Characterization of the Tensile Strength Properties of Hybrid Sandwich Composites

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Abstract:
Hybrid composites are being growingly utilized in engineering applications, and their mechanical performance is a matter of concern with the employing of various types of reinforcements and matrices. In this paper, an experimental study was performed to characterize the tensile behaviour of new hybrid sandwich composites. The sandwich composites were prepared using reinforcements from woven fabrics for the skin layers and nonwoven fabric for the core layer and two types of matrices; polyester and epoxy resins. The tensile strength of the hybrid sandwich composites produced was examined in both warp and weft directions of fabrics. A particular interest was devoted to the influence of woven fabrics (skins) constructional parameters and the matrix properties on the tensile strength of these hybrid sandwich composites. The results indicated that, the hybrid sandwich composites exhibited high tensile strength in the weft direction of fabrics. The polyester/glass sandwich composites fabricated with epoxy matrix showed the highest tensile strength compared to the other composites. Hence, the reinforcement materials properties and the fiber/matrix interface are greatly affected on the behaviour of the sandwich composites towards tensile loads.

Keywords:
- ***Hybrid composites***
- ***Sandwich structures,***
- ***Tensile strength,***
- ***Woven fabrics,***
- ***Polyester resin,***
- ***Epoxy resin***

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I. Introduction:
In the last decades, there has been a continuous increase in the usage of fiber reinforced composites as structural materials in many industries such as automotive, marine fields, aerospace engineering, constructions and sports equipments, due to their desirable properties like strength, lightweight, stiffness, high temperature resistance, corrosion resistance, design flexibility, etc. Their performance is influenced by many factors like the type of reinforcing fibers and their orientation. The reinforcing fibers may be introduced into the matrix as; short, random fibers which give relatively isotropic behavior in the composite. While long or continuous unidirectional arrangements of fibers produce anisotropic properties with particularly good strength and stiffness parallel to the fibers, and they are often designated as 0º piles in which all fibers are aligned with the direction of the applied stress [1]. Woven fabrics are widely utilized in reinforcements of composites structures as an alternative to traditional unidirectional fibers reinforcing lay-ups, due to the use of high performance fibers in high quality weaves that offers easier manipulation and lay-up during manufacturing, good drapeability, high impact resistance and damage tolerance of the composite material, in addition to low production costs [2,3].
The developments in composite materials to improve their performance based on the reinforcement of two or more fibers in a single polymeric matrix such as: synthetic fiber with another synthetic fiber or synthetic fiber with natural fiber or synthetic fiber with metallic fibers, which leads to an advanced material system called hybrid composites. The purpose of hybridization is to create a material possessing the combined advantages of the individual components and justifying their less desirable qualities, with an increase in resistance against the interlaminar toughness that cannot be obtained with only

conventional composite material. Polymeric materials reinforced with synthetic fibers such as glass, carbon and aramid provide advantages of high stiffness and strength to weight ratio. In spite of these advantages, the use of synthetic fiber reinforced polymer composites has a tendency to decline because of their high-initial costs and production processes that requires a large quantum of energy. Also, the environment suffered because of the pollution generated during the production and recycling of these materials. So, natural fibers are commonly used as reinforcement, because they are environmentally friendly, biodegradable, renewable, cheap and have low density compared to synthetic fibers [4-7].

Sandwich structured composites are a special class of composite materials that of particular interest, because they offer lightweight structures with high strength, in-plane and flexural stiffness. Sandwich panels consist typically of three layers structure; two thin, stiff and strong face sheets (skins) bonded together with a relatively thick lightweight core. The overall performance of sandwich structures depends on the material properties of the constituents (skins, adhesive and core), geometric dimensions and type of loading. The adhesion of both materials is very important for load transferring and the functioning of the sandwich as a whole [8-11].The skins carry almost all of the bending and in-plane loads and the core helps to stabilize the skins and defines the flexural stiffness and out-of-plane shear and compressive behaviour [9,10]. As for all types of sandwich structures, a wide range of damages exist during manufacturing and application. The most possible failure modes include tensile or compressive failure of the skins, the delamination occurring on the face/core interface, indentation failure under concentrated loads, core failure, wrinkling of the compression face and global buckling [8,9].

