**Composite as Biomaterials: Versatile Applications**

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**Abstract:** Composites, as biomaterials, refer to engineered materials that are specifically designed for use in medical and healthcare applications. These composite materials are composed of two or more distinct components, each with its own unique properties, combined to create a new material with desirable characteristics for biomedical use. The components of these composites work synergistically to achieve superior mechanical, biological, or functional properties compared to the individual components alone.Composites are chosen based on their biocompatibility, mechanical strength, degradation behavior (if applicable), and their ability to interact favorably with the human body. The combination of different materials allows for tailoring of specific properties, making these composites highly versatile and suitable for a wide range of medical applications. Composite biomaterials have significantly advanced medical technology and have been instrumental in various medical applications, including implants, prosthetics, drug delivery, tissue regeneration, and diagnostic tools. Their ability to mimic or enhance the properties of natural tissues makes them essential for improving patient outcomes and overall healthcare. As research and development continue, composite biomaterials are expected to play an increasingly vital role in addressing complex medical challenges and improving the quality of life for patients worldwide.

**Keywords:** Biocomposites, Matrix, Reinforcement, Orthopedics, Cancer, Drug delivery systems.

**1. Introduction:**

The word “composite” means combination on a microscopic scale, of two or more material; they are different for many factors like morphology, physical properties and combination. The term “composite” is generally reserved for those materials in which individual phases are separated on a scale larger than the atomic and whose properties, such as elastic modulus, vary significantly compared to a homogeneous material. In many cases, and depending on the constituent properties, composites can be designed with a view to produce materials with properties tailored to fulfill specific chemical, physical or mechanical requirements. Therefore over the past 40 years the use of composites has progressively increases, and today composites materials have many different applications like biomedical, automotive, and aeronautic and so on. Consequently many composites biomaterials have recently been studied and tested for medical applications. Some of them are currently commercialized for their advantages over traditional materials. Most human tissue such as bones, tendons, skin, ligaments, teeth etc., are a composites, made up of single constituents whose amount, distribution, morphology and properties determine the final behavior of the resulting tissue or organ. Man made composites can, to some extent, be used to make prostheses able to mimic these biological tissues, to match their mechanical behavior and to restore the mechanical functions of the damaged tissue.

A composites can be defined as a material composed of two or more chemically distinct phases (e.g., metals, ceramics, and polymers), which have been investigated and developed in the biomedical engineering field. Composites add the properties and advantages of metals, ceramics and polymers exhibiting improved features or new, unique features. Engineering materials, including metals, polymers and ceramics, have various unique features and have therefore been extensively investigated for many biomedical applications. Composite materials are not new and have been employed as engineering materials for thousands of years. In recent decades, especially with the emergence of nanotechnology, composites with unique structures and functions are attracting increasing attention in almost all engineering fields, including biomedical engineering. Composites materials may contain a combination of properties from each of the constituent elements (i.e., metals, ceramics and polymers) or create new properties and therefore exhibit superior or unique properties, typically as lighter but stronger and stiffer materials. The properties of composites can be controlled by the changing the composition of the components, their properties and interface ratios.

**Table 1**Mechanical property of hard tissues

133

52

7.4

10

39.3

17.7

12.8

0.4

84.3

11.0

Tensile strength (MPa)

Modulus(GPa)

Cortical bone(longitudinal direction)

Hard Tissue

Cortical bone (Transverse direction)

Cancellous bone

Enamel

Dentine

**Table 2** Mechanical properties of soft tissues

Tensile strength (MPa)

Modulus (GPa)

Soft Tissue

Articular Cartilage

Fibrocartilage

Ligament

Tendon

Skin

Arterial Tissue (longitudinal direction)

Arterial Tissue (transverse direction)

