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Factors Affecting the Performance of Biocomposite: A Review

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Abstract

This paper deals with the effect of various factors like compatibility of natural fibres with polymer resin, amount of fibre loading in biocomposite, orientation direction, and manufacturing process & its parameters on performance of biocomposites. In recent trend, biocomposites are a best solution for new and advanced materials development due to its non abrasive, high strength & stiffness, eco-friendly and bio-degradability characteristics. The mechanical behaviour of biocomposites is mainly influenced by interfacial adhesion between matrix and the fibres. Surface chemical modifications like graft co-polymerisation, and coupling agent are employed to enhance hydrophobicity of fibres which leads better adhesion between natural fibre and resin. In general, the tensile properties of biocomposites increase with increasing fibre content, up to an optimum value and then drop. Khothane observed that the tensile strength and Young's modulus of bleached hemp fibre reinforced composite increased with increasing fibre content.

***Keywords*:** Biocomposites, Tensile strength and Young's modulus, Hydrophobicity, Interfacial adhesion.

1. Introduction

Biocomposites are materials in which one of its phase either matrix or reinforcement/filler (fibres) comes from natural source (Hassan et al, 2010). The properties of composites are dependent on an optimum combination of polymer matrix and reinforcing fibres and on their interfacial compatibility. Strong fibre/matrix interfacial bonding and highly efficient stress transfer from matrix to fibre are vital requirement for reliable and eco-friendly biocomposite that can exhibit better mechanical properties (Malkapuram et al, 2009).

Natural fibres have attracted the many researchers and engineers as an alternative reinforcement in polymer composites due to their low cost, low density, non abrasive, comparable mechanical properties to conventional glass and carbon fibres, recyclability and biodegradability (Mohanty et al, 2002; Singha and Thakur, 2008). These natural fibres include sisal, coir, jute, flex, hemp, banana and many others. These fibres can combine with thermoplastic and thermosetting polymers but thermoplastic materials are currently preferred as matrix for biocomposite; the most commonly used thermoplastics are polyethylene, poly vinyl chloride (PVC) and polypropylene; while phenolic, epoxy and polyester resins are the most commonly used thermosetting matrices (Malkapuram, R. Kumar et al, 2008).

Biocomposites are suitable to wide variety of applications like construction, aerospace, packaging, sports, and automotives but the main drawback is the incompatibility between the hydrophilic natural fibres and hydrophobic matrices (Bogoeva-Gaceva et al, 2009). These result non favourable properties of composites, so it is required to modify the surface of fibre by chemical modifications to improve the adhesion between fibre and matrix. Apart from hydrophilic nature of fibre, the performance of biocomposite can also influence by fibre content, processing techniques and parameters. It is often observed that high fibre content is required to achieve high performance of biocomposites. The aim of this paper is to review the effects of various factors of natural fibre, manufacturing techniques and process parameters on the performance of biocomposites.

2. Mechanical Properties

Generally, the mechanical properties of biocomposites can be markedly improved by the addition of fibres to polymer matrix because fibres have much higher strength and stiffness as compared to matrices as shown in Tables 1, 2 and 3 (Holbery, J and Houstan D et al, 2008)

Fibre	Density (gm/cm^3)	Elongation (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)
Cotton	1.5-1.6	7.0-8.0	400	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	500-1500	27.6

Hemp	1.47	2.0-4.0	690	70
Kenaf	1.45	1.6	930	53
Ramie	1.3	3.6-3.8	400-938	61.4-128
Sisal	1.5	2.0-2.5	511-635	9.4-22
Coir	1.2	30	593	4.0-6.0
Softwood Kraft Pulp	1.5	4.4	1000	40
E-glass	2.5	0.5	2000-3500	70
S-glass	2.5	2.8	4570	86
Aramid	1.4	3.3-3.7	3000-3150	63-67
Carbon	1.4	1.4-1.8	4000	230-240

Table1: Properties of natural and synthetic fibres.

