shock section must achieve highest shearable rate (sonic injection) of chosen polymer (perhaps $M \approx 10^{-1}$ *i.e, injection velocity*). Injection shock plane Mach number depends on the rheological and shear degradation characteristics specific to the chosen polymer. Convergent nozzle and divergent sprue conduit combination, during filling phase acts as nozzle-diffuser increasing melt downstream pressure at the expense of upstream velocity *i.e increase discharge rate to expand plastic melt from higher subsonic* $\left(M < 10^{-3}\right)$ *nozzle velocity to lower subsonic* $\left(M < 10^{-5}\right)$ *sprue filling velocity*. Again the same combination acts as diffuser-nozzle to increase melt velocity at the expense of pressure during packing phase, *i,e compressed plastic melt in lower subsonic* $\left(M < 10^{-3}\right)$ *nozzle velocity to higher subsonic* $\left(M < 10^{-2}\right)$ *sprue compensation velocity*.

(iii) Sprue conduit inner surface is designed smooth, furrow-less and polished to facilitate frictionless laminar melt impulse streaming, permit clean sprue stem stripping out with minimum drag, sticking and friction [23] and nozzle tip break off. However co-efficient of frictional loss $C_{Friction\ Loss}$ can be computed as,

$$C_{Friction\ Loss} = \left(1 - \frac{U_{Sprue\ exit}}{U_{Nozzle}}\right) \quad (1)$$

c. *Sprue Base*

According to mass-momentum conservation perspective,

(i) Since laminar melt efflux pressure gradience is directly proportional to shank length and inversely proportional to fourth power of exit diameter, sprue base design is critical to maintain pressure gradience than configuring length

(ii) **Minimum:** Sprue passage exit orifice diameter should be bigger *(at least 1.5mm)* than part thickness *(i.e,* $D_{co} \geq t_{max}$ *+ 1.5mm)* to ensure consistent mass flow rate and freeze after part solidifies, thereby orifice remains live to feed melt for packing. To achieve highest volumetric injection rate through sprue bush exit turbulence should be avoided [21 and 25].

(iii) **Maximum:** Excessively oversized exit sprue diameter at runner - sprue well intersection necessitates longer moulding cycle [26]

(iv) For smooth interfacing with sprue well an external (R3) fillet geometry is designed at the sprue bush base to prevent melt pulling away from the wall in the form of a jet, that remain visibly distinct on the moulded part surface

B. Sprue Bush Design Criteria

Influx polymer melt state, viscosity characteristics, rheological behaviour, etc., prior to entering sprue conduit are key processing parameters directly influencing yield component quality and its thermal characteristics. Relative shear heat developed and/or absorbed inherent distribution range approximately exceeds 100C at injection shock geometry zone [27]. Nevertheless temperature variation is proportional to the ratio of machine shot capacity and mould shot capacity [28]. Intrusive probes into sprue bush have revealed that melt temperature sharply increase during injection followed by gradual decay during packing and significantly decrease during cooling. Probably during filling temperature intensifies due to adiabatic compression and shear friction, perhaps major thermal variation occurs consequent to hot melt volumetric injection dynamics inside sprue conduit [29].

Sprue conduit capillary ratio is determined by the ratio of sprue conduit pressure gradience available in the machine to maximum injectable true shear stress □ extent of the chosen polymer. By considering sprue conduit analogous to a generic capillary tube, it can be computed as,

$$\text{Shear Stress }(\tau) = \frac{\Delta P}{2\left(L/R\right)}$$

Since sprue shank has a straight conduit its nominal diameter would be an arithmetic average, then $R = \frac{\bar{D}}{2}$

$$\text{Shear Stress }(\tau) = \frac{\Delta P\,\bar{D}}{4L} = \frac{\Delta P}{4L}\bar{D} \quad (2)$$

For a linear conduit expansion nominal diameter can be obtained from Figure 1 as follows,

$$\bar{D} = \frac{\left(D_s + D_s + 2L\,Tan\alpha\right)}{2} = \frac{2\left(D_s + L\,Tan\alpha\right)}{2} = D_s + L\tan\alpha \quad (3)$$

So by substituting Eqn (3) in (2) we get,

$$\text{Shear Stress }(\tau) = \frac{\Delta P}{4L}\left(D_s + L\tan\alpha\right) \quad (4)$$

The apparent shear rate for a melt injected through a capillary conduit is defined as,

$$\gamma = \frac{4Q}{\pi R^3} = \frac{32Q}{\pi \bar{D}^3} = \frac{32Q}{\pi\left(D_s + L\tan\alpha\right)^3} \quad (5)$$

