

**DETERMINATION OF TENSILE STRENGTH OF  
POLYOXYMETHYLENE(CH<sub>2</sub>O)<sub>n</sub> REINFORCED WITH  
TITANIUM DIOXIDE**

*Thesis submitted to the Department of Mechanical Engineering in Partial fulfilment of the requirements for the Degree of B. Tech in Mechanical Engineering.*

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**ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES**

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SANGIVALASA, BHEEMUNIPATNAM MANDAL  
VISAKHAPATNAM (District) – 531162

(2018-2022)

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## CERTIFICATE

This is to certify that the thesis entitled “**DETERMINATION OF TENSILE STRENGTH OF POLYOXYMETHYLENE(CH<sub>2</sub>O)<sub>n</sub> REINFORCED WITH TITANIUM DIOXIDE(TiO<sub>2</sub>)**” is submitted by B.V.S.G.YASHWANTH, E.GANESH, M.RAKESH KUMAR, M.PRAVEEN, N.MANO HAR in the department of Mechanical engineering, ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES (ANITS) for the award the degree of B.Tech in Mechanical Engineering is a record of bonafide research work carried out under my supervision.

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## **ABSTRACT**

Components such as cams, brakes, bearings and gears because of their self-lubrication properties, lower friction, better wear resistance, low noise and cost. Polymers are associated with some inherent deficiencies which can be altered successfully by using various special fillers there by producing polymer composites. In recent years, polymers are extensively utilized in tribological ore and more polymer composites are now being used as sliding components, which were formerly composed only of metallic materials. Polymers used for fabrication of tribological components should have excellent friction and wear behaviour apart from having good mechanical properties. In the present work an attempt has been made to prepare composites by incorporating Titanium Nano particles in acetal copolymer which can act as self lubricant and also reduce the wear with counterpart material.

Titanium has Low Thermal Expansion. In addition to its high density and melting point, Titanium has the lowest coefficient of thermal expansion of all pure metals. This gives it the benefit of added stability under pressure of extreme heat compared to common manufacturing materials such as steel Titanium's extraordinarily high melting point makes it an excellent material for high temperature environments, hence why it is so widely used in the aerospace, automotive and construction industries – and in alloys and superalloys, making it suitable for more thermally intensive applications, where other metals would fail. Titanium also benefits from a higher density than the majority of other metals. Its density is 19.3 times that of water Titanium is an extremely robust metal with the highest tensile strength of all pure metals.

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# **CHAPTER-1**

## **INTRODUCTION TO COMPOSITE MATERIALS**

Composites are materials in which two phases are combined, usually with strong interfaces between them. They usually consist of a continuous phase called the matrix and discontinuous phase in the form of fibres, whiskers or particles called the reinforcement. Considerable interest in composites has been generated in the past because many of their properties can be described by a combination of the individual properties of the constituent phases and the volume fraction in the mixture.

Composite materials are gaining wide spread acceptance due to their characteristics of behaviour with their high strength to weight ratio. The interest in polymer matrix composites is due to the relation of structure to properties such as specific stiffness or specific strength.

Like all composites, acetyl co polymer matrix composites are not a single material but a family of materials whose stiffness, density and thermal and electrical properties can be tailored. Composite materials are high stiffness and high strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc.

The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

## **Classification of composites:**

Particulate composites consist of particles immersed in matrices such as alloys and ceramics. They are usually isotropic since the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature and oxidation resistance etc. Typical examples include use of aluminium particles in rubber, Titanium Dioxide particles in aluminium. Flake composites provide advantages such as high out of plane flexural modulus, higher strength, and low cost.

### **(a) Natural Composites**

Several natural materials can be grouped under natural composites. E.g. bones, wood, shells, pearlite (steel which is mixture of a phase FeC).

### **(b) Man-Made Composites**

Man-made composites are produced by combining two or more materials in definite proportions under controlled conditions. E.g. Mud mixed straw to produce stronger mud mortar and bricks, plywood, chipboards, Decorative laminates etc.

### **Matrix (Primary Phase)**

1. The selection of suitable matrix alloys is mainly determined by the intended application of the composite material.
2. For the development of light metal composite materials that are mostly easy to process, conventional light metal alloys are applied as matrix materials. Mainly Aluminium Alloy is used for Light weight Composites.
3. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together.
4. In structural applications, the matrix is usually a lighter metal such as Aluminium,

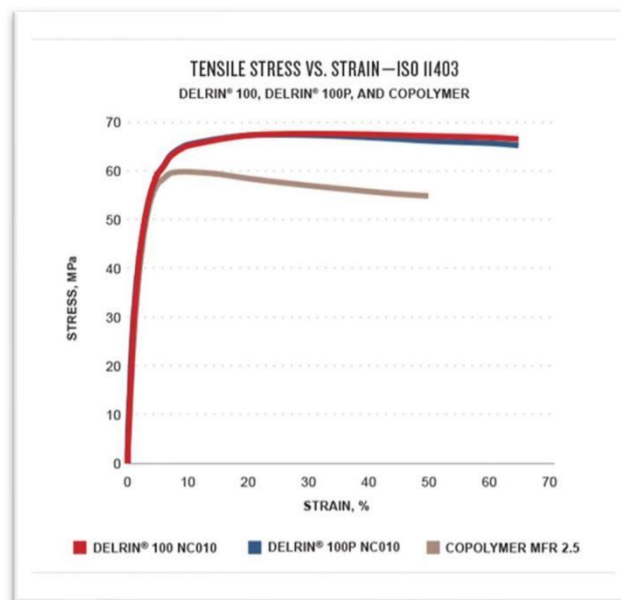
magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common.

### **ACETAL COPOLYMER:**

The Acetal copolymer have an excellent balance of properties and processing characteristics. Melting temperature can range from 360 to 450 F with little effect on part strength. The resin is available in natural translucent white color.

Properties: Acetal copolymer have high tensile and flexural strength, fatigue resistance, and hardness. Lubricity is excellent. They retain much of their toughness through a broad temperature range and are among the most creep resistant of the crystalline thermoplastics. Moisture absorption is low, permitting moulded parts to serve reliably in environments involving humidity changes.

