

Study on Reinforcement Materials for Nylon Matrix Composites - A Review

K. Shiva Kumar¹, A. Chennakesava Reddy²

Abstract Use of composites is becoming a potential substitute for the use of pure metals in many industries due to its numerous advantages like light weight and ease of fabrication. This review offers an insight into the demand for polymer composites and offers a comprehensive discussion on different reinforcements used for nylon matrix. It also gives the importance of polyamide in material industry and mechanical behaviour of polyamide when it is reinforced with different filler materials.

Index Terms— polymers, nylon, filler, reinforcement materials, solid lubrication.

1 INTRODUCTION

A polymer is made of many units like carbon, hydrogen, oxygen and/or silicon. Useful products like bearings, gears, bushes, etc., are made by polymers. Polymers are moulded into useful components by applying heat and pressure. Nearly all industries use polymer materials; synthetic and natural polymers. These can be produced with wide range of strength, stiffness, heat resistance, crystallinity and even price of the component. The consumption of polymers is dominating the consumption of steels. Based on ASTM D883 80c, polymers are classified into two groups with respect to their technological and chemical behaviour: thermosetting and thermoplastics [1-6].

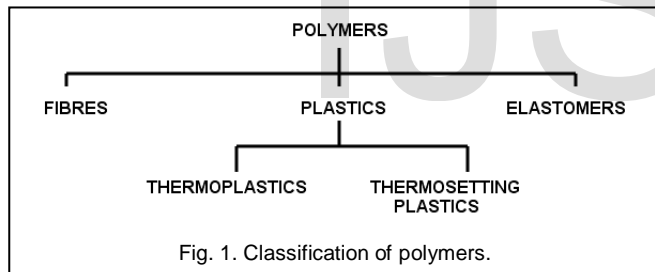


Fig. 1. Classification of polymers.

The objective of this paper is to review the use of different reinforcements in polymer composites and their influence on the mechanical properties.

1.1 Thermosets

Thermosets have cross-linked or network structures with covalent bonds with all molecules [7]. They can be either solids or liquids at normal room temperature. Thermoset materials once cured cannot be remelted or reformed. They are placed in a mould and heated. After heating they are allowed to cure (harden) to form into required shape [8]. During curing, they form three dimensional molecular chains, called cross-linking. Due to this cross linkings, the molecules are not flexible and cannot be remelted and reshaped. Rigidity and thermally sta-

bility increase with increase in the number of cross linkings [9-10]. Thermosetting polymers are more stiffer and stronger than thermoplastics and generally are used for high temperature applications. Raw polymer material is directly in shaping of these plastics and no further processing possible except for machining. This limits the possible process to just moulding [6]. Generally used thermoset resins are epoxy, phenol, polyester, vinyl esters, cyanate esters, polyurethane and so on [10].

1.2 Thermosets

Thermoplastics consist of linear or branched chain molecules having strong intramolecular bonds but weak intermolecular bonds [7]. At room temperature thermoplastics are in solid phase. Upon heating they are melted or softened, and then they are placed into a shaping device or mould to give desired shape [8]. They render the capability of repeated reforming and reshaping, as they can be solidified by cooling and melted by heating. The molecules of thermoplastics do not crosslink and therefore, they are more reformable and flexible [10]. Its properties can be changed by changing the form and length of individual chains [6]. Thermoplastics are tougher and ductile than thermosets and are used for a wide range of non-structural applications without reinforcements and fillers. They can be welded together making. At high temperatures thermoplastics exhibit poor resistance to creep and are more susceptible to solvents when compared to thermosets [10]. Generally used thermoplastics are polyethylene, polypropylene, polyvinyl chloride, polystyrene, polycarbonate, acrylics, polyamides and so on [6].

2 COMPOSITES

When two or more physically and chemically different materials are separated by distinct interface then they are called as composites. The different systems are combined to achieve a system with more useful structural or functional properties nonattainable by any one of the constituent alone [11].

A composite consists of a matrix and reinforcement. The matrix phase is the primary phase having the continuous character. This phase is usually more ductile. It holds the reinforcing phase and shares load with it. The reinforcing phase is discontinuously embedded in the matrix phase. The reinforcing phase is stronger and harder than the matrix phase [7].

