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Computational design of mould sprue for injection moulding thermoplastics

Muralidhar Lakkanna*, G.C. Mohan Kumar, Ravikiran Kadoli

Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal 575025, Mangaluru, Karnataka, India

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Abstract

To injection mould polymers, designing mould is a key task involving several critical decisions with direct implications to yield quality, productivity and frugality. One prominent decision among them is specifying sprue-bush conduit expansion as it significantly influences overall injection moulding; abstruseness anguish in its design criteria deceives direct determination. Intuitively designers decide it wisely and then exasperate by optimising or manipulating processing parameters. To overwhelm that anomaly this research aims at proposing an ideal design criteria holistically for all polymeric materials also tend as a functional assessment metric towards perfection i.e., *criteria to specify sprue conduit size before mould development*. Accordingly, a priori analytical criterion was deduced quantitatively as expansion ratio from ubiquitous empirical relationships specifically *a.k.a an exclusive expansion angle imperatively configured for injectant properties*. Its computational intelligence advantage was leveraged to augment functionality of perfectly injecting into an impression gap, while synchronising both injector capacity and desired moulding features. For comprehensiveness, it was continuously sensitised over infinite scale as an explicit factor dependent on in-situ spatio-temporal injectant state perplexity with discrete slope and altitude for each polymeric character. In which congregant ranges of apparent viscosity and shear thinning index were conceived to characteristically assort most thermoplastics. Thereon results accorded aggressive conduit expansion widening for viscous incrust, while a very aggressive narrowing for shear thinning encrust; among them apparent viscosity had relative dominance. This important rationale would certainly form a priori design basis as well diagnose filling issues causing several defects. Like this the proposed generic design criteria, being simple would immensely benefit mould designers besides serve as an inexpensive preventive cliché to moulders. Its adaption ease to practice manifests a hope of injection moulding extremely alluring polymers. Therefore, we concluded that appreciating injectant's polymeric character to design exclusive sprue bush offers a definite a priori advantage.

Keywords: Injection moulding; Sprue bush; Apparent viscosity; Shear thinning index

1. Introduction

Contemporary anthropologists assert 1.5 million years of absolute correlation between hominid evolution and manufacturing knowledge reformation; consequently, almost all materials are perpetually enabled to a broad spectrum of application domains inciting stellar functions like greater convenience, compaction, portability, etc. Such scrupulous progression has radically advanced the cognisance of underlying scientific phenomena in pursued techniques, methods, capabilities, tools, approaches, strategies, etc., from both enabled material as well as envisioned application perspective. Liken from a safety perspective[1] plastics characterise mankind's adaptive evolution at the very heart of planet's forthcoming living because they transpire from only 4% of earth's extractions (*natural oil and gas*) compared to 42% for heating and 45% for transportation. Coeval life cycle assessments (LCA)[2] commend plastics as the noblest contributor to ecology, because it absolutely reduces human dependence on fossil fuels like shrinking 150% energy demand [91]. Ever since Alexander Parkes (UK) invented parkesine (*plastic*) in 1855 [97] to substitute dwindling demands of ivory from elephants and whales, tortoiseshells and horns; they are preferred over all other material options [78]. Owing to the accomplished prominence in ambiguous applications, they are eventually turning out to be process migrations destination. Chronologically preceding decennia has witnessed

*Corresponding author. +91 8105899334.
E-mail address: lmurali@nitk.ac.in (M. Lakkanna).
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[1]United Nations WHO priority concern.

[2]ISO 14000 inter-alia tool to access environmental consequence of a material for production, application and estimate end-of-life aspects including waste, pollution, disposal, etc. [91].

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spectacular evolvements in synthetic polymers to possess appealing degree of aesthetics, functionality, ergonomics, cosmetics, etc. Beyond entwined value, most sensational allure arises from the amazing set of properties polymers contribute to the application. Likewise, from functionality perspective they are deployable to a wide range of applications requiring antistatic, fire retardant, electromagnetic shielding, extreme degree of conductivity to insulation range, etc. properties. Their very high degree of coalescence has further breed a completely new set of materials like composite, hybrid, smart, functionally graded, etc., to contemporary applications.