Property	**PP**	**LDPE**	**HDPE**	**PS**	**Nylon 6**	**Nylon 6,6**
Density (gm/cm^3)	0.899-0.920	0.910-0.925	0,94-0.96	10.4-1.06	1.12-1.14	1.13-1.15
Water absorption-24 hrs (%)	0.01-0.02	<0.015	0.01-0.2	0.03-0.10	1.3-1.8	1.0-1.6
T_g (^{0}C)	-10 to-23	-125	-133 to -100	N/A	48	80
T_m (^{0}C)	160-176	105-116	120-140	110-135	215	250-269
Heat Deflection Temp. (^{0}C)	50-63	32-50	43-60	Max.220	56-80	75-90
Coefficient of Thermal Expansion	6.8-13.5	10	12-13	6-8	8.0-8.86	7.2-9.0
Tensile Strength (MPa)	26.0-41.4	40-78	14.5-38.0	25-69	43-79	12.4-94
Elastic Modulus (GPa)	0.95-1.77	0.055-0.38	0.4-1.5	4-5	2.9	2.5-3.9
Elongation (%)	15-700	90-800	2.0-130	1.0-2.5	20-150	35-300
Izod Impact Strength (J/m)	21.4-267	>854	26.7-1068	1.1	42.7-160	16-654

Table2: Properties of Thermoplastic polymers used in natural fibre composite

PP = Polypropylene, LDPE = Low Density Polyethylene, HDPE = High Density Polyethylene and PS = Polystyrene

Property	Polyester Resin	Vinyl Ester Resin	Epoxy
Density (gm/cm^3)	1.2-1.5	1.2-1.4	1.1-1.4
Elastic Modulus (GPa)	2.0-4.5	3.1-3.8	3-6
Tensile Strength (MPa)	40-90	69-83	35-100
Compressive Strength (MPa)	90-250	100	100-200
Elongation (%)	2	4-7	1-6
Cure Shrinkage (%)	4-8	N/A	1-2
Water Absorption (24 h@20^{0}C)	0.1-0.3	0.1	0.1-0.4
Izod Impact Strength (J/m)	0.15-3.20	2.5	0.3

Table3: Properties of thermosetting polymers used in natural fibre composite

From the above tables, it can be observed that tensile strength of fibre (S-glass) is 75-150 times higher than those of the matrices (PP and Polyester resin). It can also be observed that the Young's modulus of the fibre (S-glass) is 80-160 times higher than those of the matrices (PP and Polyester resin).

Khoathane et al. analyzed the effect of bleached hemp fibre (0-30w/t %) 1-pentene/polypropylene copolymer composite. The results show the initial increase of tensile strength at 5% fibre loading from 20 MPa to 30 MPa as depicted in Fig 1. The tensile strength then decreased to 23 MPa at 20 % fibre loading and its value increased again when fibre content was 30 %.

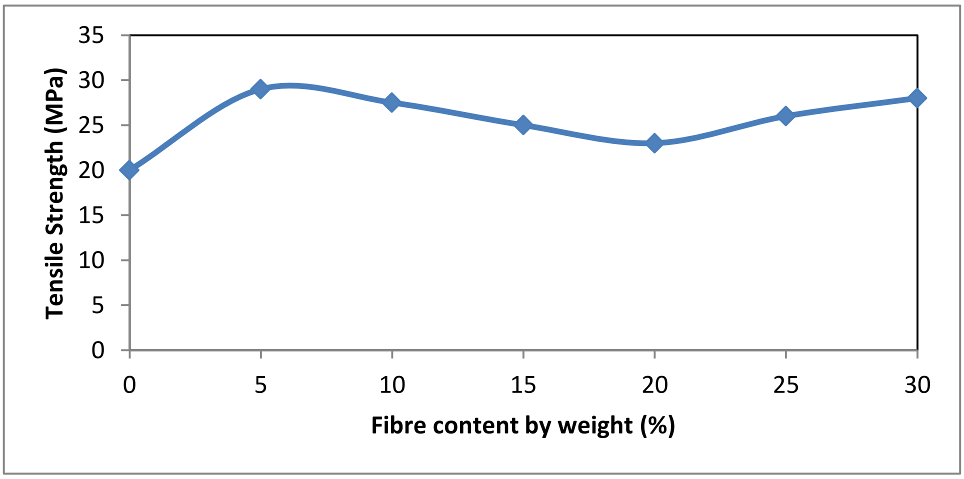

Fig 1: Effect of fiber content on tensile strength of bleached hemp fibre reinforced PP1 composites