Investigation of the damage behaviour of hybrid sandwich composites has received the attention of researchers. They highlighted that, stacking pattern of the different components in hybrid laminated composite play an important role in influencing the mechanical properties of the hybrid composites [12]. Xu et al.,[13] reported that, by using the concept of hybridization of glass, polypropylene, and PVA fibers, the resulting hybrid composite offered more attractive engineering properties than composites made with only one type of fiber. Also, Cyr et al.[14]found that, a hybrid composite with glass and PP fibers is stronger than a mono-PP fiber composite and tougher than a mono-glass fiber composite. A study was carried out on nonwoven and woven banana/kenaf hybrid composites to investigate their properties. It was indicated that, woven hybrid composites showed better tensile strength than nonwoven hybrid composites [15]. Zhang et al.,[16] studied the mechanical performance for a hybrid composites made of woven carbon/glass reinforcements with epoxy resin matrix produced with different stacking sequences. The laminates were tested against the tensile, compressive, and flexural strengths. With the glass/carbon (50:50) hybrid composition, the stacking sequence didn't show noticeable influence on the tensile properties but affected the flexural and compressive properties significantly. Cicala et al., [17] studied some hybrid synthetic/natural composites and reported that, hybrid glass/hemp/epoxy composites showed good tensile properties and lower cost and weight compared to pure glass/epoxy composites.

The aim of the present work is to experimentally investigate the behavior of new hybrid sandwich composites subjected to tensile loads in warp and weft direction of fabrics. The hybrid sandwich composites were prepared using reinforcements from woven fabrics produced with various constructional parameters as the skins and nonwoven fabric as the core layer and two types of matrices. The influence of reinforcement materials properties of the sandwich structure, as well as the matrix type was considered to characterize the tensile strength of these new structures.

II. Experimental:

A. Materials:

The reinforcements used in the study includes: Twenty seven types of woven fabrics manufactured using polyester fibers of count (5 Nm) in warp threads, with three types of weft materials; glass, Nylon and Flax fibers. The fabrics were woven using three types of weaving structures and three picks densities. 100% polyester nonwoven fabric was chosen for the core layer, its specifications are given in table (1). Thermoset resins used for the matrix are; Polyester resin used with the catalyst (Methyl ethyl ketone peroxide) and the accelerator (Cobalt Napthanate). Epoxy resin: Kemapoxy 150 was used, it is a two component solvent free liquid epoxy resin with the hardener.

Table 1. Specifications of the nonwoven polyester fabric.

Fabric material	Fiber count (denier)	Weight (g/m^2)	Thickness (mm)	Tensile Strength (kg)
100% Polyester	11.5	233	2.46	22.8

Table 2. Specifications of the sandwich composites produced.

(Skin)Woven fabric materials	Weaving structure	No. of picks/cm	Core material	Matrix type	
Polyester /Flax	Warp Rib2/2	11	Nonwoven polyester	Polyester resin	Epoxy resin
		13			
		15			
	Twill 2/2	11			
		13			
		15			
	Satin 4	11			
		13			
		15			
Polyester/Glass	Warp Rib2/2	11			
		13			
		15			
	Twill 2/2	11			
		13			
		15			
	Satin 4	11			
		13			
		15			
Polyester/Nylon	Warp Rib2/2	11			
		13			
		15			
	Twill 2/2	11			
		13			
		15			
	Satin 4	11			
		13			
		15			

B. Scouring of Polyester/flax fabrics:

Alkali treatment of the polyester/flax fabrics was applied to improve the fiber-matrix adhesion during fabrication of composites, due to the removal of the natural impurities found in the flax fibers. The fabric was emerged in a water bath containing 5 g/l sodium hydroxide (Na OH), 5 g/l sodium carbonate (Na_2Co_3) and 5 g/l a non-ionic wetting agent for 30 minutes at 70°C with liquor ratio of 1g: 40l. The fabric was washed thoroughly and then neutralized with acetic acid followed by washing and drying.

C. Preparation of the sandwich composite panels:

The sandwich composites were prepared in the form of three-layer structure using the hand lay up technique .The upper and lower layers (skins) of the sandwich structure are from the same type of each woven fabric produced, and the middle layer (core) is from the polyester nonwoven fabric. The sandwich composites were fabricated using polyester and epoxy matrices and were left to cure at room temperature. Specifications of the hybrid sandwich composites produced are presented in table 2.