- K. Shiva Kumar Research Scholar in mechanical engineering in JNTU Hyderabad, India, PH-919666619366, E-Mail: kskumar3456@gmail.com
- A. Chennakesava Reddy professor in mechanical engineering department JNTU Hyderabad, India, PH-919440568776, E-Mail: chennakesava@jntuh.ac.in

Polymers are mostly used as composite matrix in composite materials [12]. The classification of polymer matrix and reinforcement is shown in the figs. 3 and 4. Figs. 5 filler and hybrid reinforcement respectively.

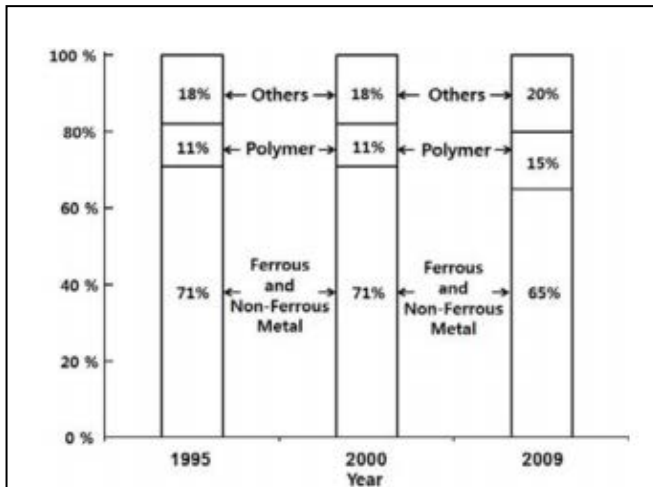


Fig.2. Material consumption ratio for polymers in a light vehicle [27].

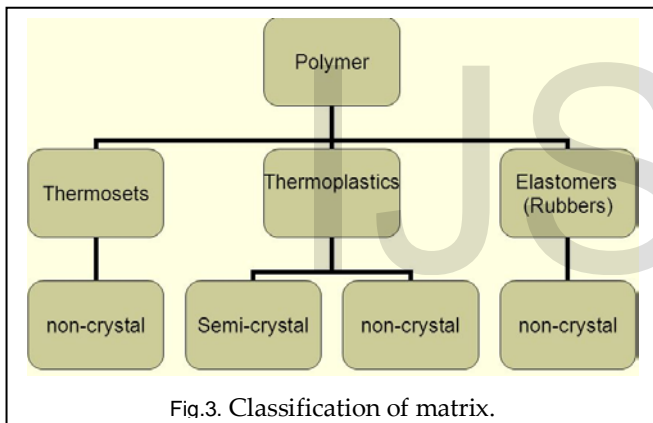


Fig.3. Classification of matrix.

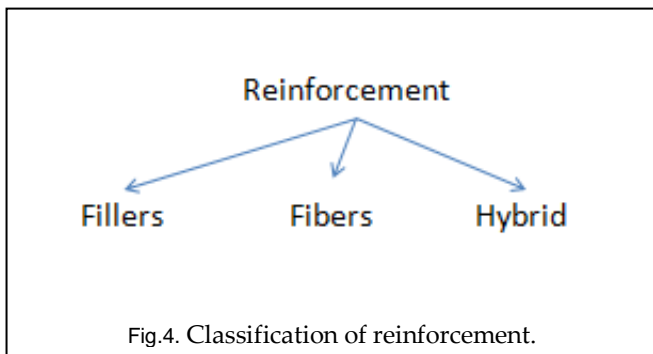


Fig.4. Classification of reinforcement.

2.1 Fillers

A common reason for adding fillers to polymers is to increase the modulus or stiffness via reinforcement mechanisms described by theories of composites [13-14]. Fillers may also be used to lower material costs by reducing the volume of matrix resin required. Fillers are used to enhance or modify properties such as thermal conductivity, friction, electrical resistivity, wear resistance, and flame resistance [15]. Fillers are a variety

of solid particulate materials that may be irregular, fibrous or plate-like in shape and that are used in reasonably large volume loadings in plastics. Generally, all the fillers used in injection moulding are classified as organic and inorganic fillers. Few of the examples for chemical family of inorganic fillers are [16]:

Oxides: Glass, MgO, SiO₂, Sb₂O, Al₂O₃, ZnO

Hydroxides: Al(OH)₃, Mg(OH)₂

Salts: CaCO₃, BaSO₄, CaSO₄, Phosphates & hydrotalcite.