Good electrical properties, combined with high mechanical strength and a UL electrical rating of 100 °C, qualify these materials for electrical applications requiring long term stability.



**Chart 1.1 :- Stress vs Strain graph comparing homo and co- polymer**

Acetal copolymers have excellent resistance to chemicals and solvents. Strength of acetal copolymer is only slightly reduced after aging for one year in air at 240 °F Impact strength holds constant for the first six months and falls off about one third during the next six months period. Aging in air at 180 °F for two years has little or no effect on properties.

### **Polymer Gear:**

A Polymer gear is a wheel with teeth on its surface designed to mesh with another gear or rack and manufactured by machining or an injection moulding process from any engineering thermoplastic polymer.

The materials include Nylon 6/6, Polyacetal, Polyphenylene sulphide, Thermoplastic polyester, long fiber reinforced plastic and liquid crystal polymers. Most plastic gears are made from nylon and acetal up to date they have been used only for gears under light loads, such as watch gears.

Typical polymers for gears are cast nylons, injection moulded nylons, polyester and acetal. Various fillers help to strengthen the base polymers such as glass and carbon fibre, aramid fibres and other additives are used to improve lubricity.

Polymer gears are common in many industries and applications. The advantages of a polymer gear include noise reduction, self lubricating features, dramatic weight reduction and cost savings. From paper mill gears to drive gears in copiers, polymer gears have been successfully used for years.

But everything you know about metal gear design gets thrown out the door with polymers. There are many different factors that have to be considered when designing gears out of plastics including thermal expansion and contraction, physical strength, moisture absorption and possible chemical exposure.

Typical polymers for gears are cast nylons, injection moulded nylons, polyester and acetal. Various fillers help to strengthen the base polymers such as glass and carbon fibre, aramid fibres and other additives are used to improve lubricity. More recently high end polymers like PEEK and Torlon have been used to make high temperature gears where exceptional strength is required.

### **Reinforcement (Secondary Phase):**

The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change Titanium dioxide properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques. Continuous reinforcement uses monofilament wires or Fiber such as carbon fiber or Titanium carbide.

Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement.

Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are nylon and Titanium dioxide.

**Examples:** of some current application of composites include the tires, diesel piston.

### **Titanium dioxide as reinforcement:**

Titanium dioxide is a chemical compound of Titanium and sulphur. It was originally produced by a high temperature reduction reaction of Titanium trioxide and hydrogen sulphide gas. Titanium dioxide is an excellent dry lubricant which exhibits similar structure of molybdenum disulphide. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractoriness, ceramics, and numerous high-performance applications.

The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Titanium dioxide is composed of tetrahedral of carbon and Titanium atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Titanium dioxide particles are shown in Figure:



**Figure1.1 : Titanium Dioxide.**

**Properties of Titanium Dioxide:-**

- High density
- High strength
- Low thermal expansion
- High thermal conductivity
- High hardness
- High elastic modulus
- Excellent thermal shock resistance
- Superior chemical inertness

**Properties of Titanium Dioxide:-**

Product	Titanium Dioxide
APS	30-50 nm
Purity	99.9 %
Molecular Formula	$TiO_2$
Molecular Weight	79.866 g/mol
Form	Powder

Density	4.23g/cm <sup>3</sup>
Melting Point	1843 °C
Solubility	Insoluble in Water

**Tensile Strength:**

Tensile properties dictate how the material will react to forces being applied in tension. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance.

Tensile tests are used to determine the modulus of elasticity, elastic limit elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties. The main product of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the engineering stress and the engineering strain are obtained by dividing the load and elongation by constant values (specimen geometry information), the load- elongation curve will have the same shape as the engineering stress-strain curve.

The stress-strain curve relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. A typical engineering stress-strain curve is shown below Figure 1.18. If the true stress, based on the actual cross-sectional area of the specimen, is used, it is found that the stress-strain curve increases continuously up for to fracture. They are tabulated for common materials such as alloys, composite materials, ceramics, plastics, and wood. Tensile strength is defined as a stress, which is measured as force per unit area.

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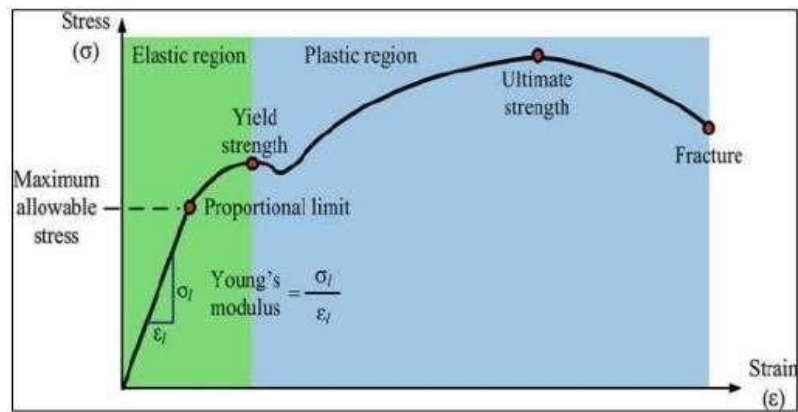


Figure: Stress Strain Curve of Ductile Material

## **Yield Point:**

In ductile materials, at some point, the stress-strain curve deviates from the straight-linear relationship and Law no longer applies as the strain increases faster than the stress. From this point on in the tensile test, some permanent deformation occurs in the specimen and the material is said to react plastically to any further increase in load or stress.

The material will not return to its original, unstressed condition when the load is removed. In brittle materials, little or no plastic deformation occurs and the material fractures near the end of the linear-elastic portion of the curve. With most materials there is a gradual transition from elastic to plastic behavior, and the exact point at which plastic deformation begins to occur is hard to determine. Therefore, various criteria for the initiation of yielding are used depending on the sensitivity of the strain measurements and the intended use of the data.

