PVC PIPE EXTRUSION TO DELIVER BEST PRACTICE END CUSTOMER REQUIREMENTS

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ABSTRACT

'Voice of the Customer' or Product Deployment cascades ensure that the end user Customer requirements are the focus of every upward step from the 'Ear of the Engineer' in Design of the Manufacturing Equipment through optimum Extruder Process Conditions through Pipe Performance to Customer Demands. How do you target the holistic process in practice to deliver quality PVC pipe made by best manufacturing practice towards clearly understood and correlated customer quality requirements? The 'big picture' is to deliver a safe, sustainable, confident long product lifetime at predictable lifetime cost.

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INTRODUCTION

PVC pipes are important to the quality of our modern life. Safe, clean water, efficient energy and communication flow to millions of people. Also, inert, durable, with long life, with environmental advantages over competitive products, [1], cost-efficient flow of fluids, sustainable and completely recyclable from 'cradle to cradle'. There are over one million tonnes of new PVC pipelines keeping life flowing for people each year around the world [5].

How do you make sure that you are not spending valuable Resources, Energy, Time and Profit when it does not directly add value to the product and the customer?

How do you make sure that the customers' needs and wants at the end of the process become the beginning of the process and are prioritised into the right design elements for the production machines, equipment and raw materials? It is a big jump. What happens in between? How do you make it easy to produce on-target pipe and difficult to produce off-target pipe? A Win for the Customer, Pipe Manufacturer, Industry and the Environment.

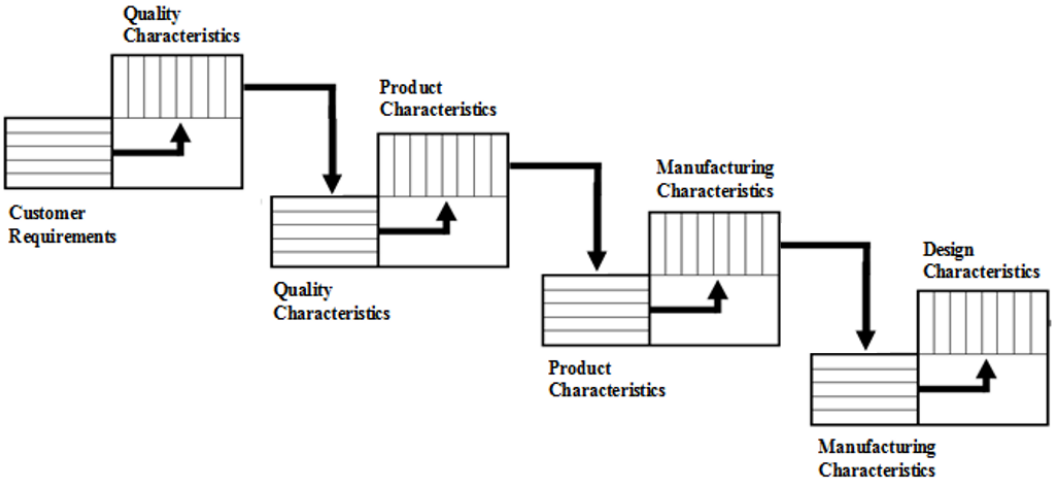


Figure 1: The Structure and Flow cascade of Quality Function Deployment (aka House of Quality)

Quality Function Deployment (QFD) [2] or "House of Quality" is a simple and powerful method to connect the full scope of Customer, Quality, Product, Process and Design requirements in a cascade flow. This gives best and predictable performance and product lifetime cost, highest confidence, lowest variation and least waste of resources.

You can see how the requirements are connected from finish to start: chained and correlated. There are no 'orphan" items, no special interest requirements, and only value adding activities. The correlation strength can be seen in the rectangular matrix – synergistic or antagonistic relationships. (see Figure 2). The overlap of similar characteristics can also be seen in the pyramid matrix often on top of the QFD chart but in this presentation - they are presented more clearly in simpler overlapping Venn diagrams. (see Figure 3).

OVERVIEW

Society, Customer Applications & Civil Engineering Pipeline designs have varied **Customer Demands** that must be converted into Pipe Specifications with the right Quality Characteristics.

End-use customer and engineering pipeline applications have demands that are designed from the Quality Characteristics. This is called Pipeline Design.

Quality Characteristics are described in Standards, Specifications, Industry Guides, Installation Manuals and Technical Notes. This is called PVC Pipe and Connector Design and Specification. This predicts pipeline performance and lifetimes.

Pipe Specifications must be converted into long-term & short-term Tests and International & National Standards that match Applications and help predict pipe lifetimes. The Application based Tests must be converted into Pipe Characteristics tests related to the way PVC pipes are formed and made.