Silicates: Talc, Mica, Kaolin, Wallastonite, Montmorillonite, feldspar, asbestos.

Metals: Boron & steel.

Few of the examples for chemical family of organic fillers are [16]:

Natural polymers: Cellulose fibers, wood flour and fibers, flax, cotton, sisal and starch.

Synthetic Polymers: Polyamide, Polyester, aramid and polyvinyl alcohol fibers.

Carbon, Graphite: carbon fiber, graphite fiber & flakes, carbon nanoTube and carbon black.

Inorganic compounds are added into polymer as a filler, to improve heat resistance, mechanical strength, impact resistance and to decrease the properties like electrical conductivity and dielectric constant [17]. The main functions of filler materials are listed below:

- Improves physical and mechanical properties
- Increases translucency
- Reduces the consumption of matrix material
- Strengthens the composite
- Reinforcement of the matrix resin: increases strength, hardness and decreases wear.
- Reduces polymerization shrinkage
- Increased viscosity and improved workability
- Reduction in water sorption, softening and staining [16-18].



Fig.5. Filler material.

2.2 Solid Lubricants

The solid lubricants reduce friction coefficient and wear rate through the decrease of adhesion with a counter face or by creating a transfer film with low shear strength at the interface. When nano solid lubricants are added to a polymer matrix to form a composite, they play an important role in en-

hancing tribological characteristics of composites. The inclusion of the ceramic nano-solid lubricants into the more flexible and lower thermal resistance polymer can significantly increase its stiffness and thermal stability [19].

3 POLYAMIDES (NYLONS)

Polyamides are also known as nylons. These are crystalline in nature. Polyamides are many in number like nylon 6, nylon 6.10, nylon 6.6 and nylon 6.11. The most commonly used polyamides are nylon 6 and nylon 6.6. Among various thermoplastic matrices available, nylon 6 represents one of the best choices for its use in various composites. Most of the engineering plastics use nylon because of its desirable properties like stiffness, high strength and resistance to non polar solvents [6].

3.1 Consumption of polyamides

The global consumption rate of nylon 6 and nylon 6.6 is about 6.8 tons per annum. It is expected that this consumption rate will grow by 2.4 percent by 2020. Among all the polyamides the consumption of nylon 6 and nylon 6.6, is about 85-90 percent.

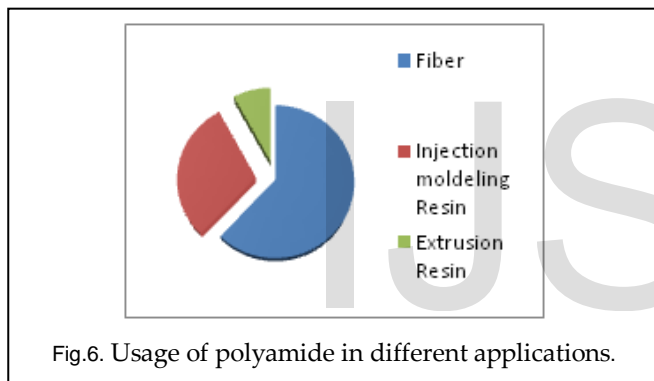


Fig.6. Usage of polyamide in different applications.

Global demand for nylon 6

- Asia is the largest consumer of nylon 6.
- According to Chemical Market Associates Inc (CMAI), strong demand for nylon 6 in china is leading market growth for the engineering polymer.
- Most of the growing production demand for polyamides is needed to supply china which is already consuming 30 percent of the total production.
- The global demand for nylon 6 is expected to grow at an annual rate 5% [20].