For most engineering design and specification applications, the yield strength is used. The yield strength is defined as the stress required producing a small, amount of plastic deformation. The offset yield strength is the stress corresponding to the intersection of the stress-strain curve and a line parallel to the elastic part of the curve offset by a specified strain (in the US the offset is typically 0.2% for metals and 2% for plastics). To determine the yield strength using this offset, the point is found on the strain axis (xaxis) of 0.002, and then a line parallel to the stress-strain line is drawn. This line will intersect the stress-strain line slightly after it begins to curve, and that intersection is defined as the yield strength with a 0.2% offset. A good way of looking at offset yield strength is that after a specimen has been loaded to its 0.2 percent offset yield strength and then unloaded it will be 0.2 percent



longer than before the test. Even though the yield strength is meant to represent the exact point at which the material becomes permanently deformed, 0.2% elongation is considered to be a tolerable amount of sacrifice for the ease it creates in defining the yield strength. Some materials such as gray cast iron or soft copper exhibit essentially no linear-elastic behavior. For these materials the usual practice is to define the yield strength as the stress required to produce some total amount of strain.

- True elastic limit is a very low value and is related to the motion of a few hundred dislocations. Micro strain measurements are required to detect strain on order of  $2 \times 10^{-6}$  in/in.
- Proportional limit is the highest stress at which stress is directly proportional to strain. It is obtained by observing the deviation from the straight-line portion of the stress-strain curve.
- Elastic limit is the greatest stress the material can withstand without any measurable permanent strain remaining on the complete release of load. It is determined using a tedious incremental loading-unloading test procedure. With the sensitivity of strain measurements usually employed in engineering studies ( $10^{-4}$  in/in), the elastic limit is greater than the proportional limit. With increasing sensitivity of strain measurement, the value of the elastic limit decreases until it eventually equals the true elastic limit determined from micro strain measurements.
- Yield strength is the stress required to produce a small-specified amount of plastic deformation. The yield strength obtained by an offset method is commonly used for engineering purposes because it avoids the practical difficulties of measuring the elastic limit or proportional limit.

### **Ultimate Tensile Strength:**

The ultimate tensile strength (UTS) or, more simply, the tensile strength, is the maximum engineering stress level reached in a tension test. The strength of a material is its ability to withstand external forces without breaking. In brittle materials, the UTS will at the end of the linear-elastic portion of the stress-strain curve

or close to the elastic limit. In ductile materials, the UTS will be well outside of the elastic portion into the plastic portion of the stress-strain curve.

On the stress-strain curve above, the UTS is the highest point where the line is momentarily flat. Since the UTS is based on the engineering stress, it is often not the same as the breaking strength. In ductile materials strain hardening occurs and the stress will continue to increase until fracture occurs, but the engineering stress-strain curve may show a decline in the stress level before fracture occurs. This is the result of engineering stress being based on the original cross-section area and not accounting for the necking that commonly occurs in the test specimen. The UTS may not be completely representative of the highest level of stress that a material can support, but the value is not typically used in the design of components anyway. For ductile metals the current design practice is to use the yield strength for sizing static components. However, since the UTS is easy to determine and quite reproducible, it is useful for the purposes of specifying a material and for quality control purposes. On the other hand, for brittle materials the design of a component may be based on the tensile strength of the material.

### **Measures of Ductility (Elongation and Reduction of Area):**

The ductility of a material is a measure of the extent to which a material will deform before fracture. The amount of ductility is an important factor when considering forming operations such as rolling and extrusion. It also provides an indication of how visible overload damage to a component might become before the component fractures. Ductility is also used as a quality control measure to assess the level of impurities and proper processing of a material. The conventional measures of ductility are the engineering strain at fracture (usually called the elongation) and the reduction of area at fracture. Both of these properties are obtained by fitting the specimen back together after fracture and measuring the change in length and cross-sectional area.

Elongation is the change in axial length divided by the original length of the specimen or portion of the specimen. It is expressed as a percentage. Because an appreciable fraction of the plastic deformation will be concentrated in the necked

region of the tensile specimen, the value of elongation will depend on the gage length over which the measurement is taken. The smaller the gage length the greater the large localized strain in the necked region will factor into the calculation. Therefore, when reporting values of elongation, the gage length should be given. One way to avoid the complication from necking is to base the elongation measurement on the uniform strain out to the point at which necking begins.

This works well at times but some engineering stress-strain curve are often quite flat in the vicinity of maximum loading and it is difficult to precisely establish the strain when necking starts to occur. Reduction of area is the change in cross-sectional area divided by the original cross-sectional area. This change is measured in the necked down region of the specimen. Like elongation, it is usually expressed as a percentage.

Polymer nanocomposites are produced by incorporating materials that have one or more dimensions on the nanometer scale (<100 nm) into a polymer matrix. These nanomaterials can be nano fillers, nanoparticles, nanoscale building blocks or nano reinforcements. The incorporation of nanomaterials into polymers is an attractive approach because it enables the creation of materials with new or improved properties by mixing multiple constituents and exploiting synergistic effects. In many cases, the stiffness, strength, toughness, thermal stability, barrier properties and flame retardancy of polymer matrix have been improved by the presence of nanoparticles. Nano reinforcements are also unique that they will not affect the clarity of the polymer matrix. Only a small content of these nanomaterials are normally incorporated (1–10 wt. %) into the polymer and the improvement is vast due to their large degree of surface area. As a consequence of their high specific surface area and energy, nanoparticles usually have a strong tendency for aggregation, which makes it difficult to homogeneously disperse them in polymeric hosts. When this happens, the creation of the nanocomposite is unsuccessful. When using clay fillers, it is necessary to separate the particles into the right shape and layer structure called “exfoliation”.