27.5

10.4

29.5

46.5

7.6

0.1

1.1

10.5

159.1

303.1

401.5

0.1-0.2

For example, modern composites such as metals or plastics reinforced with glass fibers or CFs are widely used in the automobile and aircraft industries, which possess good mechanical properties but are lighter in weight than conventional metals or plastics. Their strength and stiffness can be varied by changing the reinforcement/matrix ratio. Due to their distinctive properties, composites materials have advantages for many applications in the biomedical field. Human body is a complex system with different compositions, structures, and different functions. Tissues are generally classified into hard tissues (i.e., bone and tooth) and soft tissues (i.e., skin, cartilage, and blood vessels), which have different mechanical properties (Table 1 and Table 2). Accordingly, metallic and ceramic biomaterials with relatively high stiffness are often employed for hard tissue repair/replacement, while polymers are commonly used for soft tissue repair. However bone is a natural nanocomposite material, consisting of a tough but brittle material and a collagen, natural polymer. The composite nature of bone makes it strong and resilient, capable of withstanding high stresses, carrying high loads (for 5 times the body weight for the hip joint during walking and a peak load of more than 10 times the body weight during jumping), and many endurance motion cycles (around 106motion cycles for a finger and hip joint in a year). Due to the high stiffness of metals and ceramics and the brittle nature of ceramics, it is extremely difficult to use one single type of metallic or ceramic material, if possible, to make bone replacement materials which are mechanically compatible to natural bone. The mechanical mismatch between the implanted material and the natural bone leads to unsatisfactory result such as loosening of implants since bone is remodeled because of high stress caused by the implantation of prosthesis with very high stiffness. According to “Wolff’s Law” and load sharing principle in composites, bone remodeled until the stress and strain retained at a certain level. In addition, “ideal” bone replacement materials must be biocompatible and bioactive (i.e., osteoconductive) to achieve good interaction between the implant and host tissue. Composite materials composed of bioactive ceramics and suitable polymers, therefore, become attractive candidates for bone replacement that can simultaneously provide excellent properties in terms of strength, biocompatibility and bioactivity. In many other fields such as medical imaging and drug delivery metallic or ceramic nanomaterials have shown their great potential. Overall, it is important to use composite approaches to develop new biomaterials to meet specific and important biomedical requirements.

Composites materials have been extensively used in dentistry and prosthesis designers are now incorporating these materials into other applications. Typically, a matrix of ultrahigh-molecular-weight polyethylene (UHMWPE) is reinforced with carbon fibers. These carbon fibers are made by pyrolizing acrylic to obtain oriented graphitic structures of high tensile strength and high modulus of elasticity. The carbon fibers are 6-15μm in diameter, and they are randomly oriented in the matrix. In order to high modulus property of the reinforcing fibers to strengthen the matrix, a sufficient interfacial bond between the fiber and matrix must be achieved during the manufacturing process.

Composites have unique properties and are usually stringer than any of the single materials from which they are made. Workers in the field have taken advantages of this fact and applied it to some difficult problems where tissue in-growth is necessary. Such as:

* Deposited Al2O3;
* Carbon/ PTFE;
* Al2O3/ PTFE;
* PLA-coated Carbon fibers

**2. Classifications of composite:**

A variety of composite materials have been investigated for various biomedical applications. According to different matrix materials (i.e., major phase), composites are classified into ceramic- matrix composites,polymer-matrix composites, and metal-matrix composites. Generally, the type of matrix materials defines the general properties of composites. Alternatively, composites are classified by different geometries of reinforcement (i.e., dispersion phase): fiber-reinforcement composite, particle-reinforcement composite, and structure composites.

**Thermo set-matrix composites**

**Sandwich composites**

**Thermoplastic-matrix composites**

 **Structural composites**

**Particle composites**

**Fiber-reinforcement composites**

**Composite Materials**

 **(Based on matrix reinforcement)**

**Thermoset-matrix composites**

**Thermoplastic-matrix composites**

**Polymer-matrix composites**

**Ceramic-matrix composites**

**Composite Materials**

 **(based on matrix)**

**Metal-matrix composites**

**Laminated composites**

 Fig. 1: Classifications of Composites

**Composite**

**Structural**

**Fiber-reinforced**

**Particle-reinforced**

**Dispersion**

-**strengthened**

**(10**~**100nm)**

**Continuous**

**(aligned)**

**Discontinuous**

**randomly oriented**

**Discontinuous**

**(Short, aligned)**

**Large particle**

**Laminated**

**Sandwich**

**panels**

Fig. 2: Composite classification according to the geometry of the reinforcement (the second, minor phase)

Biomedical composites can also be classified into bioinert composites, bioactive composites, and biodegradable composites. Bioinert composites are generally composed of two or more chemically different bioinert materials. Bioactive composites contain a materials (as either matrix or reinforcement), that induces specific biological responses for cell functions, such as A-W glass ceramics, and other bioactive bioceramics. In the case of biodegradable composites, biodegradable materials for example biodegradable polymers (PLA, PLGA, PCL, etc.), and bioceramics (e.g., TCP) which can be completely degraded in the human body with no or limited side effects are employed as constituting materials, resulting in the desired composites for new generation of implants.