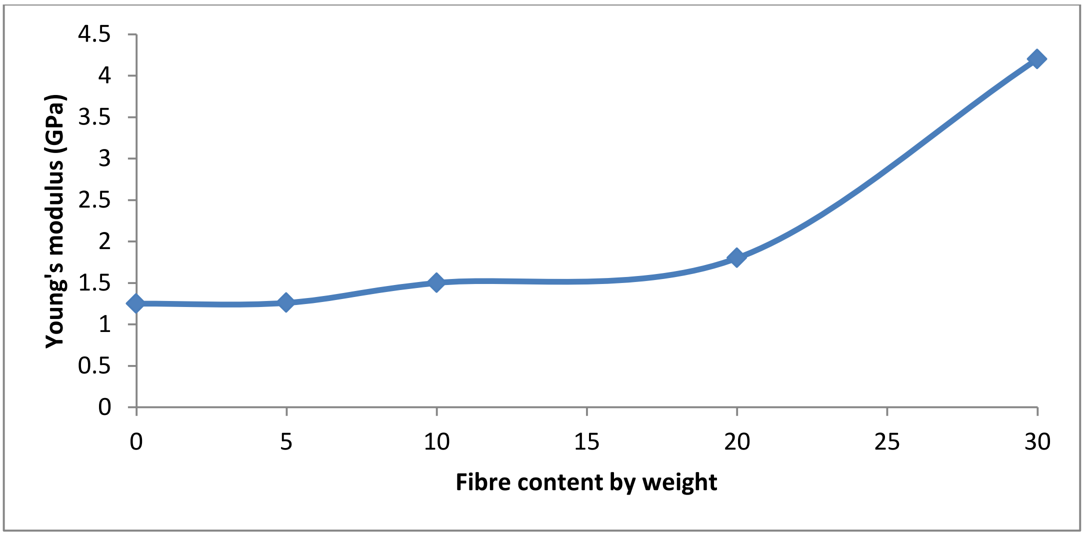

Fig 2: Effect of fibre contents on Young's Modulus of bleached hemp fibre reinforced PP1 composites

Fig 2 depicted the variation of tensile young's modulus with fibre content. The results shows that the value of Young's modulus increased by over twice from 1.3 GPa (neat resin) to 4.4 GPa (30 % w/t).

Fibre orientation in a polymer matrix is also an important parameter that affects the performance of biocomposite. From fig.3, it can be concluded that tensile strength of composite material made by hemp and polypropylene fibre with fibres in the perpendicular direction was (20-40) % lower than those of composites in parallel direction. The tensile strength of biocomposite is reduced to 34% at 70% of hemp but it shows different trend and maximum value with increasing fibre loading. From the above observations, it can be concluded that the perpendicular oriented fibres cannot act as load bearing elements in the composite matrix structure (Hajnalka, Anandjiwala et al, 2008).

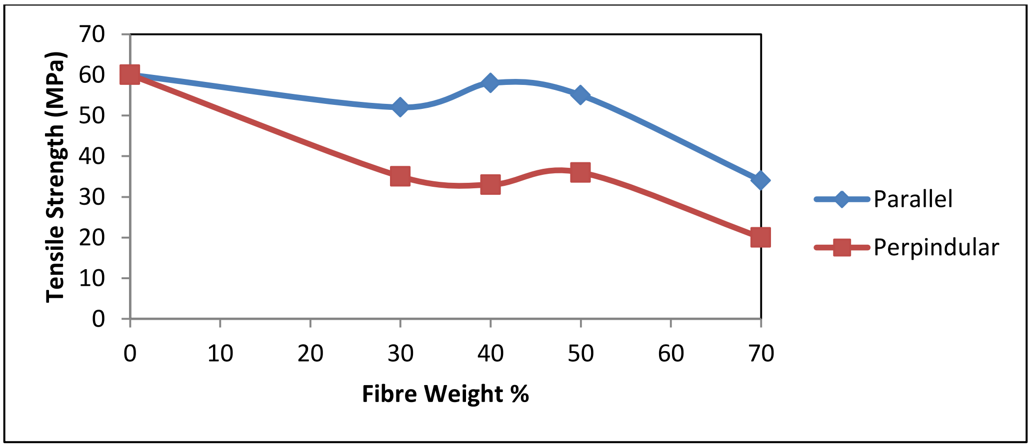

Fig 3: Tensile strength of polypropylene/hemp fibres with varying % of weight of fibres

Fig.4 shows that the Young's modulus of composite materials increases with an addition of fibre content in polymer matrix. The maximum value of Young's modulus was achieved at 50% fibre loading and then decreased slightly at 70% hemp fibre content.