In the case of the promising carbon nanotube nano reinforcements, the main approach to solve this problem is through surface functionalization (i.e. covalent

and non-covalent pre-treatments), which mediates particle–particle and particle–polymer interactions and significantly influences nanoparticle dispersion. New strategies such as the dispersion of inorganic fullerene-like materials (IF) open up new opportunities to prepare stronger, lighter polymeric materials without the complexity and processing cost associated with exfoliation and modification. The revolutionary properties of inorganic fullerene-like nanoparticles (E.g. Titanium dioxide, IF- TiO<sub>2</sub>), such as high modulus and low friction coefficient, attributed to their small size, closed structure and chemical inertness, make them potential candidates to improve the thermal, mechanical and tribological properties of thermoplastic polymers without using modifiers or surfactants (e.g. isotactic polypropylene, and polyphenylene sulphide). Fullerene-like nanoparticles have been shown to exhibit excellent solid lubrication behaviour, suggesting many applications, for example, in the automotive and aerospace industries, home appliances, and recently for medical technology. Numerous development programmes are in progress, some of them at a very advanced stage or even having made products. The first medical application (E.g. alleviating friction in orthodontic wires) was recently demonstrated, with numerous others to follow. These findings open up vast opportunities for various potential applications in the field of polymer nanocomposites. More recently, we have successfully prepared new melt-processable formulation based on high performance poly ether ether ketone (PEEK) and IF- TiO<sub>2</sub>. In particular, the overall thermal and mechanical performances have confirmed the potential use of IF- TiO<sub>2</sub> for the preparation of advanced PEEK nanocomposites as lightweight alternative for use in critical industrial applications, particularly for the aircraft industry. Polyamide-6,6 (nylon-6,6) is an important semicrystalline polymer which is used in many engineering products, such as fibres, films and various moulding articles. Toyota group first explored the synthetic strategy and molecular design in acetal co polymer based nano-composites. The dispersed montmorillonite (MMT) particles in the have some contribution to enhance the nucleation (i.e. nucleating agents)

## CHAPTER-2

### PREHEATING AND BLENDING

#### PREHEATING PROCESS:

Usually, the plastic materials are formed in the shape of granules and sent from the raw material manufacturers in paper polythene bags, etc.

Since these granules might have absorbed the moisture in the atmosphere, if they are used for injection moulding while they still contain a lot of moisture, depending on the type of material, they can undergo hydrolysis, or their physical properties can change. Further, it is possible for silver streaks to appear on the surface of the moulded product, and it is also possible for short shots or burn due to gas to occur.



**Figure 2.1: acetyl co-polymer (pom-c granules )**

In view of this, in the case of most moulding materials, before they are put into the hopper drier, it is necessary to carry out pre-drying in a box type drying oven.

In pre-drying it is recommended to observe the appropriate drying temperature and drying time. This is because, if the drying is done at a temperature less than the

appropriate temperature, even if the drying is done for a long time, the moisture content cannot be removed as desired. A material whose pre-drying has been completed should be used as quickly as possible. When any leftover material is to be used some days later, carry out its pre-drying again before use.



**Figure 2.2: Thermostatically controlled ovens used to preheat acetyl copolymer at its softening temperature of 80°C for about 24 hours**

Granules of plastic moulding materials generally absorb moisture from the atmosphere to a certain extent. If the quantity of absorbed moisture is large, the plastic can undergo hydrolysis (there are plastics that undergo chemical dissociation with water as the initiator) in the process of being melted and mixed in the cylinder of the injection moulding machine, or, when moulding is done, this can cause silver streaks, air bubbles, or glossiness defects on the surface of the moulded product, or can cause copying defects, etc. Therefore, it is necessary beforehand to put the granules of moulding materials in a drying apparatus and remove the moisture content in them. If the pre-drying is not done appropriately, it can lead to variations in the fluidity, deterioration of physical characteristics, and moulding defects.

The pure acetyl copolymer is preheated using thermo statically controlled ovens for 24 hrs and at a working temperature of 80°C before use, to minimize the effects of any moisture and gases that are present. After cooling down of the material, air tight packing is done to ensure the prevention of moisture absorption.

### **EXTRUSION PROCESS:**

Extrusion is a high volume manufacturing process. The plastic material is melted with the application of heat and extruded through die into a desired shape. A helical rotating screw is placed inside material is then mixed with the IF – TiO<sub>2</sub> in batches in different compositions



**Figure 2.3: Titanium Dioxide ( IF – TiO<sub>2</sub> ) supplied in air tight plastic container**

## **Working Principle:**

In this process, plastic material in the form of pellets or granules is gravity fed from a top mounted hopper into the barrel. Additives such as colorants and ultraviolet inhibitors (liquid or pellet form) can be mixed in the hopper. The plastic material enters through the feed throat and comes into contact with the rotating screw. The rotating screw pushes the plastic beads forward into the barrel. The barrel is heated using the heating elements up to the melting temperature of the plastic. The heating elements are used in such ways that gradually increase the temperature of the barrel from the rear to the front. There are three possible zones in a rotating screw i.e. feed zone, melting zone, and metering zone. In the feed zone, the plastic beads melt gradually as they are pushed through the barrel.



**Figure 2.4: Twin Screw Extruder fitted with circular die powered by servo motors operated at 175°C with a rotor speed of 100 rpm for 5 minutes.**

The plastic material is completely melted in the melting zone. A thermostat is used to maintain the inside temperature of the barrel. The overheating of plastics should be minimized which may cause degradation in the material properties. A cooling fan or water cooling system is used to maintain the temperature of the barrel during the process. At the front of the barrel, the molten plastic leaves the screw and travels through a screen pack to remove any contaminants in the molten plastic. The screens are reinforced by a breaker plate.



The breaker plate assembly also serves to create back pressure in the barrel. The back pressure gives uniform melting and proper mixing of the molten plastic material into the barrel. After passing through the breaker plate, molten plastic enters into die. The die gives the desired shape of plastic product. An uneven flow of molten plastic would produce unwanted stresses in the plastic product. These stresses can cause warping after solidification of molten plastic. Plastics are very good thermal insulators and therefore it is very difficult to cool quickly. The plastic product is cooled by pulling through a set of cooling rolls.

There are five important process parameters to be considered before extrusion process:

- Melting temperature of plastic
- Speed of the screw
- Extrusion pressure required
- Type of die used
- Cooling medium

Several compositions of IF-  $\text{TiO}_2$  (0.1, 0.5, 1.0 and 2.0 wt. %) were introduced in the nylon-6, 6 matrix by using vertical screw type extruder. The extruder is allowed to reach slightly above the melting temperature of nylon-6, 6 i.e.,  $265^\circ\text{C}$  & a rotor speed of 100 rpm for 5 mins, to ensure the uniform dispersion of  $\text{TiO}_2$  in the polymer matrix.