To design a specific sprue conduit, its operational characteristic features have to be described by functional metrics. Therefore, melt's resistance to diffuse through sprue conduit is quantitatively represented by apparent local viscosity, more specifically resulting melt strain rate for an applied (injection) shear stress. Thermoplastic melt viscosity being a true thermodynamic property varies with spatiotemporal melt state. Therefore based on Sir Isaac Newton's resistance law postulated in 1687, the capillary rheologic formulation for polymer melt injection neglecting strain angle $\theta(t)$ would be [30],

$$\text{Sprue exit Viscosity }(\mu) \neq \frac{\text{Shear Stress }(\tau)}{\text{Shear Rate }(\gamma)} \quad (6)$$

Shear stress is maximum at the peripheral wall and declines towards central core proportional to velocity profile slope. Now substituting Eqn (4) and (5) in (6) we get,

$$\text{Apparent Viscosity }(\mu) \neq \frac{\left(\frac{\Delta P}{4L}\left(D_s + L\tan\alpha\right)\right)}{\left(\frac{32Q}{\pi\left(D_s + L\tan\alpha\right)^3}\right)} \neq \frac{\Delta P\pi}{128QL}\left(D_s + L\tan\alpha\right)^4$$

The above inequality represents non-newtonian melt injection across nonlinear viscosity distribution and could be equated by adopting Rabinowitsch correction as follows,

$$\mu = \frac{\Delta P\pi}{128QL}\left(D_s + L\tan\alpha\right)^4\left(\frac{4n}{3n+1}\right) = \frac{\Delta P\pi}{32QL}\left(D_s + L\tan\alpha\right)^4\left(\frac{n}{3n+1}\right) \quad (7)$$

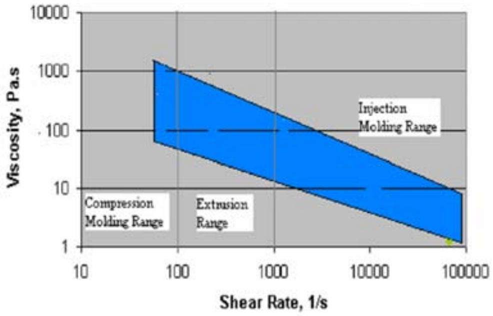

Figure 2 Shear rate effect on viscosity for thermoplastics [17]

Here n is flow behaviour or shear-thinning index, according to power law n can be obtained as slope of log viscosity vs log shear stress particularly for a particular injection moulding case.

$$n = \frac{d \log_e \mu}{d \log_e \tau} \tag{8}$$

However, for non-newtonian shear thinning viscoelastic thermoplastic melts $n < 1$ as shown in Figure 2

Shear rate dependency is a prominent injection-moulding process feature *i.e, high viscosity at low shear rates (as in blow moulding) and low viscosity at high shear rates (such as extrusion)*. So thin viscoelastic thermoplastic melt rapidly occupies thinner mould gaps at high shear rates. Shear thinning behaviour of injected melt (at purge shot temperature) prior to entry is almost equal to sprue conduit exit; hence viscosity change would be bare minimum $\left(\frac{d\mu}{dx} \approx 0\right)$ at $x \in [0, L]$. Melt experiences heavy shear rates as well significant fluctuation through each cycle, particularly during filling and packing. Injection shear rates typically range from 10^1 to 10^4 per second. So it is crucial to specifically design sprue bush conduit for the best shear rate and maintain as much as possible uniformity throughout the conduit. Therefore constant viscosity (μ) assumption for idealism could be substantiated because conduit size is finite or rigid. Accordingly rearranging Eqn. (7),

$$\left(D_s + L \tan\alpha\right)^4 = \frac{32\mu QL}{\Delta P \pi}\left(\frac{3n+1}{n}\right)$$

$$\left(D_s + L \tan\alpha\right) = \sqrt[4]{\frac{32\mu QL}{\Delta P \pi}\left(\frac{3n+1}{n}\right)} \tag{9}$$

Now resolving for conduit expansion slope,

$$\tan\alpha = \frac{1}{L}\left[\sqrt[4]{\frac{32\mu QL}{\Delta P \pi}\left(\frac{3n+1}{n}\right)} - D_S\right] \tag{10}$$

Substituting from sound velocity definition $\Delta P = C_P P_{max}$, where C_P is the characteristic co-efficient of a thermoplastic melt representing the extent to which sprue conduit has to recover pressure and P_{max} is rated injection pressure available in the machine [31] also discharge rate,

$$Q = \frac{\text{Shot Volume}}{\text{Injection Time}} = \frac{V_{Shot}}{t_{Injection\ time}}$$

$$t_{Injection\ time} = \frac{\text{Stroke Volume of M/c}}{\text{Injection rate}} = \frac{V_{Stroke}}{U_{Injection}}$$