The **Pipe Characteristics** need to be converted into the successful Extruder Processing variables and responses. These are derived from the basic physics and thermodynamic properties of Pressure, Temperature and Time. These properties become more specific as Shear Energy, Heat Energy, Output rate and Residence time.

The conversion of Pipe Characteristics into **Extrusion Control Characteristics**, variables & responses is called Process Optimisation. It is about manufacturing to the best practice.

The Extruder Control to convert PVC morphology, rheology and viscoelastic properties determines the **Extruder Design Characteristics** for Motor Power, Barrel/Screws, Head, Tooling and downstream cooling, forming, cutting, socketing and packaging equipment. The Screw Design (a heated pump) must achieve all processing, compounding, gelation, dispersion, and gas removal in its length. The Head & Spider Design must achieve a strong re-weld to complete the pipe integrity.

Formulation of minor additives, screw design, & processing must be a matching triad. Formulation and screw design maximise the optimum or best practice processing, give high process capability, wide 'windows', low variation, lowest economic impact and lowest use of energy resources.

Working this cascade forwards and backwards ensures focus on the activities and technology that delivers to the final end-customer with the best practice possible. The upward hierarchy is from uniform melt flow to gelation to pipe integrity to predictable lifetimes to a sustainable civilization.

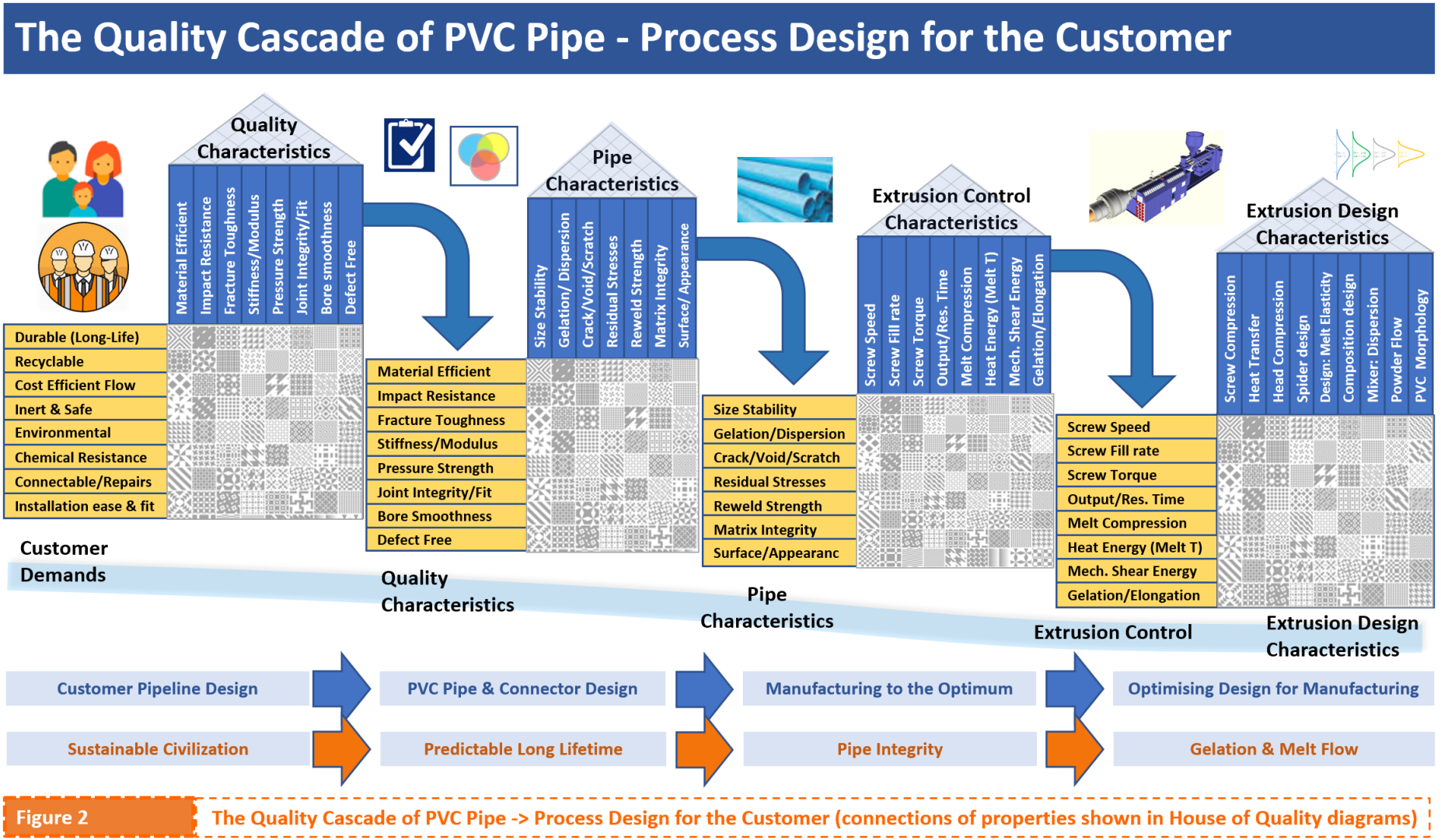


Figure 2 The Quality Cascade of PVC Pipe -> Process Design for the Customer (connections of properties shown in House of Quality diagrams)