D. Mechanical Testing:

1) Tensile strength test of the woven fabrics:

The tensile properties of the woven fabrics used were determined according to ASTM D5035 [18].The test was done in both warp and weft directions of the fabric. The fabric specimen was placed in the grips and pulled until failure. The test was carried out at the textile testing laboratory at National Research Center.

2) Tensile strength test of the hybrid sandwich composites:

The tensile strength of the sandwich composite specimens was determined according to ASTM D638 using Instron type 5500R device [19]. The test was performed in both the warp and weft directions of the fabrics. The tensile strength of the composite specimens is calculated from the formula: $TS = L/A$. Where TS is the tensile strength in (kg/cm^2), L is the maximum tensile load in (kg) and A is the area of the specimen in (cm^2). Figure 1 shows the specimen placement before applying tensile loading and figure 2 shows the specimen after loading and fracture. The test was carried out in the Material testing laboratory in the Central unit for analysis and scientific services at National Research Center.

Figure 1. The placement of the specimen before tensile loading.

Figure 2. The specimen after applying loading and fracture

III. Results and Discussion:

A. Tensile strength test results of woven fabrics:

The tensile strength test was primarily applied on the woven fabrics (skins) that will be used in the sandwich structure, to study the influence of the constructional parameters on their performance. The test was performed in both warp and weft direction of fabrics.

1) Tensile strength of woven fabrics in warp direction:

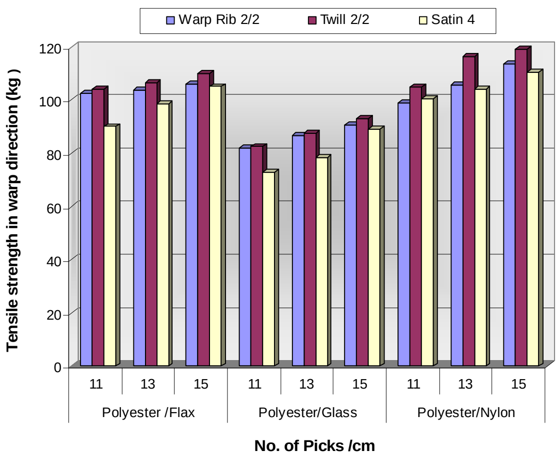

Figure 3. Tensile strength of woven fabrics in warp direction.

Figure 3, shows the tensile strength test results of woven fabrics in the warp direction. It was observed that, the results are close to some extent for each type of fabric due to the constant of warp material (polyester fibers). The polyester/nylon fabric weaved with twill 2/2 and 15 picks/cm had the highest tensile strength. This may be related to the high tenacity of nylon fibers due to the presence of the amide group which provides hydrogen bonding between chains giving nylon fibers high strength and elongation. While the polyester/glass fabrics showed lower tensile strength compared to the other fabrics, especially the one woven with satin 4 and 11picks/cm. Due to glass fibers characteristics such as low elongation and high smoothness, slippage occurs between yarns during applying tensile load. In general, all of fabrics woven with twill 2/2 structure showed higher tensile strength values followed by the warp rib 2/2 and satin 4 fabrics. This is related to the effect of yarns intersections in the weaving structure since as floats decrease, the more the yarns gripping points in the fabrics increase. Also, the tensile strength showed improvement with increasing picks densities, due to increasing the number of yarns sharing the load which leads to lacking of air spaces between them, increasing the friction areas and their resistance to tensile load.

2) Tensile strength of woven fabrics in weft direction:

Figure 4, shows the tensile strength test results of woven fabrics in the weft direction. It was clear that, the tensile strength of the fabrics in weft direction is higher than that in warp direction. The polyester/nylon fabrics showed the highest values of tensile strength especially the fabric woven with twill 2/2 and 15 picks/cm. This is related to the high tenacity and elongation properties of nylon fibers as mentioned above. While the polyester/glass fabrics showed the lowest values of tensile strength especially the fabric woven with warp rib 2/2 and 11 picks/cm. It was indicated that, fabrics woven with twill 2/2 structure recorded the highest tensile strength followed by satin 4 and warp rib 2/2 fabrics for the polyester/nylon fabrics and polyester/glass fabrics. Also, the tensile strength of fabrics enhanced with increasing picks densities due to increasing the number of yarns sharing the load.