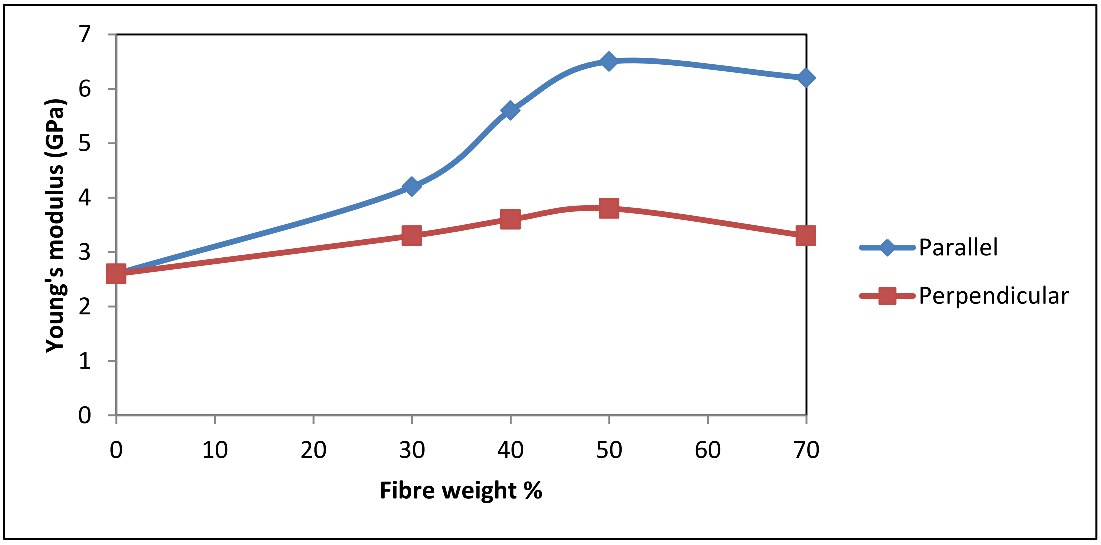

Fig 4: Young's modulus of polypropylene /hemp fibre with varying % by weight of fibre

From the above discussion, it can be concluded that the tensile strength and Young's modulus of natural fibre reinforced composites increased with increasing fibre loading. On the other hand, some researchers found totally the opposite trend to increase of composite strength with increasing fibre content. This can be attributed to many factors such as incompatibility between matrix and fibres, improper manufacturing process, fibre degradation & others.

The hydrophilic nature of natural fibres is incompatible with hydrophobic polymer matrix which results poor performance of composite material. The hydrophobic fibres exhibit poor resistance to moisture which leads to poor tensile properties of natural fibre reinforced composites (Li et al, 2007). This hydrophilic characteristic of natural fibre is due to presence of waxes and other cellulosic substances such as hemicelluloses, lignin and pectin which create poor adhesion between matrix and fibres.

In order to improve adhesion between natural fibres and resin, it is required to increase fibre's hydrophobicity by surface treatment. This surface chemical modification improve the interfacial bonding between matrix and fibre, roughness and wet ability, fibres hydrophobic leading to enhancement of mechanical behaviour of the composites (Sreekla and Thomas, 2010).

The different surface chemical modifications such as chemical treatments, coupling agent and graft co-polymerization, of natural fibres aimed at to improve the mechanical performance of biocomposites (Rosa et al, 2009). Usually, alkali treatment of surface with sodium hydroxide (NaOH) is used to remove the hydrogen bonding in the cellulose fibres network structure, wax and oil which covers the outer surface of fibres cell wall results that fibre surface roughness and hydrophobic property increases (Das et al, 2000; Shukla and Pai, 2005; Corrandini et al, 2006). The other method which improves the interfacial adhesion between natural fibres and polymer resin is “chemical coupling”. In this method the fibre surface is treated with a compound that forms a bridge between fibre and matrix . Researchers found that chemical coupling treatment is an effective action that forms a strong adhesive force between fibre and resin.