The Quality Cascade of PVC Pipe - Process Design for the Customer

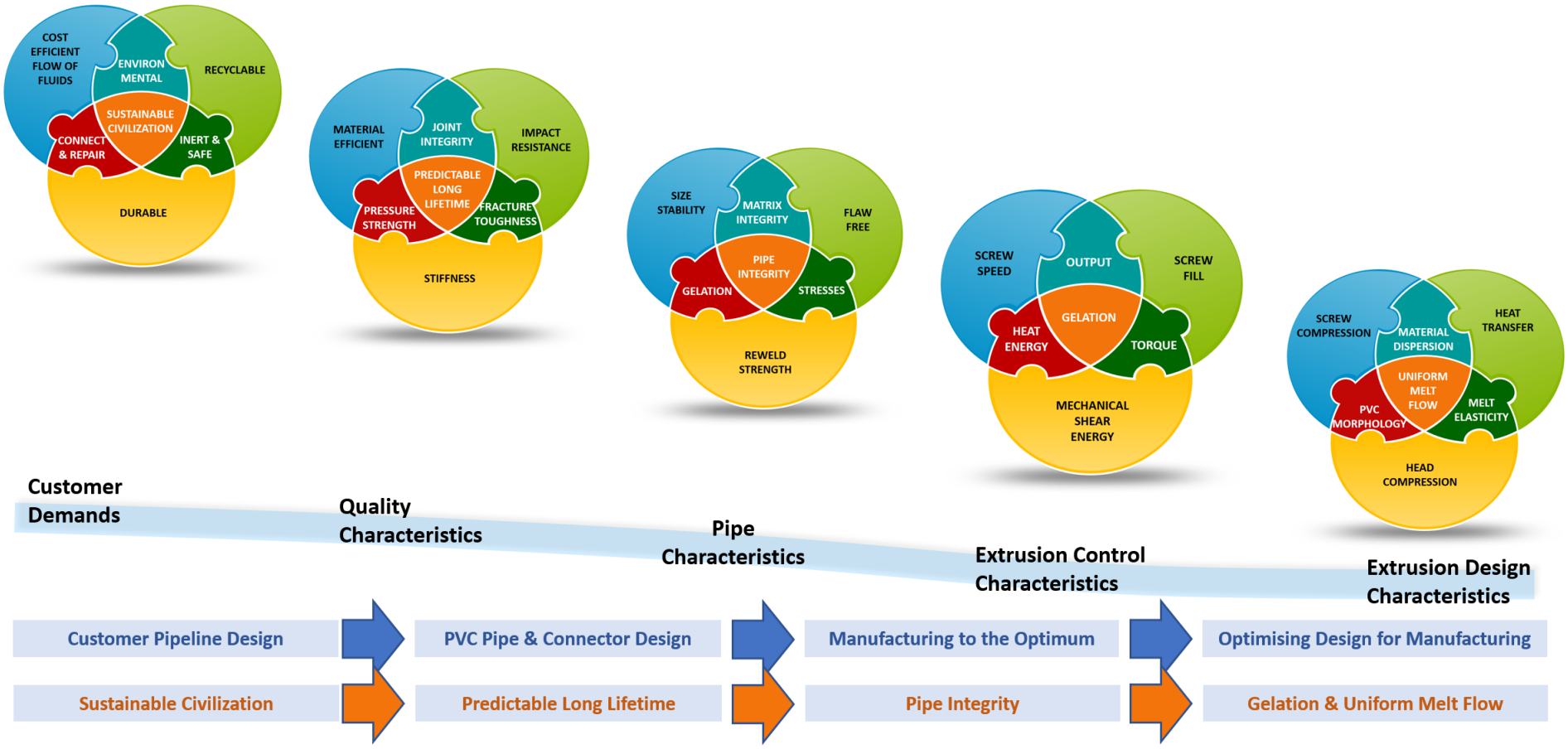


Figure 3 The Quality Cascade of PVC Pipe -> Process Design for the Customer (correlations of properties shown in Venn diagrams)