In industries polyamide 6 is used for manufacturing nano-composites. Polyamide 6 is used in producing consumer products as it has superior mechanical properties and light weight. For optimising and improving the mechanical properties. Nano sized fillers are incorporated in the high performing polymers [12]. The melting point of nylon 6 is 220°C and density at 25°C is 1.23 g/cc. Nylons are favourable materials for producing gears, bearing, cam applications. In nylon the wear behaviour exhibited by it is adequate for dry sliding conditions at higher speeds. When nano solid lubricants are added

to them [19].

4 EFFECT OF SIGNIFICANT FILLER MATERIALS ON NYLON 6

4.1 Teflon (PTFE)

Polytetrafluoroethylene (PTFE) is one of the excellent solid lubricants commonly used for bearing and seal applications. Teflon has melting point of 327°C and a density of 2.20 g/cc. The load bearing capacity of the nylon-teflon composite increases with the increase of teflon content (fig. 7). This may be due to the increased stiffness induced with the addition of Teflon. The breaking strength, tensile strength and true tensile strength also increase with the increase of teflon content in the composite. This may be due to good adhesion between the particles which is result of good interface bonding between nylon 6 and teflon. With increase in teflon the hardness of the composite increases while the percentage elongation decreases. This is due to the reason that the hardness of teflon is greater than that of the nylon 6. As the ductility of Teflon is less when compared to nylon 6, the ductility of the composite decreases [21].

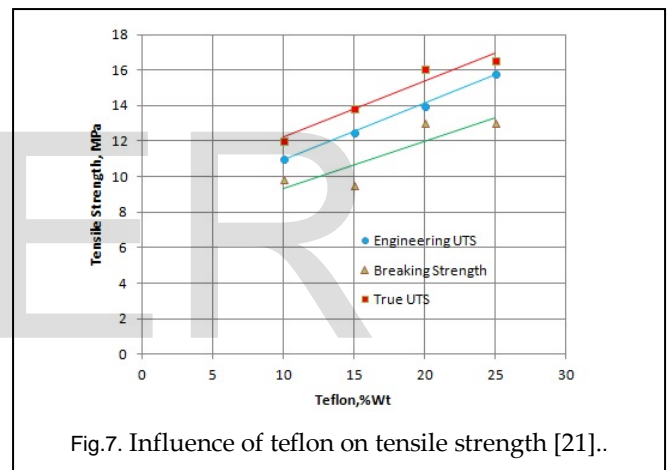


Fig.7. Influence of teflon on tensile strength [21].

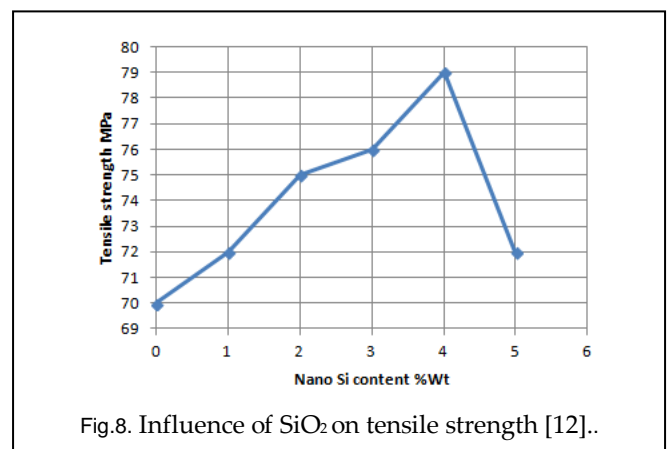


Fig.8. Influence of SiO₂ on tensile strength [12].

4.2 Silica

When polyamide 6 (nylon) is filled with 0 to 5 wt% of silica nano particles, the property which has a notable change is the strain-to-failure. An increase in tensile strength was observed from 0% to 4% addition of silica nano particles and beyond 4%

addition a decrease in tensile strength was observed (fig.8). The other mechanical properties which are enhanced are: the impact strength increased and Young's modulus increased [12].

4.3 Organo-Montmorillonite

Among the naturally occurring clays, montmorillonite is the most abundantly available member. Because of its hydrophilic nature it is not compatible with most of the polymers. Its compatibility is increased by using organo-montmorillonite [23]. The tensile strength and tensile modulus has a significant increase in the presence of organo-montmorillonite. Due to the reinforcement effects of OMMT, the stiffness of the OMMT filled PA6 was improved notably when compared with pure nylon 6. Flexural modulus and strength of the composite also increases [24].