Hu and Lim et al. analysed the effect of Alkali treatment on tensile strength and modulus of composite made by hemp fibre reinforcement in polylactic acid (PLA). Fig 5 and 6 illustrate that the composites with 40% volume fraction of alkali treated fibre have the best tensile properties. The tensile strength and modulus of composites are 54.6 MPa and 85 GPa resp. which are much higher than neat PLA.

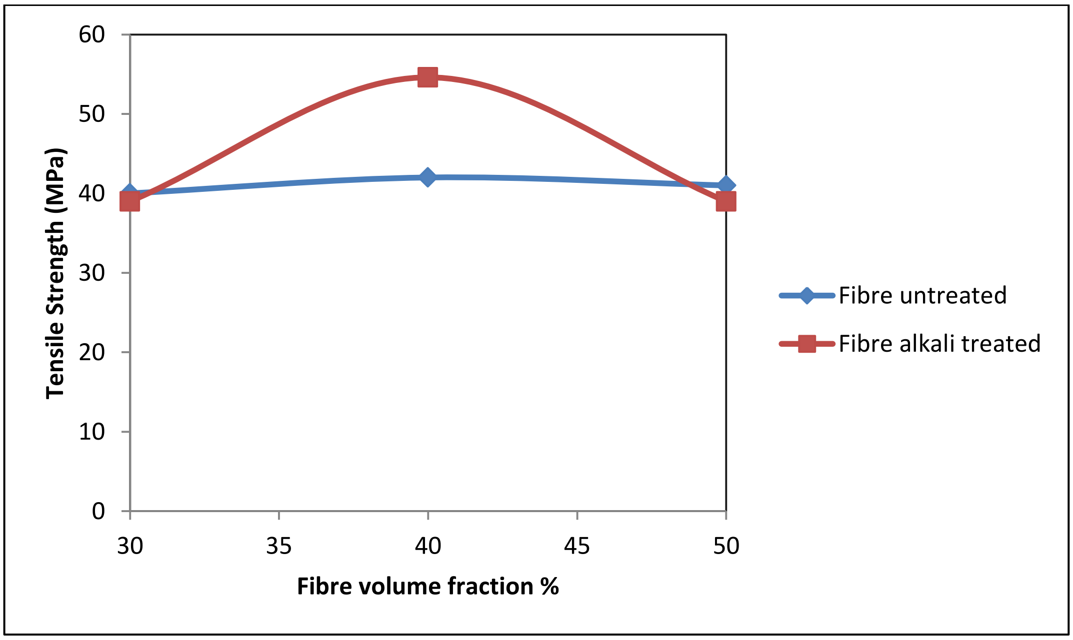

Fig: 5 Effect on tensile strength of treated and untreated hemp-PLA composites with fibre volume fraction.