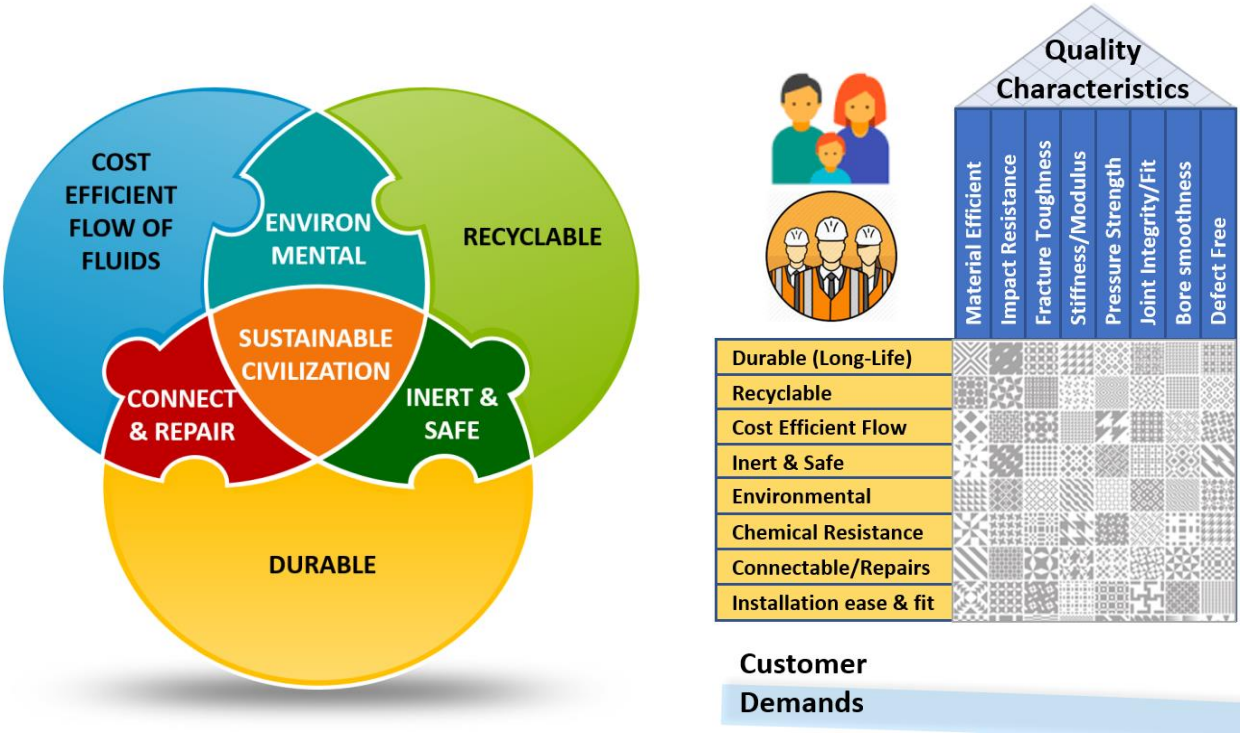
QUALITY DEPLOYMENT

A) CUSTOMER DEMANDS and REQUIREMENTS

Major pipeline applications like Buildings, Infrastructure, Irrigation, Mining and Industrial all demand quality, reliable pipelines with predictable lifetime performance and cost.

High performance pressure applications are predicted to last over 100 Years, are environmental, transport safe drinking water, have good hydraulic flow, and can be resistant to pressure cycling, resist soil loading, have good chemical resistance, are connectable to multiple systems, are repairable, and have ease of installation, and fit.

The inset Venn diagrams and House of Quality grids that follow in each section are meant to be read as integral with the text. The point of this type of chart is that it says shows connections and relationships much better than sentences and paragraphs – so please read them as 'text that does not stay in the lines'. Figures 2 & 3 contain all content of this article as one-page poster knowledge.



B) QUALITY CHARACTERISTICS

An understanding of required Quality Characteristics and material properties allows engineers and designers to correctly specify a product for a given customer application or demand. Material properties include physical properties such as density and molecular weight, electrical, thermal properties and mechanical properties. Mechanical properties, which are commonly measured using standard tests. They describe the reaction of a material to an applied load - this includes properties such as strength, ductility, impact strength and toughness.

These properties can be constant or can depend on one or more variables. Plastics materials are viscoelastic & have mechanical properties that are dependent on both loading time & temperature. Plastics pipes, which require long service lives, are designed based on their long term rather than their short term mechanical properties [3,4].