TABLE 1

EFFECT OF OMMT ON THE MECHANICAL PROPERTIES OF PA6 [24].

PROPERTIES	UNIT	PA6	PA6/OMMT
Tensile modulus	GPA	2.3 ± 0.02	3.0 ± 0.02
Tensile strength	MPA	40.1 ± 0.05	68.7 ± 0.10
Elongation at break	%	58.4 ± 0.05	3.5 ± 0.02
Flexural modulus	GPA	2.1 ± 0.02	2.9 ± 0.01
Flexural strength	MPA	94.2 ± 0.10	105 ± 0.10

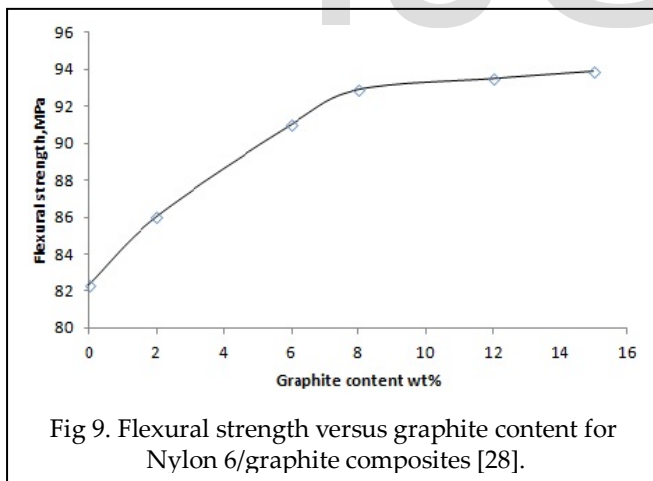


Fig 9. Flexural strength versus graphite content for Nylon 6/graphite composites [28].

4.4 Graphite

Elemental carbon is the most universal of elements of the periodic table. Carbon is available in many allotropic forms like diamond, graphite, glassy carbon, etc. Graphite and all its types are widest used carbon materials [25]. Graphite as an engineering material has many excellent electrical, thermal and lubricating properties. This is one of the reasons for its wide usage in industries. When graphite is added to nylon 6, it imparts good lubrication, very high resistance to alkali, low thermal expansion and very good heat and electrical expansion [26].

When compared to pure nylon 6, the thermal stability of nylon 6 graphite composite is enhanced. With increase in graphite concentration the flexural modulus and flexural strength increase while the Notched Impact Izod strength decreases. The effect of addition of graphite, from 0-15%, on nylon 6 is shown in figure 9. [28]

5. CONCLUSIONS AND RECOMMENDATIONS

From this review, it can be concluded that nylon 6 is one of the best available materials for matrix in a polymer composite material. The mechanical properties of the composite are greatly influenced by the filler materials. Although a lot of research is carried in the area of polyamide and the effect of filler materials on it, the following are recommended

1. From the above study it is observed that at low temperatures nylon has poor toughness. Further research may be focussed on this area.
2. Nylon is also sensitive to moisture, studies may be furthered on improving its moisture sensitivity.
3. It is also observed that graphite has less affinity towards PA6 matrix, study in the direction of improving affinity of graphite towards PA6 matrix is recommended.