**3. Matrix, Reinforcement, and Interface:**

**Polymers:**

There are a large number of polymeric materials that have been used as implants or part of implant systems. The polymeric systems include acrylics, polyamides, polyesters, polyethylene, polysiloxanes, Polyurethane, and a number of reprocessed biological materials.

Some of the applications include the use of membranes of ethylene-vinyl-acetate(EVA) copolymer for controlled release and the use of poly-glycolic acid for use as a restorable suture material. Some other typical biomedical polymeric materials applications include: artificial heart, kidney, liver, pancreas, bladder, bone cement, catheters, contact lenses, cornea, and eye-lens replacements, external and internal ear repairs, heart valves, cardiac assist devices, implantable pumps, joint replacements, pacemaker, encapsulations, soft tissue replacements, artificial blood-vessels, artificial skin, and sutures.

As bioengineers search for designs of ever increasing capabilities to meet the needs of medical practice, polymeric materials alone and in combination with metals and ceramics are becoming increasingly incorporated into devices used in the body.

**Metals:**

Metals are used as biomaterial due to their excellent electrical and thermal conductivity and mechanical properties. Since some electrons are in metals, they can quickly transfer an electric charge and thermal energy. The mobile free electrons as the binding force to hold the positive metal ions together. The attraction is strong, as evidence by the closely-packed atomic arrangement resulting in high specific gravity and high melting points of most metals. Since the metallic bond is essentially non-directional, the position of the metals ions can be altered without destroying the crystals structure, resulting in a plastically deformable solid.

The metallic systems most frequently used in the body are:

1. Iron-base alloys of the 316L stainless steel

2. Titanium and titanium-base alloys, such as

(a). Ti-6% AI-4%V, and commercially pure ≥ 98.9%

(b). Ti-Ni (55% Ni and 45% Ti)

3. Cobalt base alloys of four types

(a) Cr (27-30%), Mo (5-7%), Ni (2-5%)

(b) Cr (19-21%), Ni (9-11%), W (14-16%)

(c). Cr (18-22%), Fe(4-6%), Ni (15-25%), W (3-4%)

(d). Cr (19-20%), Mo (9-10%), Ni (33-37%)

The most commonly used implant metals are the 316L stainless steels, Ti-6%-4%V, and Cobalt-base alloys of type “ⅰ” and “ⅱ”. Other metal systems being investigated include Cobalt-base alloys of type “ⅲ” and “Ⅳ” , and Niobium and shape memory alloys, of which (Ti 45%-55%Ni) is receiving most attention.

Some metals are used as passive substitutes for hard tissue replacement such as:

1. Total hip:
2. Knee joints;
3. For fracture healing aids as bone plates and screws;
4. Spinal fixation devices;
5. Dental implants, due to their excellent mechanical properties, and corrosion resistance;
6. Vascular stents;
7. Catheter guide wires.

**Ceramics:**

Ceramics are inorganic, nonmetallic, and solid materials. Due the high stiffness and mechanical strength(Table 3) of bulk bioceramics such as (Al2O3), make them good candidates for load-bearing medical devices in orthopedics and dentistry. The most frequent used ceramic implant materials include aluminum oxides, calcium phosphates, and apatites and graphite. Glasses have also been developed for medical applications. The use of ceramics was motivated by:

1. Their inertness in the body,
2. Their formability into variety of shapes and porosities,
3. Their high compressive strength, and
4. Some cases their excellent wear characteristics.

**Selected applications of ceramics include:**

1. Hip prostheses,
2. Artificial knees,
3. Bone grafts,
4. A variety of tissues in growth related applications in
* Orthopedics
* Dentistry, and
* Heart valves.

Applications of ceramics are in some cases limited by their generally poor mechanical properties: (a) in tension; (b) brittleness; (c) load bearing, implant devices that are to be subjected to significant tensile stresses must be designed and manufactured with great acre if ceramics are to be safely used.