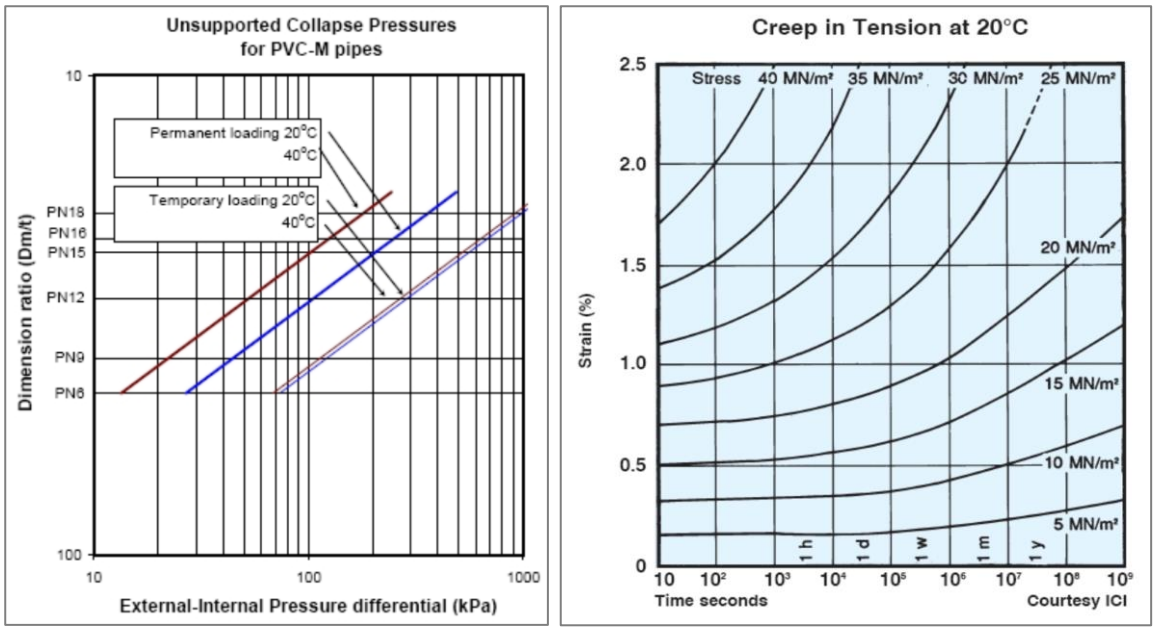
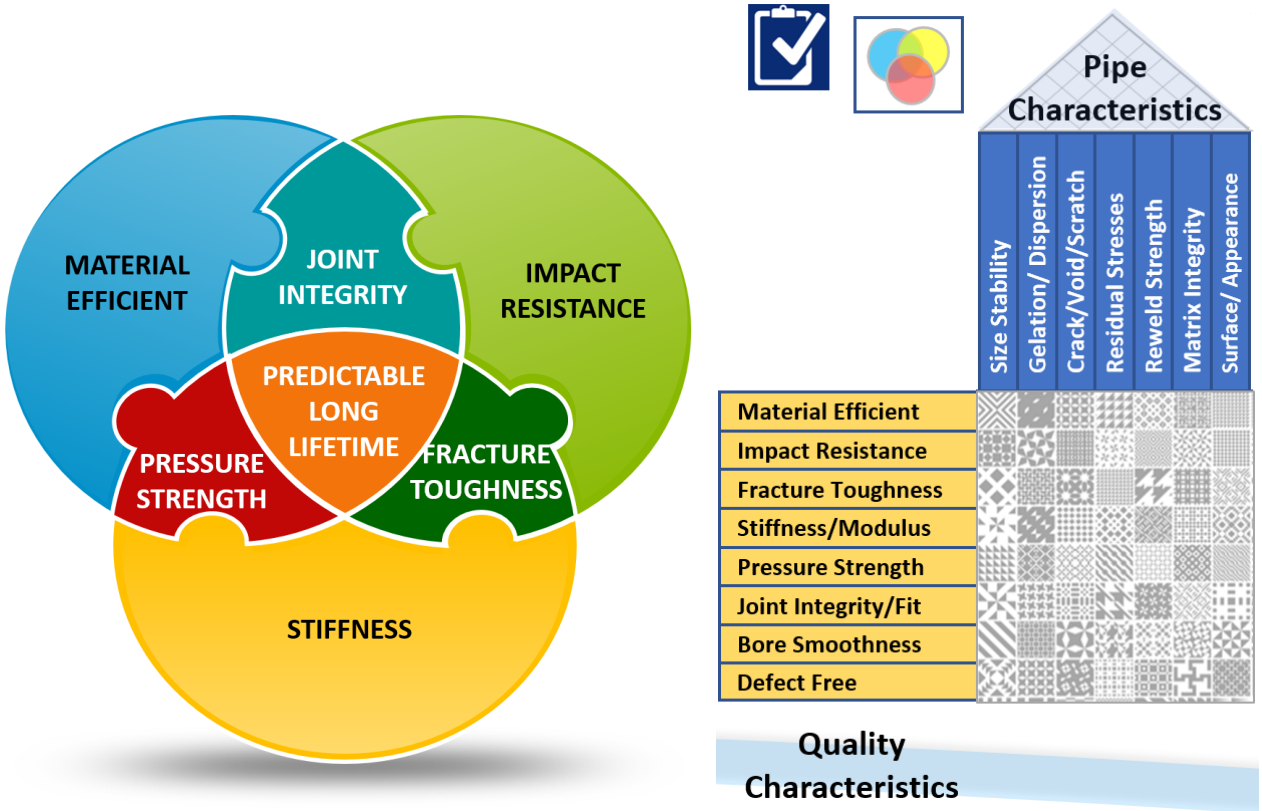