The blended mixture that is coming out from the extruder is cooled down by passing it through water for solidification, the composite obtained in the form of wires are fed directly into a grinder that is set at a rpm of the extruder (100 rpm) to obtain



pellets of the composite by grinding.

**Figure 2.5: Grinding or chipping machine for chipping the extruded.**

Care is taken to make sure that the temperature is no much greater than the melting temperature of acetyl co polymer as it might effect the crystallography of the material.

The extruded material is then chipped using grinder fitted with blades on rotor and is driven by a servo motor and belt drive mechanism. The speed of the driver ( i.e., servo motor ) is set such that the feed rate of the extruded wires is optimal to obtain correct or suitable chip size for further processing i.e., injection moulding. The chipped material looks dry as it is extruded hot and has to be pre heated again before injection moulding.

POM-C drastically obesrves 2% by weight of moisture on exposure of 12 – 16 hours to the environment

## **CHAPTER-3**

### **PREHEATING PROCESS:-**

After the process of blending and grinding, the process of preheating is carried. Heating of composite materials is done by placing the materials in the thermostatically controlled ovens at a temperature of 60°C up to 24 hours. The main objective of the preheating process is to remove the moisture content present in the composite materials.

Care should be taken while inserting the material into the oven. Temperature of the oven is set as 60°C and material is placed in the oven. After heating of the material for about 24 hrs the material is taken out and packed in the polythene covers and placed them properly such that moisture would not enter into the bag.

### **INJECTION MOULDING:-**

Injection Moulding is a high production process of producing a vast variety of thermoplastic parts into shapes ranging from fairly simple to quite complex. Injection mould cavities are fed with melted plastic material that is forced under high pressure through a sprue, which feeds a runner system, then through a gate into the cavity. The material is then cooled to the point that the material is solid and then ejected from the mould as a finished part. Certain thermoset materials can also be injection moulded after several modifications to the standard injection moulding machine are affected. Injection moulding along with extrusion ranks as one of the prime processes for producing plastic articles. It is a fast process and is used to produce large numbers of identical items from high precision engineering components to disposable consumer goods.

Most thermoplastics can be processed by injection moulding; the most common materials used include:

- Acrylonitrile-Butadiene-Styrene ABS

- Nylon PA
- Polycarbonate PC
- Polypropylene PP

**Working Principle:-**

Material granules for the part is fed via a hopper into a heated barrel, melted using heater bands and the frictional action of a reciprocating screw barrel. The plastic is then injection through a nozzle into a mould cavity where it cools and hardens to the configuration of the cavity. The mould tool is mounted on a moveable platen when the part has solidified, the platen opens and the part is ejected out using ejector pins. After a product is designed, usually by an industrial designer or an engineer, moulds are made by a mould maker (or toolmaker) from metal, usually either steel or aluminium, and precision-machined to form the features of the desired part.

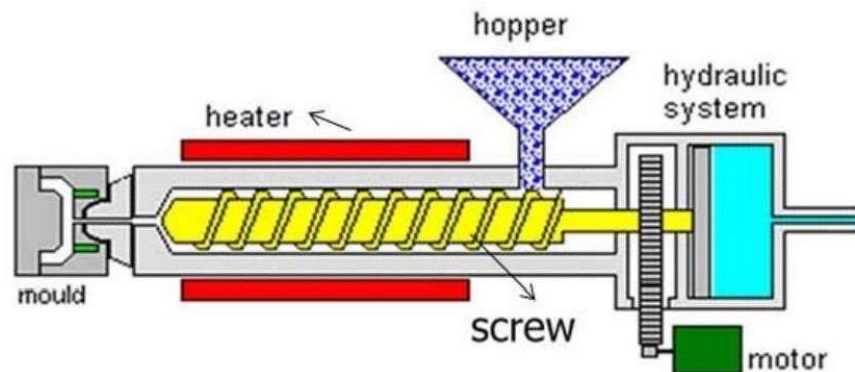
Injection mouldings count for a significant proportion of all plastics products from micro parts to large components such as car bumpers and wheelie bins. Virtually all sectors of manufacturing use injection moulded parts. The flexibility in size and shape possible through use of this process has consistently extended the boundaries of design in plastics and enabled significant replacement of traditional materials thanks to light weight and design freedom.

Plastic injection moulding or injection moulding Machine is to make require shape by using mould include high pressurized Melton Plastic metal. The Melton plastic may be as thermoplastic Material and inject to image cavity part (Mould or Die) to take small time and product released by using ejector pin



**FIGURE 3.1:- Tensile and Flexural specimens' mould fastened to machine for producing the tensile and flexural specimens ( mould with ejector pins in original position )**

Metals like polystyrene, nylon, polypropylene and polythene are typically used in this process. The material is stored in the hopper Part and is passed to Archimedes Screw. Now Screw Part is Rotate by using electric Motor or Hydraulic Drive.



**Figure 3.2 : Typical sketch of Injection Moulding system.**

The metals are heated by using Heater Bands to raise the minimum temperature at 150°C and Maximum temperature at 370°C typically. So, the Solid Metal will be converted to molten metal. The Archimedes Screw is periodically rotated and then molten metal pressure is increased and send to mould section.

The mould part having two part, one is fixed another one is movable. The metal inserts in this image cavity (Required shape of the product) and cool the product to take small time. After the product released by using ejector pin.Repeat the process continuously to increase the mass production for same shape.

Type of machine used is “**VERTICAL SCREW TYPE INJECTION MOULDING MACHINE**”.



**Figure 3.3 : Vertical screw type injection moulding machine with Tensile specimens' mould fixed to it.**

Injection moulding machine moulds can be fastened in either a horizontal or vertical position. The three main parts of the machine are SCREW MOTOR DRIVE, RECIPROCATING BARRELS, HEATERS AND THERMOCOUPLES.

Injection moulding is a process of producing parts by pouring molten material into the mould. Material of the part is feed into the heated barrel and injected into the mould cavity where it is cooled and hardened to required shape of the design. Care should be taken between the time gap given to the material for hardened. Different types shapes or patterns can be performed by changing the mould or die attached to the machine. Place the composite material in the hopper after the post heating process. The thermocouples are set to a temperature of 175°C and raised. After the required temperature is reached the composite material is sent into the pallet and molten with the same temperature. The molten metal is pressurised and sent inside the mould cavity and left 45 seconds for the material to be hardened. The specimens are ejected off the mould with the help of ejector pins placed to the mould.