**Table 3: Mechanical Property of Ceramics**

 Tensile Strength (MPa)

Modulus(GPa)

P

 Ceramics

300

820

42

50

380

220

35

95

Alumina

Zirconia

Bioglass

HA

**4. Reinforcements:**

**Particles:**

For biomedical composites, rigid particulate reinforcements are usually dispersed in ductile materials (e.g., polymers). The mechanical and biological properties of particle-reinforced composites are significantly influenced by the properties (such as compositions, size and shape) of reinforcing particles. Bioactive bioceramic nanoparticles, such as Ca-P, and A-W glass-ceramic particles are used for making bone-mimicking bioactive composites for orthopedic and/or dental applications.

**Whiskers and chopped fibers:**

Composite with fibrous reinforcements are capable of significant improvement in mechanical properties, which are influenced by the mechanical properties of fibers themselves, aspect ratio ( i.e., fiber length and fiber diameter ratio), fiber diameter, and fiber volume fraction etc. In fiber-reinforced composites, the fibrous reinforcements are either continuous (aligned long fibers) or discontinuous (whiskers or chopped fibers), and the distribution of whiskers or chopped fibers in the matrix is aligned or randomly oriented. The mechanical properties of composites reinforced by aligned whiskers and chopped fibers are anisotropic, while randomly oriented and discontinuous fiber-reinforced composite can be considered as isotropic. Aligned whiskers and chopped fibers as reinforcements are usually high-cost thin single crystals such as alumina, SiC, and SiN that have nearly perfect crystal structures and extremely high stiffness, enabling significant mechanical property improvement for metal or ceramic matrix. Chopped glass fibers are used to reinforce the polymer matrix.

**Long fibers:**

Continuous fiber reinforced composites (i.e., long fiber as reinforcement) are also used in the biomedical field. Long fibers are generally either polymer or ceramic fibers and include aramid fibers, UHMWPE fiber, cellulose fibers, CFs, glass fibers, and Ca-P fibers. CFs is made from a variety of precursor fibers (polymer, mesophase pitch, etc.)

**5. Interface:**

**Bonding mechanism:**

The interface between the reinforcement and the matrix strongly affects the resulting composites properties, which are controlled by different bonding processes involving either strong or weak. Generally, a strong interface results in high strength of resultant composites but leads to low toughness of composites. Conversely, a weak interface can result in composites with low strength and sometimes cracks. The interfacial bonding between the reinforcement and the matrix is either physical or chemical, as illustrated in figure 3.

 **Matrix**

Matrix

**Matrix**

 **A A A A A A** A

 **B B B B B B B**

**Reinforcement**

Reinforcement

**Reinforcement**

**Chemical reaction**

**Electrical attraction**

**Molecular entanglement**

**Following inter-diffusion**

**Mechanical interlocking**

**Cationic-anionic**

**interaction**

 **Matrix**

 **Reinforcement**

 **Matrix**

Fig. 3: Schematic diagrams showing interfacial bonding between the reinforcement and matrix in composites.

**6. Interfacial bond strength:**

The interfacial bond strength of composite materials refers to the bond strength between the different components or phases of the composite. Composites are generally made by combining two or more materials with distinct properties to create a new material with improved mechanical, thermal or electrical properties.

n a composite material, you have two main components:

**Matrix:** The matrix is the continuous phase that surrounds and binds the other component(s) together. It can be polymer, metal, ceramic, or other types of materials.

**Reinforcement:** The reinforcement is the discontinuous phase that is embedded within the matrix to provide additional strength, stiffness, or other desirable properties. The reinforcement can be in the form of fibers, particles, or flakes.

The interfacial bond strength is critical to the overall performance of the composite because it affects how well the matrix and reinforcement transfer stress between each other. If the bond between the matrix and reinforcement is weak, it can lead to poor load transfer, reduced mechanical properties, and premature failure of the composite.

The interfacial bond strength of various types of fibrous composites is investigated through experiments and theoretical analysis,Aims to study the shear stress that causes debonding of the reinforcement from the matrix and the debonding process. Single fiberPull-out or single fiber push-out tests are often used to determine the critical interfacial shear stress for debonding (Figure 5), thereby measuring the interfacial bond strength.