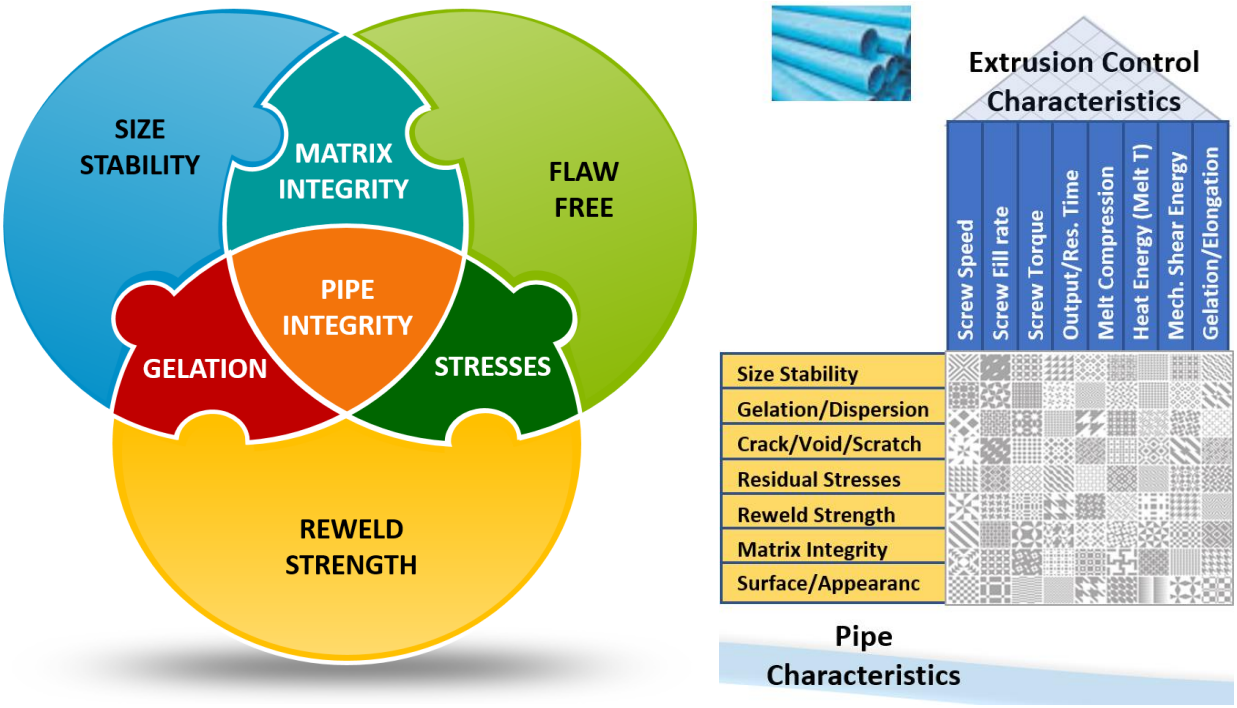
Figure 4: Two typical examples of Quality Characteristics [3]



Impact Resistance and Stiffness combine to form Fracture Toughness. A Material efficient pipe with high Impact Resistance needs Joint Integrity. A pipeline that is Material Efficient still needs Pressure Strength through orientation or Stiffness through structure.

Toughness, Pressure Resistance & Joint integrity makes pipelines with a predictable Long Lifetime.

C) PIPE CHARACTERISTICS



Quality characteristic tests like pressure resistance testing and impact resistance testing are rightly intended to correlate to service performance. Sometimes the tests are modified to accelerate time by using higher testing temperatures, pressure cycling or high velocity impact. They are excellent tests and secondary by nature of their testing combinations of the primary properties of Reweld strength, Flaws, Stresses, and Gelation.