## CHAPTER 4

### EVALUATION OF MECHANICAL PROPERTY

Tests were performed to evaluate various mechanical properties of acetal co-polymer / IF – TIO<sub>2</sub> nano composite. The samples produced in injection moulding are cross checked to ensure no flaws. To evaluate tensile strength, young's modulus of the material, flexural strength and the reaction of the material of the same loads respectively, and wear of the material, we have performed the tests.

1. To perform ASTM D638, begin by cutting your material into a “dogbone” sample.
2. Load the sample into a pair of tensile grips and attach your extensometer (if required).
3. The speed at which you separate your tensile grips depends on the shape of the specimen and can range from 0.05-20 inches per minute. End the test at sample break (rupture).

#### **Calculations:**

- Tensile Strength
- Elongation at Yield
- Elongation at Break
- Nominal Strain at Break (Grip Separation)
- Modulus of Elasticity
- Secant Modulus
- Poisson's Ratio (Requires Transverse Extensometer)

#### **STANDARDS:**

There are five allowable specimen types for ASTM D638 which differ in size depending on the thickness of the specimen and the amount of material available. The most commonly used are Type I specimens, which are 3.2 mm thick and are generally created by injection moulding. Type I specimens have an overall length of 165 mm and width of 13 mm, with a gauge length of 50 mm. Flat specimens



are typically moulded, die-cut, or machined into a “dogbone” or “dumbbell” shape, which ensures that the break occurs in the center of the specimen rather than at the clamping areas. In addition to flat specimens, ASTM D638 also allows for the testing of rigid tubes and rods, both of which must also be machined into a dogbone shape.

#### **SPECIMEN MEASUREMENT :**

- All specimens must be measured before testing in accordance with ASTM D5947. Most typical micrometers should be suitable for performing these measurements. For the test system to display Stress measurements rather than just Force measurements, operators will be asked to input the cross-sectional area (or thickness and width) of the specimen, because  $\text{Stress} = \text{Force} / \text{Cross-Sectional Area}$  (this is shown in units of Psi, Pa, kPa, GPa, etc).
- Die-cut or machined samples need to be measured individually, but operators using injection moulded specimens only need to measure a single sample from a sample lot providing the variation in that sample lot is proven to be less than 1%. Injection moulded specimens are often produced with a draft angle instead of being perfectly square, which must be taken into consideration when measuring the specimen. Always make sure that width measurements are taken at the center of the draft angle.

The Automatic specimen measuring device feature in Blue hill Universal allows operators to connect up to two micro meters or measurement devices to the computer and input the data directly into the software. This eliminates the chances of input errors and increases efficiency.

#### **MATERIALS TESTING SYSTEM:**

Most ASTM D638 testing is performed on a table top universal testing machine. A 5 KN or 10 KN (1125 or 2250 lbf) system is most common, but as reinforced plastics and composites increase in strength, higher capacity units – such as 30 KN or 50 KN systems - may be required.

## **GRIPS:**

It is important that specimens are held securely inside of the tensile machine. Side action pneumatic grips with serrated jaw faces are often the best grips for holding rigid plastics. With pneumatic grips, the gripping force is maintained by air pressure, which remains constant even if the specimen thickness changes significantly during the test. For forces above 10 KN, typically only found with reinforced materials, manual wedge action grips are preferred.

## **Specimen alignment:**

In order to test properly, specimens must be held perpendicular to the jaw faces and not tilted on an angle. Specimen misalignment can cause major variations in results, and proper care should be taken to ensure that the specimens are all aligned consistently for each test.

One way of addressing misalignment is by using a jaw face that is close to the same width as your specimen, making it relatively easy to visually adjust alignment. But the easiest way to prevent misalignment is to use a specimen alignment device which mounts directly onto the grip bodies. This is a simple bar that provides an adjustable stopping point so operators can easily tell that their specimen has been aligned correctly.

When the grips are tightened onto the plastic specimens in preparation for running a test, unwanted compressive forces are frequently applied. These forces, although minute, can interfere with test results if not treated properly: It is important that they not be balanced after the specimen is inserted, as this will cause an offset in results. Blue hill Universal software can be programmed to normalize forces across multiple specimens and remove any slack or compressive force, ensuring consistent results between specimens. On the 5900 series universal testing machines, we also recommend the use of specimen protect , which is designed to prevent damage to the specimen or system during the set-up phase of a test, before a test's operational limits are defined. When turned on, Specimen Protect automatically adjusts the cross head to keep any unwanted forces under a certain limit.



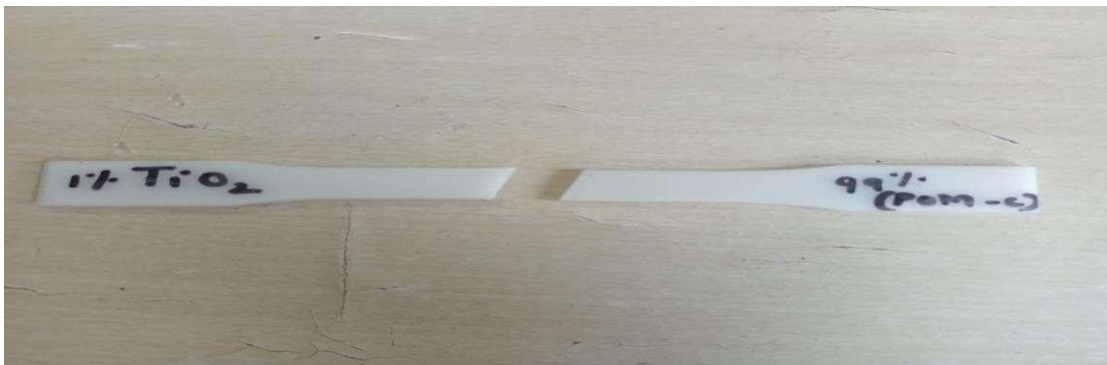
**Fig 4.1:-Universal testing machine(UTM) for performing tensile test on the specimen**