**7. Design of composites:**

**Major influencing factors for composite properties**

Properties (Physical, structural, mechanical, biological, etc.) of composites are affected by many factors. Major influencing factors for biomedical composites include:

(1) Matrix properties (average molecular weight of polymer, average grain size of metal or ceramic, etc.)

 (2) Bioactivity of the reinforcement or matrix

(3) Stability and biodegradability of the reinforcement or matrix

(4) Reinforcement shape, size, and size distribution

 (5) Reinforcement properties and volume percentage in composite

(6) Distribution (and orientation) of the reinforcement in the matrix

(7) Reinforcement-matrix interfacial state

**σ\***

**σ\***

**Matrix**

 Matrix

**Matrix**

**Single fiber push-out test**

**Single fiber pull-out test**

Fig.5: Schematic diagrams showing mechanical tests for determining interfacial bond strength.

**8. Biomedical applications of composites materials:**

**a) Composites in dentistry:**

Almost every person faces dental problems in his/her life. Various biomaterials are used for various dental treatments ranging from cavity filling to tooth replacement.Biocomposites have found various applications in dentistry due to their advantageous properties. Biocomposites are used as dental filling materials to restore the form and function of damaged or decayed teeth. These materials provide good mechanical strength and durability, making them suitable for withstanding the forces of chewing. Biocomposites can be used as implant materials due to their biocompatibility, which reduces the risk of rejection or adverse reactions from the body. They also have a bone-like structure, which encourages osseointegration, the process of the implant fusing with the surrounding bone. Biocomposite-based dental adhesives are used to bond restorative materials to tooth structures. The adhesive properties of these materials ensure a strong and durable bond, reducing the risk of restoration failure.

 **b) Composites in orthopedics:**

Biocomposites in orthopedics are designed to promote tissue integration, reduce inflammation, and enhance the healing process, making them ideal for various medical devices and implants used in orthopedic treatments. Biocomposites have been explored for cartilage repair and tissue engineering applications. They can be used as scaffolds to support the growth of new cartilage cells and aid in the regeneration of damaged cartilage. In the field of tissue engineering, biocomposites are being investigated to create joint scaffolds that can help repair or regenerate damaged joint tissues, such as articular cartilage and menisci. Biocomposites can be used in orthopedic applications that involve soft tissue repair, such as tendon and ligament repairs. These materials can provide support and promote healing while gradually breaking down and being replaced by natural tissue. Biocomposites are used in the manufacturing of various orthopedic implants, such as plates, screws, and rods, which are implanted in the body for bone fixation and stabilization.

**c)Composites in Tissue Engineering:**Composites play an important role in tissue engineering, a multidisciplinary field that aims to create functional biological tissues and organs using combinations of cells, biomaterials and bioactive molecules. Tissue engineering composites are designed to mimic the complex structure and properties of native tissues, ultimately promoting cell adhesion, growth and differentiation to regenerate or replace damaged or diseased tissues. issue engineering scaffolds are three-dimensional structures that provide a template for cell attachment and tissue regeneration. Composites are often used as scaffolding materials due to their versatility and ability to combine different properties. Biocompatible polymers, ceramics, and natural materials such as collagen or fibrin are commonly combined to form composite scaffolds. These composites match the mechanical properties of specific tissues, providing mechanical support during tissue formation.Biodegradable composites are used in tissue engineering to create temporary scaffolds that degrade over time as new tissue forms. These composites often consist of a combination of synthetic polymers and natural materials, which allows them to provide structural support in the early stages of tissue regeneration while gradually making room for newly formed tissue.Nanocomposites, which consist of nanoscale materials, are used in tissue engineering to improve properties such as mechanical strength, surface roughness, and bioactivity. Incorporating nanoparticles into composite matrices can improve cell adhesion, proliferation and tissue integration.

**d) Composites in drug delivery:**

Composites in drug delivery refer to the use of composite materials to improve controlled release and targeted delivery of pharmaceutical agents to specific sites in the body. These compounded drug delivery systems are designed to enhance the therapeutic efficacy of drugs, reduce side effects, and increase patient compliance. Composites used in drug delivery are usually composed of different materials, such as polymers, ceramics, metals or nanoparticles, that work together to achieve specific drug delivery objectives. Here are some common types and applications of composites in drug delivery:

**Polymeric Composites:** polymeric composites are widely used in drug delivery systems due to their biocompatibility, tunable properties and ease of fabrication. These composites can be designed to encapsulate drugs within a polymer matrix, allowing controlled release over time. In addition, functionalization of polymer matrices with specific ligands or targeting moieties can enable targeted drug delivery to specific tissues or cells.