The primary properties must be separated and measured directly so that the Extrusion Control correlated parameters can be determined accurately. This is the most efficient way to target optimum processing conditions that create the best Pipe Integrity. Different parts of the manufacturing process are important for these primary properties (like pipe Head for reweld strength, extruder screws for Gelation [7,8] and cooling for Stresses) although Gelation does affect melt elasticity which affects reweld relaxation time as PVC is more an elastic solid than a true melt.

It is made clearer and de-mystified when science is applied and the connections revealed, measured and controlled. Graphical techniques such as this reveal otherwise hidden connections, show where loosely understood items fit correctly and tightly, or highlight gaps in understanding that are sometimes the reason why outcomes and observations are not always predictable and need intuition and experience to make the leaps across the gaps.

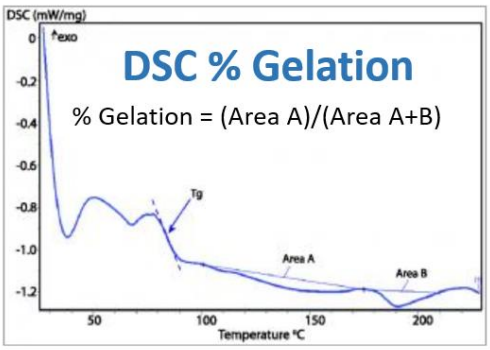


Figure 5: DSC Gelation measurement

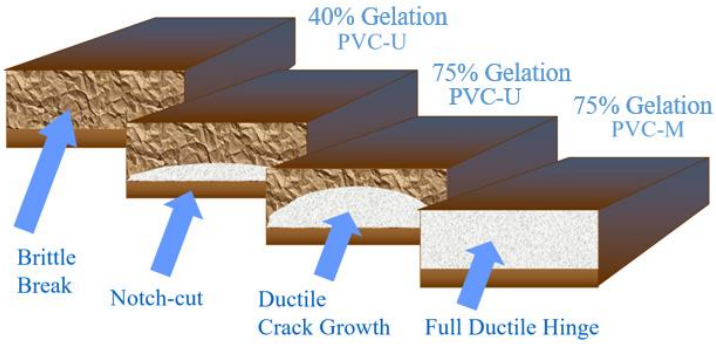
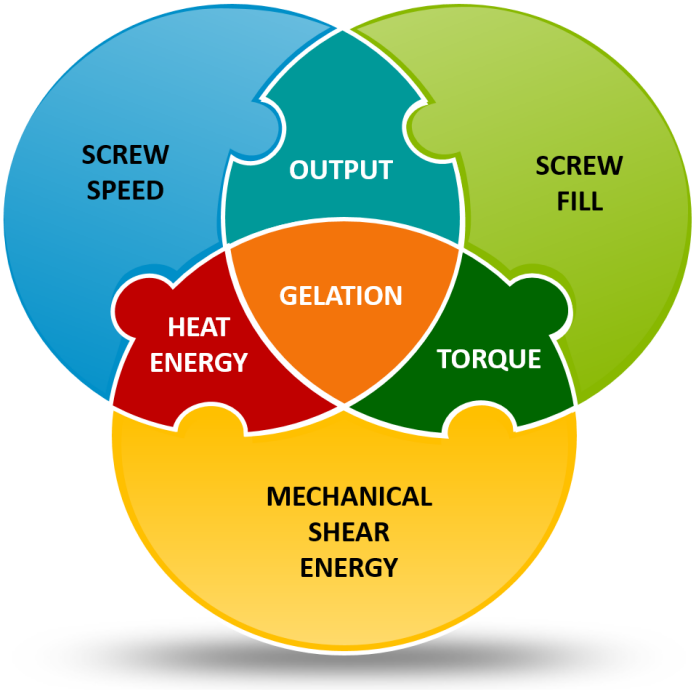
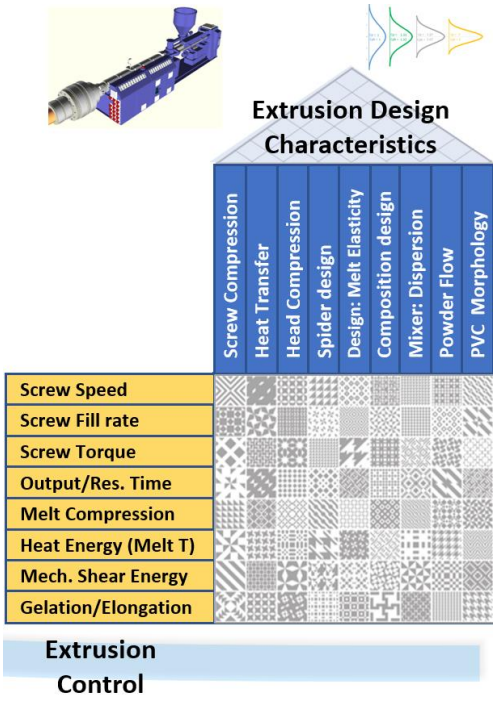