**Fig 4.2 :- sample tensile test specimen after injection moulding**



**Fig 4.3 :- Tensile test sample at the beginning of the test.**



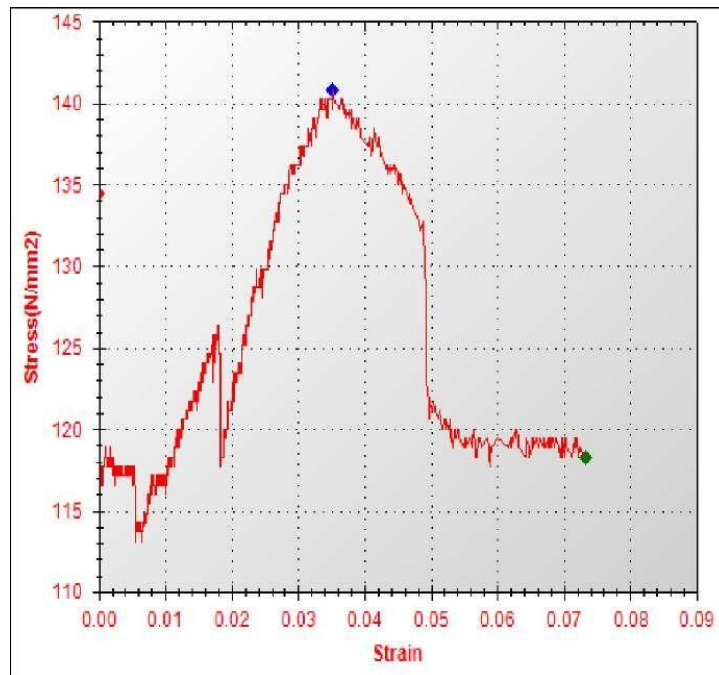
**Fig 4.4: Specimen after the test ( 99% wt POM-C, 1% wt TiO<sub>2</sub>)**

<b>Specimen shape</b>	<b>Flat</b>
<b>Specimen type</b>	<b>Acetyl co polymer</b>
<b>Specimen description</b>	<b>99% pom-c ,1%TiO2</b>
<b>Specimen width</b>	<b>13mm</b>
<b>Specimen thickness</b>	<b>4mm</b>
<b>Initial G.L for elong</b>	<b>115mm</b>
<b>Pre load value</b>	<b>0KN</b>
<b>Maxx load</b>	<b>600KN</b>
<b>Max. elongation</b>	<b>200mm</b>
<b>Specimen cross section area</b>	<b>52mm<sup>2</sup></b>
<b>Final specimen width</b>	<b>10 MM</b>
<b>Final specimen thickness</b>	<b>3mm</b>
<b>Final gauge length</b>	<b>124mm</b>
<b>Final area</b>	<b>30mm<sup>2</sup></b>

**Input table**

<b>Load at yeild</b>	<b>6.69KN</b>
<b>Elongation at yeild</b>	<b>0.00N</b>
<b>Yeild stress</b>	<b>128.654N/mm<sup>2</sup></b>
<b>Elongation at peak</b>	<b>4.000mm</b>
<b>Load at peak</b>	<b>7.320 KN</b>
<b>Tensile strength</b>	<b>140.789N/MM<sup>2</sup></b>
<b>Load at break</b>	<b>6.150KN</b>
<b>Elongation at break</b>	<b>8.430mm</b>
<b>Breaking strength</b>	<b>118.269 N/mm<sup>2</sup></b>
<b>%reduction area</b>	<b>42.31%</b>
<b>%erlongation</b>	<b>7.83 %</b>

**Output table**



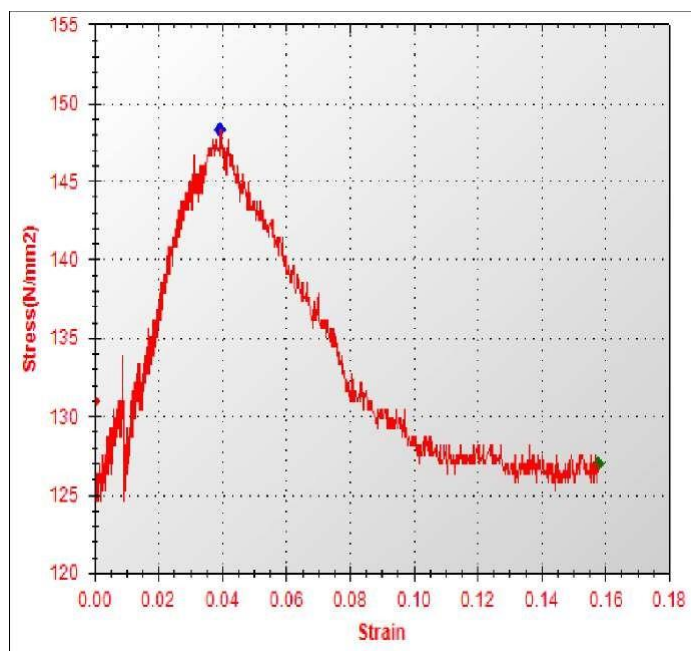
**Fig:- stress strain curve of (99% wt pom-c, 1% wt TiO<sub>2</sub>)**



**Fig 4.5: Specimen after the test (98% wt POM-C, 2% wt TiO<sub>2</sub>)**

<b>Specimen shape</b>	<b>Flat</b>
<b>Specimen type</b>	<b>Acetyl co polymer</b>
<b>Specimen description</b>	<b>98% pom-c ,2%TiO2</b>
<b>Specimen width</b>	<b>13mm</b>
<b>Specimen thickness</b>	<b>4mm</b>
<b>Initial G.L for elong</b>	<b>115mm</b>
<b>Pre load value</b>	<b>0KN</b>
<b>Maxx load</b>	<b>600KN</b>
<b>Max. elongation</b>	<b>200mm</b>
<b>Specimen cross section area</b>	<b>52mm<sup>2</sup></b>
<b>Final specimen width</b>	<b>10 MM</b>
<b>Final specimen thickness</b>	<b>3mm</b>
<b>Final gauge length</b>	<b>124mm</b>
<b>Final area</b>	<b>30mm<sup>2</sup></b>