**Nanocomposites:** Nanocomposites, which consist of nanoparticles dispersed within a polymer matrix, are used to improve drug delivery efficiency. Nanoparticles can enhance drug stability, protect drugs from degradation, and provide sustained release profiles. Examples of nanoparticles used in drug delivery include liposomes, micelles, and solid lipid nanoparticles (SLNs).

**e) Composites in medical imaging:**

Composites play a significant role in medical imaging, contributing to improved image quality, diagnostic accuracy, and patient safety. Medical imaging composites are designed to enhance the performance of imaging modalities, such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and nuclear medicine. These composites often consist of a combination of different materials, coatings, or contrast agents to optimize image acquisition and visualization. Here are some common applications of composites in medical imaging:

**Contrast Agents:** Composites are used as contrast agents in various imaging modalities to improve the visualization of specific tissues or structures. For example, in CT and X-ray imaging, iodinated composites are used as contrast agents to enhance the visibility of blood vessels, organs, and tumors.

**MRI Contrast Agents:** In MRI, composites containing paramagnetic or superparamagnetic materials, such as gadolinium or iron oxide nanoparticles, are used as contrast agents. These composites alter the relaxation times of nearby protons, resulting in enhanced image contrast and better tissue characterization.

**Ultrasound Contrast Agents:** Ultrasound imaging benefits from the use of microbubble-based composites as contrast agents. These microbubbles resonate in response to ultrasound waves, producing strong echoes that improve the imaging of blood flow and perfusion in organs.

**Radiopaque Coatings:** Composites can be used as radiopaque coatings for medical devices, such as catheters or guidewires, to aid their visualization during X-ray procedures. These coatings enable accurate device positioning and placement within the body.

**f) Composites in cancer treatments:**

Composites are being explored and developed for various applications in cancer treatments. These composite materials leverage the unique properties of their components to enhance the effectiveness of cancer therapies and improve patient outcomes. Some key areas where composites are making an impact in cancer treatments include:

**Drug Delivery Systems:** Composite materials can serve as carriers for chemotherapy drugs or other therapeutic agents. These drug-delivery systems offer controlled and targeted release of medications, allowing for more efficient drug delivery to cancerous cells while minimizing side effects on healthy tissues. By precisely delivering drugs to the tumor site, composite drug carriers can increase the therapeutic efficacy and reduce systemic toxicity.

**Radiotherapy Enhancements:** Composites can be employed as radiation-sensitizing agents to enhance the effects of radiotherapy. By incorporating radiation-sensitizing nanoparticles or high-Z materials into a polymer matrix, the composite can increase the radiation absorption within the tumor, leading to improved tumor cell kill rates during radiotherapy.

**Imaging and Diagnostic Tools:** Composite materials with imaging agents, such as fluorescent dyes or nanoparticles, can be used in various imaging modalities (e.g., MRI, CT, and PET). These imaging composites aid in early cancer detection, precise tumor localization, and treatment monitoring. Additionally, composites may be developed for image-guided interventions, allowing for more accurate and targeted biopsies or surgical procedures.

**Photothermal and Photodynamic Therapies:** Composites can be designed for photothermal therapy (PTT) or photodynamic therapy (PDT), where specific components in the composite generate heat or reactive oxygen species upon exposure to light. These treatments can selectively destroy cancer cells, making them potential options for localized tumor ablation.

**Conclusion:**Composites have various applications as biomaterials in the field of medicine and healthcare due to their versatility, tunable properties, and biocompatibility. These composite biomaterials are designed to interact with biological systems, promote tissue regeneration, and improve patient outcomes. The unique properties of composites, such as mechanical strength, biodegradability, and tailored drug release, make them valuable biomaterials for a wide range of medical applications. As research in materials science and biomedical engineering continues to advance, composite biomaterials are expected to play an increasingly vital role in developing innovative medical solutions and improving patient care.

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