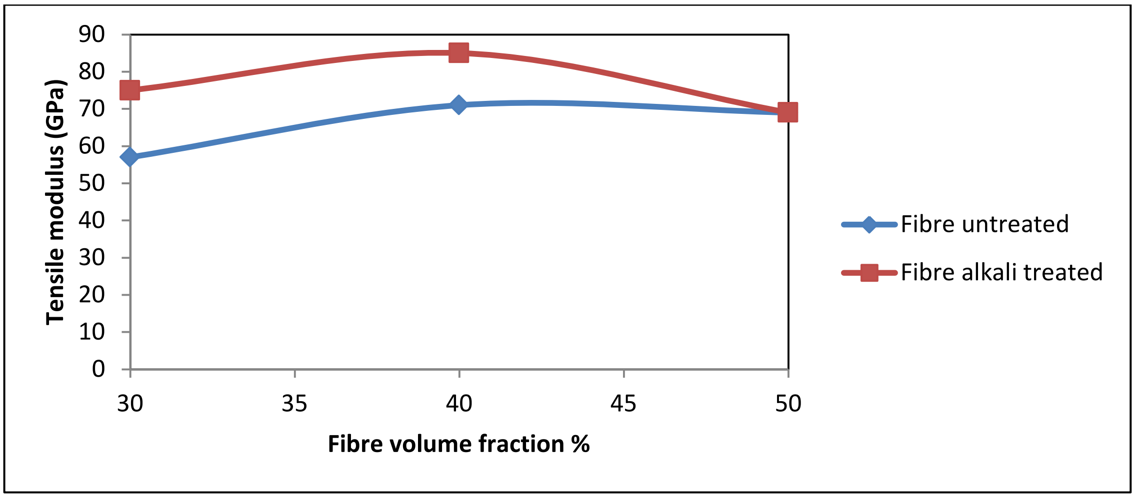

Fig 6: Tensile modulus of treated and untreated hemp PLA composites with Fibre %

Another important factor that significantly influences the performance of biocomposite is processing techniques and parameter used. The most common methods for manufacturing natural fibre reinforced thermoplastic composites are extrusion injection moulding and compression moulding. Sombatsompop analysed the difference in tensile characteristics of E-glass fibre reinforced wood/PVC (WPVC) composites, manufactured by twin screw extrusion and compression moulding processes. The experimental results shows that compression moulding manufacturing process gave better tensile modulus than twin screw extrusion process as depicted in fig. 7 The composite manufactured by compression moulding gave higher specific density, which result stronger composite than any manufacturing process.

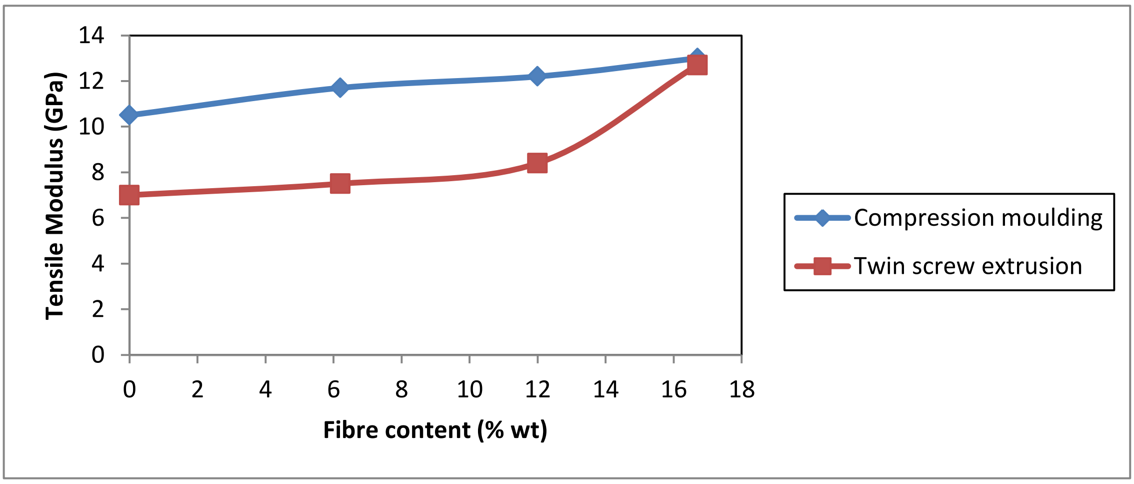

Fig 7: Tensile modulus of glass fibre reinforced WPVC composites manufactured by twin screw extrusion and compression moulding process.

Li determined the optimum value of Injection temperature and pressure for manufacturing flax fibre reinforced high-density polyethylene biocomposite. From his observation, it was concluded that injection temperature should not be lower than 160^0 C and not be greater than 192^0 C. At higher temperature, fibre degradation & at lower temperature, incomplete melting of polymer resin problem might have occurred. Higher injection pressure is suitable to obtain a better biocomposites.

3. Conclusions

From the above discussion, it can be concluded that the tensile properties of natural fibre reinforced biocomposite are very good and it can be adopted as an alternative material to conventional materials. A major problem of using natural fibres as reinforcement in polymer resin is the improper adhesion resulting poor mechanical properties. In order to improve fibre-matrix adhesion, novel processing technique, physical and chemical modification methods are developed. This paper clearly shows that tensile strength and modulus increase with increasing fibre content up to a certain amount, further increment in fiber weight has resulted in decreased tensile strength.

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