<b>Load at yeild</b>	<b>7.23KN</b>
<b>Elongation at yeild</b>	<b>0.00N</b>
<b>Yeild stress</b>	<b>139.038N/mm<sup>2</sup></b>
<b>Elongation at peak</b>	<b>3.120mm</b>
<b>Load at peak</b>	<b>8.550 KN</b>
<b>Tensile strength</b>	<b>164.423N/MM<sup>2</sup></b>
<b>Load at break</b>	<b>7.470KN</b>
<b>Elongation at break</b>	<b>13.390mm</b>
<b>Breaking strength</b>	<b>143.654 N/mm<sup>2</sup></b>
<b>%reduction area</b>	<b>36.54%</b>
<b>%erlongation</b>	<b>7.83 %</b>



**Fig:- stress strain curve of (98% wt pom-c, 2% wt TiO<sub>2</sub>)**



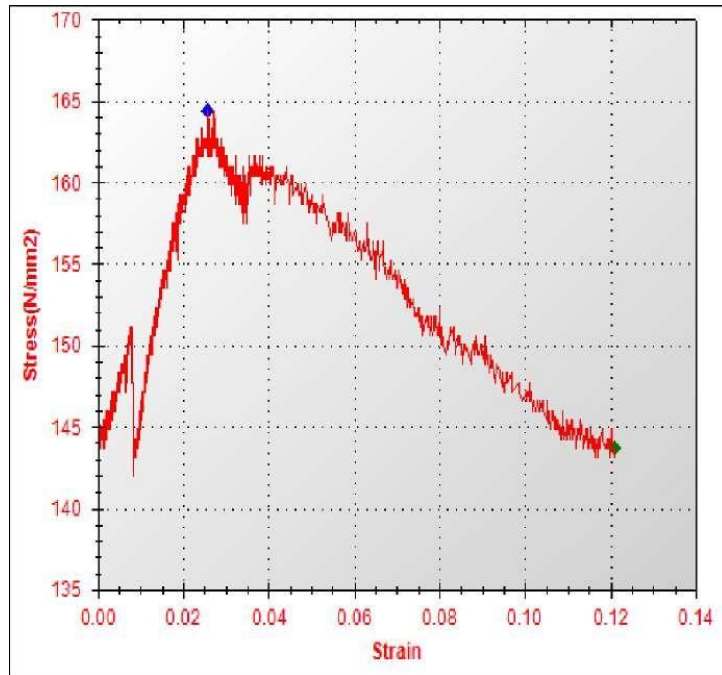
**Fig 4.6 : Specimen after the test (97% wt POM-C, 3% wt TiO<sub>2</sub>)**



<b>Specimen shape</b>	<b>Flat</b>
<b>Specimen type</b>	<b>Acetyl co polymer</b>
<b>Specimen description</b>	<b>98% pom-c ,2%TiO2</b>
<b>Specimen width</b>	<b>13mm</b>
<b>Specimen thickness</b>	<b>4mm</b>
<b>Initial G.L for elong</b>	<b>115mm</b>
<b>Pre load value</b>	<b>0KN</b>
<b>Maxx load</b>	<b>600KN</b>
<b>Max. elongation</b>	<b>200mm</b>
<b>Specimen cross section area</b>	<b>52mm<sup>2</sup></b>
<b>Final specimen width</b>	<b>10 MM</b>
<b>Final specimen thickness</b>	<b>3mm</b>
<b>Final gauge length</b>	<b>124mm</b>
<b>Final area</b>	<b>30mm<sup>2</sup></b>

<b>Load at yeild</b>	<b>6.51KN</b>
<b>Elongation at yeild</b>	<b>0.000N</b>
<b>Yeild stress</b>	<b>125.192N/mm<sup>2</sup></b>
<b>Elongation at peak</b>	<b>4.570mm</b>
<b>Load at peak</b>	<b>7.710KN</b>
<b>Tensile strength</b>	<b>148.269N/MM<sup>2</sup></b>
<b>Load at break</b>	<b>6.600KN</b>
<b>Elongation at break</b>	<b>18.130mm</b>
<b>Breaking strength</b>	<b>126.923654 N/mm<sup>2</sup></b>
<b>%reduction area</b>	<b>36.54%</b>
<b>%erlongation</b>	<b>6.96 %</b>

**INPUT.OUTPUT TABLES**



**Fig:- stress strain curve of (97% wt pom-c, 3% wt TiO<sub>2</sub>)**

SL NO.	Material	Ultimate tensile strength (UTS) MPA	Increase or decrease in UTS in percentage
1	Pure pom-c	143.7	-
1)	99% pom-c, 1% TiO <sub>2</sub>	140.7	-2.1%
2)	98% pom-c, 2% TiO <sub>2</sub>	164.4	+14.40%
3)	97% pom-c, 3% TiO <sub>2</sub>	148.2	+3.1%

**Table :- Tensile strength comparison**

It can be observed that the universal tensile strength is increased from to and is around increment in case of TiO<sub>2</sub> nano composite .

## **CONCLUSIONS**

1. The results confirmed that blended and Injection moulded POM-C with IF - TiO<sub>2</sub> reinforced composites is clearly superior to base acetyl co polymer (pom-c) in the comparison of tensile strength, and Flexural Strength.
2. Dispersion of TiO<sub>2</sub> particles in POM-C matrix improves the Ultimate tensile strength of the matrix material.
3. It is found that elongation tends to decrease with increasing particles wt. percentage, which confirms that addition of Titanium dioxide particles increase brittleness.
4. POM-C matrix composites have been successfully fabricated by melt mixing technique.
5. It appears from this study that Yield strength trend starts increases with increase in weight percentage of TiO<sub>2</sub> in the matrix.
6. Twin Screw extrusion can successfully distribute the TiO<sub>2</sub> particles uniformly in the POM-C matrix.

## **SCOPE OF FUTURE STUDY**

1. Results might vary with grain size and shape.
2. Crystal kinetics can be studied to better understand the internal arrangements and distribution of the nano particles.
3. Storage modulus has to be studied to know the life and its performance.

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