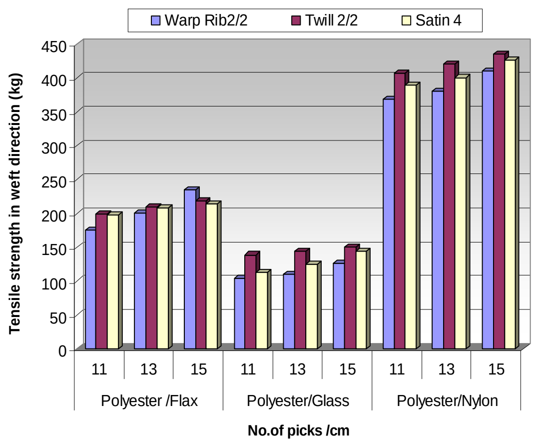

Figure 4. Tensile strength of woven fabrics in weft direction

B. Tensile strength test results of the hybrid sandwich composites:

The tensile strength test was applied on the hybrid sandwich composites produced using polyester and epoxy matrices. The influence of fiber/matrix interface and fibers orientation with respect to skins constructional parameters on the tensile strength was investigated. The test was performed in the warp and weft direction of fabrics.

1) Tensile strength of the hybrid sandwich composites in warp direction:

Figures 5 and 6, show the experimental results of the tensile strength test applied on the hybrid sandwich composites fabricated using polyester and epoxy resins, respectively. It was observed that, the sandwich composites fabricated using epoxy resin showed higher values of tensile strength compared with those fabricated using polyester resin. This may be related to epoxy resin high adhesive properties due to the presence of hydroxyl and ether groups which leads to good interfacial bonding between the fibers and the matrix, increasing the composites stiffness and resistance to delamination. Woven fabrics properties (skins) are able to withstand the tensile stress and the core layer nonwoven porous structure allows it to impregnate well with the resin, resulting in good adhesion in skin/core interface of the sandwich structure to withstand the forces applied on it. As it increases the strength and stiffness of the structure by absorbing the stresses and distributes them in the sandwich layers.

It was cleared from figure 5 that, the sandwich composites fabricated using polyester resin with skins from the polyester/nylon fabric woven with warp rib 2/2 and 13 picks/cm showed the highest value of tensile strength. While the sandwich composites with skins fabricated from the polyester/glass fabric woven with warp rib 2/2 and 15 picks/cm showed the lowest tensile strength. Moreover, it was clear from figure 6 that the sandwich composites fabricated using epoxy resin with skins from the polyester/glass fabric woven with twill 2/2 and 13 picks/cm showed the highest values of tensile strength. While the sandwich composites with skins from the polyester/nylon fabric woven with warp rib 2/2 and 15 picks/cm showed the lowest tensile strength value. This may be owing to glass fibers low volume and thickness which allows epoxy resin to penetrate the skins fabrics, bonding the sandwich layers together and increasing their interlaminar fracture resistance. It was observed that, for either the sandwich composites fabricated using polyester or epoxy resins that, the tensile strength enhanced to certain extent with increasing picks densities to 13 picks/cm then decreased with 15 picks/cm. Due to of lacking of free spaces for yarns to move during exposure to load, so they begin to exhibit less resistance.

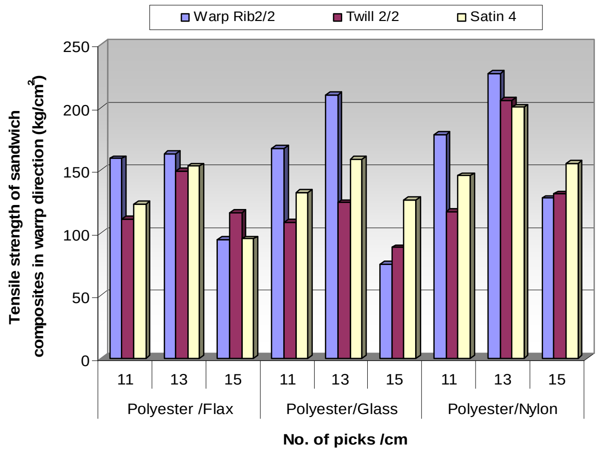

Figure 5. Tensile strength of sandwich composites fabricated using polyester resin in warp direction.