So,

$$Q = \left(\frac{V_{Shot}}{V_{Stroke}}\right) U_{Injection} = \frac{U_{Injection}}{BSR}$$

Where Barrel to Shot volume ratio (BSR) should ideally range from 50% to 75% [1]. Hence substituting ΔP and Q we get,

$$\tan\alpha = \frac{1}{L}\left[\sqrt[4]{\frac{32\mu L}{\pi C_P P_{max}}\left(\frac{V_{Shot}}{V_{Stroke}}\right) U_{Injection}\left(\frac{3n+1}{n}\right)} - D_S\right] \tag{11}$$

However traditionally $1^o \geq \alpha \geq 5^o$ taper is independently adopted to conserve additional feed system volume expense, perhaps may not be idealistic. So analogous extrusion expansion ratio (E_r) has been proposed based on Eqn. (11) as simplified design criteria,

$$\tan\alpha = \frac{(E_r - D_s)}{L} \tag{12}$$

Expansion ratio (E_r) is an important quadrupled parametric ratio collectively representing spatial conduit geometry change across initial nozzle tip and final sprue well base. It is obtained by comparing Eqn (11) and (12) as,

$$E_r^4 = \left(\frac{32}{\pi}\right)\underbrace{\left(\frac{3n+1}{n}\right)\left(\frac{\mu}{C_P}\right)}_{\text{Material}}\underbrace{\left(\frac{U_{Injection}}{P_{max} V_{Stroke}}\right)}_{\text{Machine Setting}}\underbrace{\left(L_{Sprue} V_{Shot}\right)}_{\text{Moulding}}$$

$$E_r^4 = \left(\frac{32}{\pi}\right)\underbrace{Poly}_{\text{Material}}\ \underbrace{Ms}_{\text{Machine Setting}}\ \underbrace{Comp}_{\text{Moulding}} \tag{13}$$

Further simplifying,

$$E_r^4 = \left(\frac{32\ \mu}{\pi}\right)\left(\frac{3n+1}{n}\right)\left(\frac{U_{Injection}}{P_{Max}}\right)\left(\frac{BSR}{C_P}\right) \tag{14}$$

Typically for perfectly injection mould, $BSR = C_P$, then Eqn reduces further to,

$$E_r^4 = \left(\frac{32\ \mu}{\pi}\right)\left(\frac{3n+1}{n}\right)\left(\frac{U_{Injection}}{P_{Max}}\right) \tag{15}$$

As per Eqn (13) sprue conduit expansion geometry is specifically sensitive for a particular set of moulding, material and machine combination. The sensitivities are highly reliable as the influences of material, machine and moulding are specifically quantified. Sensitivity information is highly valuable to responsibly configure conduit design with respect to any given perturbations in the functional configuration. As E_r is proportional to machine specifications, desired moulding features and chosen polymer characteristics like polymer viscosity, perhaps highly viscous materials like POM require large taper.

III. ILLUSTRATION

Traditional design criteria typically focus on direct mathematical substitution just enough to specify some discrete or numerical value. Whereas Continuous Sensitivity Equation Method (CSEM) represented by Eqn (12) contrasts by examining relational sensitivity at infinite dimensional level. CSEMs are capable of adopting illustrative intervention to deliberate conduit design sensitivity at wisdom level very much beyond pragmatic experimentation or classical analytical studies. Although the inference is still wonted, the analogous derivations offer a unique perspective than those prevailing belief. Current holistic design sensitivity study is part of a broader investigation scope. Accordingly, we choose injection grade Acrylonitrile butadiene styrene (ABS) as the thermoplastic to be moulded,

Table 1: Characteristic properties of ABS were obtained from MATWeb

Injection Temperature	190 – 210 °C
Capillary Rheometry	
power law index, n	0.2390 to 0.4340
Apparent Viscosity	96.99 - 22.19 (N/m^2) -sec
In-mould Injection Pressure required to contrive impression gap	4.14 – 130 MPa

Similarly horizontal injection moulding machine of Windsor Machines Ltd., Mumbai, Sprint series have be representatively adopted especially for case A and C, 650 ton machine is chosen. Also a 1000cc component size or impression shot volume is chosen with 80mm sprue bush length requirement. So specifically three different situational combinations of practical scale could be illustrated, by perturbing each at a time.

A. Sensitivity to component size

Ideally actual shot volume for a component should always be 0.5 to 0.75 of the total swept volume per stroke of the barrel [32]. Using the material data in table 1, the material term range of Eqn (13) is computed as $\text{Poly} = \{159.41, 530.36\} = 344.888$. Similarly for 650T Sprint machine, machine setting term of Eqn (13) is also computed to be $\text{Ms} = 1.4482 \times 10^{-6}$. A typical 80mm sprue bush length is considered to illustrate component volume sensitivity.