Due to inextricable key link with civilisation global plastic economy ranks among tenacious sectors [15]; concomitantly that snares a perpetual compulsion to elate sophistication, quality, performance, durability benchmarks, staunch lead-time besides economising [32]. In lieu several polymer processing techniques have transpired under adept commerce patronage; off them injection moulding happens to be at the foremost [45], like one among every third [32% by weight [77]] part is injection moulded [81]. Despite appreciable progresses near net-shape mould making; coherent processing advances like smart set-up or intelligent control; questing product design expectations are yet to synchronise and reconcile enough, because mould designing still amply resorts to heurism [6]. This impuissance frequently evidences as extended lead-time, penalised performance, poor yield and/or compromised quality, hence polymer-processing technology mandates are certainly far ahead of existing capabilities. Principally injection moulding attributes remarkably depend on the combination of in-situ factors {*temperature*: *pressure*: *velocity*}, intrinsic resin properties and configured mould design. These key factors interactively influence the overall thermo-mechanical transformation and ensue performance as well as quality of ultimate moulded products [26,27]

Regardless of exclusive advances in mould design as well as material characteristics, from global resoluteness perspective maturity is still fictive. Severe complexity involved owes relative abstruseness to analyse and inhibit collective decisiveness, so exhaustive simulation, deliberate modifications and multifarious trails are inevitable both interactively and iteratively [85], obviously owing to them uncertainty befalls [82]. Despite higher injection capacity machine being available, its injection pressure gradient rarely suffices progressive energy transformations through nozzle, sprue, runner, gate and moulding impression gap. Recovery quotient of in-mould pressure head from influx kinetic velocity within sprue bush depends significantly on its conduit geometry design perfection. From mould-function assessment perspective this recovery quotient becomes a prominent performance metric as well as conspicuous factor for design perfection. Conscientiously in-situ sprue conduit (*a feed system constituent*) pressure-recovery criteria meticulousness is where performance hearth is for critical insight [19]. Hence embracing fundamental intra-conduit in-situ injection momentum mechanics seems to be a rational approach for efficient mouldability.

2. Literature

Both constraining or liberally expanding sprue conduit invariably hesitate injection, consume more energy or eventually deprive in-mould pressure recoverability [55]. So to design an appropriate feeding system both quality and performance have to be adjudicated as expectant factors. Profound reasons attributed for such ascribes are injectant's characteristic,

1. shear strain along melt-to-conduit wall interface [2]
2. hydrodynamic instability *(a.k.a injection pattern twisting to form spirals or helixes as quantified by Wiesenberger number* [96]*)*.

Nevertheless, an in-depth comprehension relating gross defects arousing physics; phenomenal injectant conveyance; pressure recovery; injectant phase transformation; and collimated interactions with sprue conduit expansion [39] is still fictional. Such phenomenal traits should drastically constrain conduit region design *(both cross-section geometry and expansion design)* and its performance,

1. to be wilfully deterministic across melt injection rate adequacy and shear stretching enormity; while ensuring intrinsic uniformity; as well as minimising shear heating. Perhaps this analogy might be complicated, because transit viscosity aggressively reduces *(shear thins)* as injectant traverses through the conduit length and its enormity physically impairs resin properties [12] i.e., *AQL and APL seesaw over design fulcrum.*
2. to essentially accomplish ideal injection. i.e., *injectant's characteristic intra-conduit deformability degree, speed and duration* [9]
3. to intrinsically inoculate polymeric injectant's concurrent in-situ behavioural vitrifications i.e., *non-Newtonian behavioural traits causing premature freezing, impression filling incompleteness,* etc., *explicitly restrain as ideal sprue conduit expansion design limits* [1]
4. by being imperatively generic, simple, inexpensive and preventive; the criteria would still be applicable to all injectants despite large in variety.

2.1. Acceptable quality level (AQL)

In general, injection moulding involves deformation, transportation, solidification [39] to contrive a polymeric injectant through its aqueous molten state i.e., *above their respective glass transition level* [99]. Invariably such a state excites complex non-Newtonian behaviours that stimulate various erratic unstable mechanical demeanours [51]. Typically, injection-moulding process imperils polymeric injectant to severe physical aggression involving high temperatures, extreme pressures and rapid shear rates [66]. Since most viscoelastic shear thinning thermoplastic melts are vulnerable to aggression magnitude[3] and duration[4] [7]; in-situ chemical transmutations secede most likely phases and eventually

[3]Like to inject long segment block co-polymers (*such as polyurethane, polyetheramides, styrenic SEBS, etc.*) creep level laminar shear rates are required, while significantly immiscible blends like ABS that easily segregate would necessitate rapid laminar shear rate [86].

[4]For instance, polyacetals instantly decompose under excess shear force exertions, especially at higher pressure and temperatures [94].