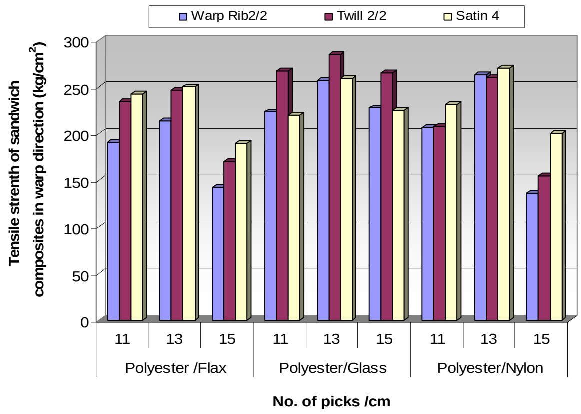

Figure 6. Tensile strength of sandwich composites fabricated using epoxy resin in warp direction

2) Tensile strength of the hybrid sandwich composites in weft direction:

Figures 7 and 8, show the experimental results of the tensile strength test applied on the sandwich composite specimens fabricated using polyester and epoxy resins, respectively. It was observed that, the tensile strength of the sandwich composites in weft direction is higher than that in the warp direction. The sandwich composites fabricated with epoxy resin showed higher tensile strength values compared with those fabricated with polyester resin. Also, the sandwich composites fabricated with polyester/glass skins using either polyester or epoxy resins exhibited higher values of tensile strength compared to the other specimens .While the sandwich composites fabricated with polyester/flax skins using either polyester or epoxy resins showed lower tensile strength values. This may be related to glass yarns orientation in the direction of load and their high stiffness, because they are characterized by the presence of very thin continuous fibers in their cross-section which bend during applying loads, leads to increasing the structure strength and resisting delamination. In addition to, the weak interfacial bonding between the polyester/flax fabrics and the matrices and their low interlaminar fracture resistance.

It was indicated that, the sandwich composites fabricated using polyester resin with skins from the polyester/glass fabrics woven with twill 2/2 and 13 picks/cm showed the highest tensile strength. Although, the sandwich composites fabricated with skins from polyester/flax fabric woven with satin 4 and 11 picks/cm had the lowest value. The tensile strength increased with increasing picks densities to 13 picks/cm then decreased with 15 picks/cm. Furthermore it was observed from figure 8 that, the sandwich composites fabricated with epoxy resin and skins from the polyester/glass fabric woven with warp rib 2/2 and 15 picks/cm presented the highest values of tensile strength. While the sandwich composites with skins from polyester/flax fabric weaved with warp rib 2/2 and 11 picks/cm showed the lowest values of tensile strength compared with all specimens. It was indicated that, the tensile strength in weft direction increased with increasing picks densities due to increasing the number of yarns bearing the tensile load, and to the high adhesive properties of epoxy resin that leads to good interfacial bonding between fibers and matrix and increasing the composites stiffness and strength.

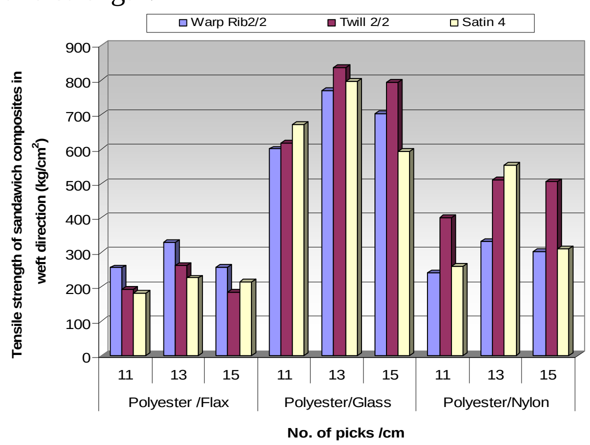

Figure 7. Tensile strength of sandwich composites fabricated using polyester resin in weft direction