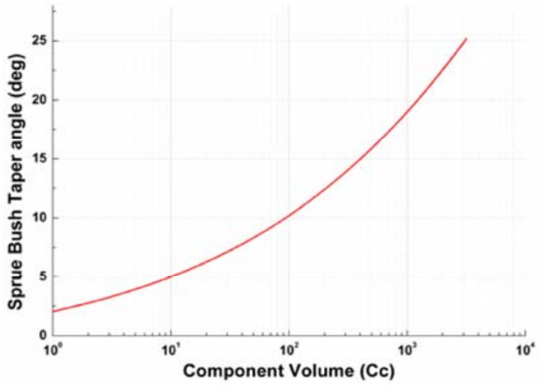

Figure 3 Sprue taper expansion relative to component volume

According to figure 3, sprue conduit expansion is exponentially sensitive to component volume extent. Should mould design intend to accomplish best feasible performance by perturbing component size has a significant influence on overall sprue conduit expansion. Therefore sprue bushes have to be very specifically design for a particular component.

B. Sensitivity to Machine size

Despite large conduit volume intimidates rapid injection, however its accomplish-ability depends on injection rate availability in the machine. So spure conduit expansion along the injection direction is sensitive to feasible machine specifications. However injection moulding machine capacity is correlative to its size or tonnage, hence material data in table 1 is used to compute material term range of Eqn.(13)

$$\text{Poly} = \{159.415, 530.362\} = 344.888$$

Similarly a typically representative component of 1500cc,

Figure 4 curve illustrates that sprue conduit expansion is inversely proportional to machine size as well as a stouter conduit itself could suffice with bigger size machines. Machine size influence has very modest influence on sprue expansion extent. Hence switching over a range of machines has little influence on sprue conduit expansion.

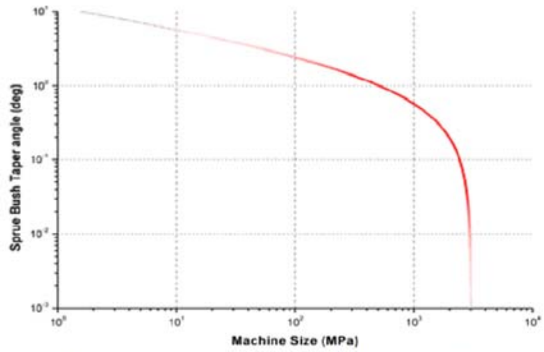

Figure 4 Sprue taper expansion relative to machine size

C. Sensitivity to thermoplastic material

Inherently sprue conduit expansion is sensitive to thermoplastic material characteristics and state, which can be appreciated to critically regulate best processing. In-situ melt characteristics and state very much influences design and implementation success of polymer processing particularly thermodynamic and transport perspective [33]. As we understand from momentum conservation perspective, material viscosity directly governs the consequent mechanics, accordingly sprue conduit expansion has to be configured for best functionality. To illustrate this sensitivity Sprint 650T horizontal injection moulding machine specification is adopted to compute machine setting term to be $\text{Ms} = 1.4482 \times 10^{-6}$. Similarly a typical representative component of 1500cc is considered. Considering a nominal power law index value of $n = 0.3365$, melt viscosity is perturbed over its natural range.

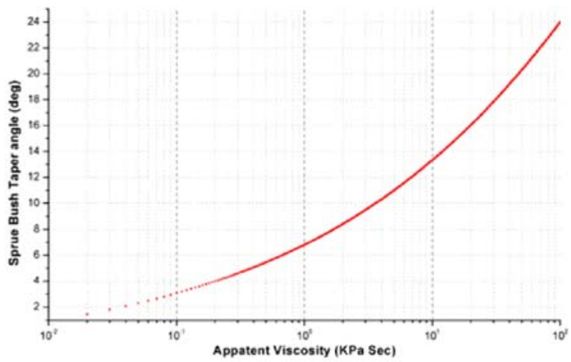

Figure 5 Sprue taper expansion relative to material type

Figure 5 illustrates that although melt viscosity is exponentially proportional, conduit expansion is negligibly sensitive to in-situ material state.

IV. CONCLUSION

Above extensive CSEM deliberation manifests exemplary sprue bush conduit can be specifically configured. Sprue conduit could be institutively designed by attributing prevalent configuration situate. Therefore it is inferred that component size has considerable influence on sprue conduit expansion compared to either material or machine changes. Further configuring reliable sprue bush conduit expansion feature very much specific for a particular combination ensures best performance, productivity and quality as gainable benefits.

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