REFERENCES

- [1] J.F Shachelford, "Introduction To Material Science For Engineering," Prentice Hall, Upper Saddle River, NJ, USA, 2000.
- [2] I. Alaudin, . A. Choudhury, M.A El Baradie and M.S.J. Hashmi, "Plastics and their machining a review: a review," Journal of Materials Processing Tech, vol. 54, no. 1-4, pp. 40-46, 1995.
- [3] S.K De and J. R. White. Short Fiber-Polymer Composites. Woodhead, Cambridge, U.K, 1996.
- [4] E.H. Cornish, Materials and Designer, Cambridge University Press, Cambridge, U.K, 1999.
- [5] W. Bolton, Engineering Materials Technology, Butterworth Heinemann UK, 3rd edition, 1998.
- [6] B. Aldousiri, A. Shalwan, W. Chin. "A Review on Tribological Behaviour of Polymeric Composites and Future Reinforcements", Advances in Materials Science and Engineering, Hindawi Publishing Corporation, Volume 2013, Article ID 645923.
- [7] Polymer Composites: Volume 1, First edition. Published 2012 by Wiley-VCH Verlag GmbH & Co. KGaA.
- [8] Sharifah Imihezri Syed shaharuddin et.al., A review of the effect of moulding parameters on the performance of polymeric composite injection moulding, Turkish J. Eng. Env. Sci. 30 23-34. (2006),
- [9] L. English, .K., Honeycomb: million-year-old material of the future, Mat. Eng., P-29, January 1985.
- [10] K. Sanjay Mazumdar. Composites Manufacturing, Materials, Product, and Process Engineering.
- [11] A. Shaw, Sriramula, S., Gosling, P.D., and Chryssanthopoulos, M.K. Composites Part B, 41, 446-453. (2010).
- [12] K. Maryam Hafshejani, Mehdi Khazaei, Amaneh Langari. Influence of the addition of nano-Silica particles as reinforcement on the tensile yield properties of polyamide 6 polymeric matrix used in medical applications, Life Science journal 2013; 10(4).
- [13] TD Fornes , Paul DR, Polymer 2003;44:4993.

- [14] LMPaul, Robenson. Polymer nanotechnology: Nanocomposites, Elsevier, Polymer 49 3187-3204. (2008)
- [15] Part 1 Polymers and fillers, Functional Fillers for Plastics, ISBN 3-527-31054-1.
- [16] Marino Xanthos, "Functional Fillers for Plastics", Wiley Publicaitons, ISBN: 978-3-527-32361-6, pp:12-13
- [17] H. S. Katz, J. V. Mileski, "Handbook of Fillers for Plastics", Van Nostrand Reinhod, ISBN: 0-442-26024-5, pp: 27
- [18] Arunkumar Lagashetty and A Venkataraman, "Polymer Nanocomposites", General Article - Resonance, pp: 49-60. July 2005
- [19] A. Chennakesava Reddy. Characterization of Mechanical and Tribological behaviour of (Nylon 6+Graphite+Teflon) Nano Particulate Composite: Application perspective, International Journal of Scientific & Engineering Research, Volume 6 , Issue 4, , ISSN 2229-5518 April 2015
- [20] A Hisham . Maddah. Comprehensive review on C5, C6 and C9 Chemicals- Production Processes, Applications and Market Analysis. International Journal of Scientific & Engineering Research, Volume 6 , Issue 10, October 2015.
- [21] A. Chennakesava Reddy. Characterization of mechanical behaviour of Nylon/Teflon Nano Particulate Composites, International Journal of Advanced Research, Volume 3, issue 5, 1241-1246. (2015)
- [22] Farzana Hussain et.al. Review article: Polymer-matrix Nanocomposites, processing, manufacturing and application: An overview, Journal of COMPOSITE MATERIALS, VOL. 40. No. 17/2006.
- [23] Zanetti M., S. Lomakin and G. Camino. 2000. Polymer layered silicate nanocomposites, Macromolecular Materials and Engineering. 279:1-9.
- [24] W. S. Chow, Z. A. Mohd Ishak. Mechanical, morphological and rheological properties of polyamide 6/organo-montmorillonite nanocomposites, eXPRESS Polymer Letters Vol1. No.2 77-83.(2007).
- [25] P. Scharff, New carbon materials for research and technology, Carbon 36/5-6 481-486. (1998)
- [26] J. Stabik et.al. Carbon materials as fillers for polymer matrix composites, Archives of Materials Science and Engineering. Volume 53, Issue 1, January 2012.
- [27] Min-Young Lyu and Tae Gyun Choi. Research Trends in Polymer Materials for Use in Lightweight Vehicles, international journal of precision engineering and manufacturing Vol. 16, No. 1, pp. 213-220. January 2015/213
- [28] GH. RUSU, E. RUSU. In situ nylon6/graphite composites. Physico-mechanical properties, journal of photoelectronics and advanced metals, Vol 9, No.7, , P 2102-2109.. July 2007.