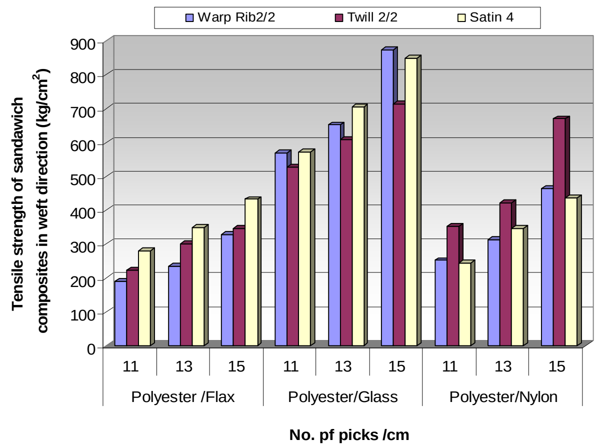

Figure 8. Tensile strength of sandwich composites fabricated using epoxy resin in weft direction.

Surface morphological analysis of the hybrid sandwich composites was carried out using a scanning electron microscope JEOL, JXA -840A. SEM images were obtained on the sandwich composites after applying load and fracture. Figures 9 and 10 show, SEM images of the polyester/glass sandwich composites fabricated using polyester and epoxy resins, respectively. In figure 9 it was observed that, the polyester resin coated the skin layer and distributed uniformly over it because of its low viscosity which eases impregnation of the fibers within the polymer matrix, resulting in a good interfacial bonding between matrix and fibers. While in figure 10 it was clear that, the sandwich composite specimen is coated with epoxy resin making a thick layer on it, because of its high viscosity which is affected by the fibers volume and the fabric thickness and weaving structure. Also its adhesive properties caused in better bonding between the sandwich composite layers. Figures 11 and 12, show SEM images of the polyester/glass skin layer in the sandwich composites fabricated with polyester and epoxy resins after applying load, respectively. It was observed, the fracture happened due to presence of matrix cracks in the direction of stress during applying load, which leading to propagation of cracks and fibers debonding from matrix. This is related to the low inter laminar fracture toughness that causes delamination in the structure and rupture of specimen.

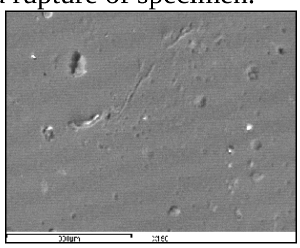

Figure 9. SEM of polyester/glass sandwich composite fabricated with Polyester resin

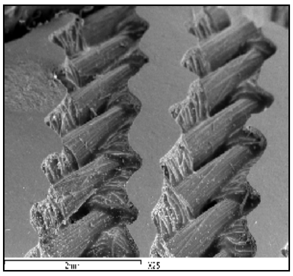

Figure 10. SEM of polyester/glass sandwich composite fabricated with Epoxy resin.

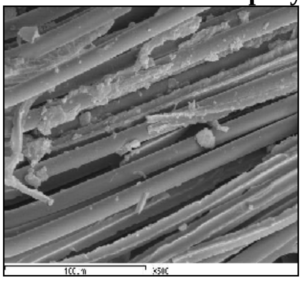

Figure 11. SEM of the polyester/glass skin layer in the sandwich specimen fabricated with Polyester resin.

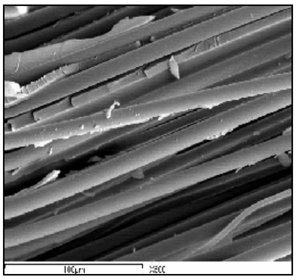

Figure 12. SEM of the polyester/glass skin layer in the sandwich specimen fabricated with Epoxy resin.

IV. Conclusion

The tensile properties of new hybrid sandwich composites were investigated and the influence of reinforcement materials properties and matrix type were considered and studied. The main results were as follows:

1- The tensile strength of the sandwich composite in weft direction is higher than that in warp direction.

2- The sandwich composites fabricated using epoxy resin showed high tensile strength values in both directions of fabrics compared with similar specimens fabricated using polyester resin.

3- The sandwich composites with polyester/glass skins produced using polyester and epoxy resins exhibited high tensile strength in the weft direction.

4- Woven fabrics (skins) materials properties and structure in addition to fiber/matrix interface had a great influence on the tensile behaviour of the hybrid sandwich composites produced.

5- Increasing picks densities had a different effect on the tensile strength in the warp and weft directions and it is affected by the matrix type.

Thus, the new hybrid sandwich composites developed in the present study could be employed as cost-effective structural materials and tailored in several industrial applications.

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