Figure 6: Fracture Toughness (crack resistance) measurement

D) EXTRUSION CONTROL CHARACTERISTICS





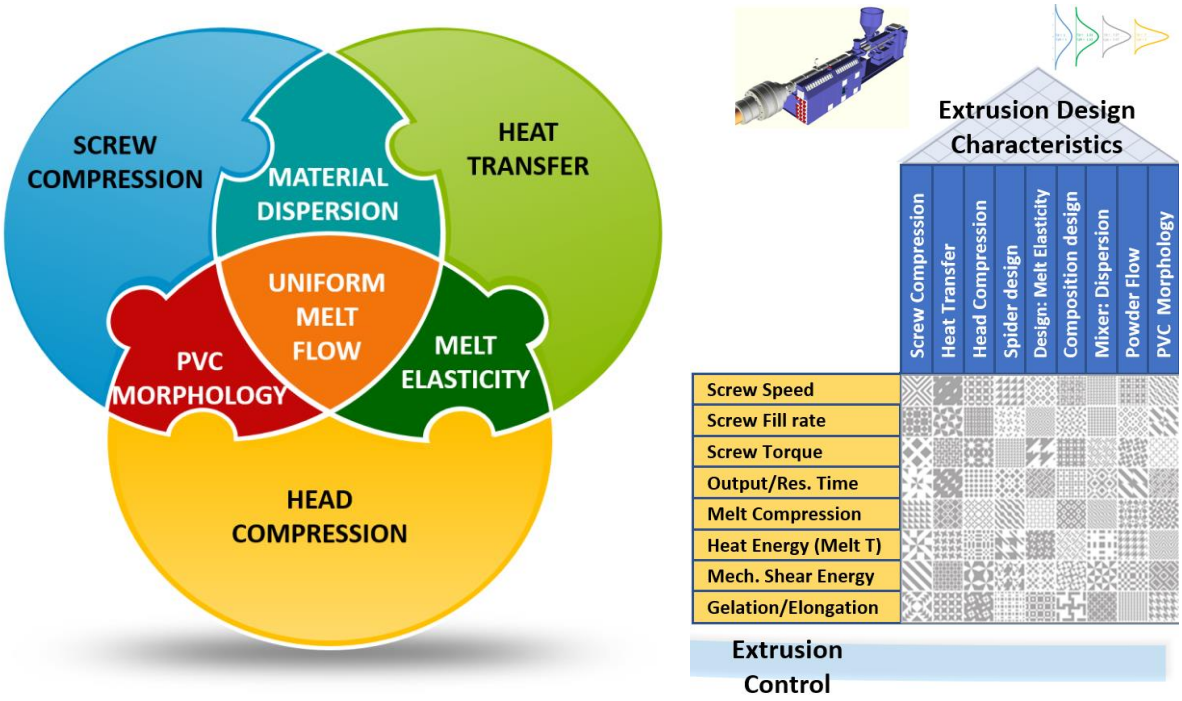
The Screw Speed and the Fill of the screw determine the Output.

The screw fill, mechanical Shear Energy and maximum installed motor Power determine the extruder motor Torque.

The Screw Speed and the mechanical Shear Energy fixes the balance of Heat Energy (melt temperature) required for the minimum Gelation.

The Gelation is the product of the Screw Speed, Screw Fill, Heat Energy and Shear Energy.

E) EXTRUSION DESIGN CHARACTERISTICS



The Screw Compression design and the Barrel & Screws Heat Transfer determines the Material Dispersion. The Heat Transfer and the Head Compression design determine the Melt Elasticity for good reweld. The Head Compression and Screw Compression design is related to the PVC Morphology and Elasticity. Uniform Melt Flow with low variation for consistent uniform properties with no burning is the product of Material Dispersion, Melt Elasticity and PVC Morphology.

SUMMARY

We all want a sustainable civilization with safe, clean water and efficiently transported energy. This can be cost efficiently delivered by PVC pipes and pipelines that are durable and designed to stay in service for a very long time. They are safe, inert, recyclable & can be material-efficient. The best practice is delivered when all the activities & technologies are tightly correlated from Society & Customers' demands of a sustainable civilization through the chain of Quality characteristics to give safe, long, predictable lifetimes - in the right PVC Pipe characteristics for Pipe Integrity - with Manufacturing Control to deliver the optimum processing gelation - using the targeted Designed equipment & material characteristics for needed melt flow. From the Voice of the Customer to the Ear of the Engineer and repeated back exactly.

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