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A Review on the Matrix Toughness of Thermoplastic Materials

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Abstract

Composite material has attracted increasingly remarked interest over the last few decades and set it apart in its own class due to its distinct properties. This paper is a review on the matrix toughness of thermoplastic polymer composites. Toughness of thermoplastics has been actively studied since the 1980s.the main advantage in using thermoplastics to toughen resins is that their incorporation need not result in important decreases in desirable properties such as modules and yield strengths. However, the predominant criteria for achieving optimum toughness enhancement in the thermoplastic toughening of epoxy resins are still not all that clear from the literature. Epoxy and polyester resins are commonly modified by introducing carboxyl-terminated butadiene-acrylonitrile copolymers (ctbn). A tough elastomeric phase, for example, a silicone rubber with good thermal resistance in a polyimide resin, produced a tough matrix material. It summarizes what the authors believe are the important requirements for good thermoplastic toughening.

Keywords: toughness; ctbn; polymer; thermoplastic; epoxy

1. Introduction

In recent years considerable attention has been focused on the use of tough, high-temperature, solvent-resistant thermoplastic polymers as matrix materials for fiber-reinforced composites. Thermoplastic resin systems have shown potential for reducing manufacturing costs and improving the damage tolerance of composite structures. In order to produce high-quality composite laminates from continuous fiber-reinforced thermop1astic prepregs the processing temperature and pressure must be selected so that intimate contact (coalescence) at the ply interfaces is achieved resulting in the formation of strong interfacial bonds (consolidation).

Thermoplastics [1] are polymers that require heat to make them processable. After cooling, such materials retain their shape. In addition, these polymers may be reheated and reformed, often without significant changes in their properties.

This review has focused upon the importance of the thermoplastic materials and the matrix toughness of the thermoplastic.

The results of this study show that matrix toughness influences the long-term behavior of fiber composites. The transcendent criteria for accomplishing ideal toughness enhancement in the thermoplastic toughening of epoxy resins are still not too clear from the literature. Epoxy and polyester resins are ordinarily altered by presenting carboxyl- terminated butadiene-acrylonitrile copolymers (ctbn). However, a tough elastomeric stage, for instance, a silicone elastic with great thermal resistance in a polyimide resin, delivered a tough matrix material. It outlines what the authors accept are the critical prerequisites for good thermoplastic toughening.

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2. Composite Materials

Engineering materials can be classified in different ways according to various criteria. The classification in Figure 1 is helpful in illustrating the fact that composite materials are basically combinations of the three conventional engineering materials; namely metals & alloys, polymers and ceramics & glasses.

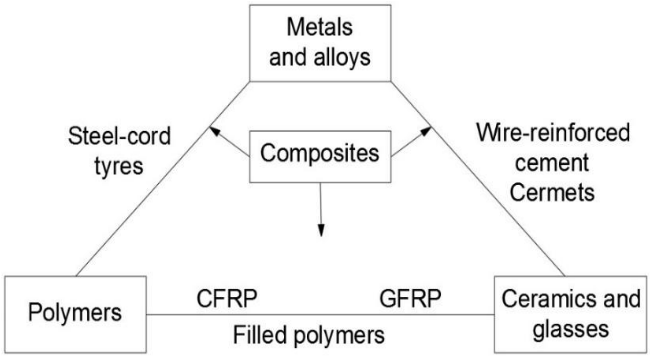

Figure 1: The classes of engineering materials from which articles are made

A composite material is composed of two main components/constituents/phases bound together: Matrix and reinforcement. Matrix is the phase that binds the reinforcement material, which is usually the stronger one. While matrix is a continuous phase, reinforcement is discontinuous and its arrangement within the matrix strongly affects overall performance of the final product; i.e. the composite.

Figure 2 clearly illustrates benefit of reinforcement, which, in this particular composite, is discontinuous fiber, can stop crack propagation, enhancing overall strength of the composite [2].

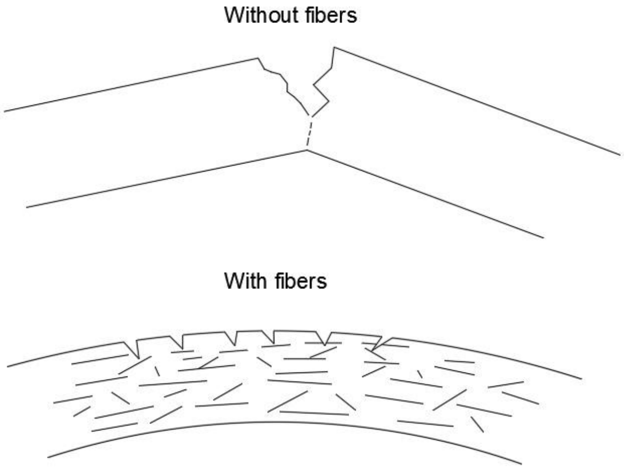

Figure 2: Demonstration of how cracks are prevented from running in a brittle material because of fibers in their path.

Composite materials have been increasingly used in manufacturing a large variety of products, ranging from sports equipments to cutting tools used in machinery, from automotive to medical products. For example, the Boeing 787 Dreamliner consists of 50% composite material by weight [3]. Figure 3 shows application areas of composites.

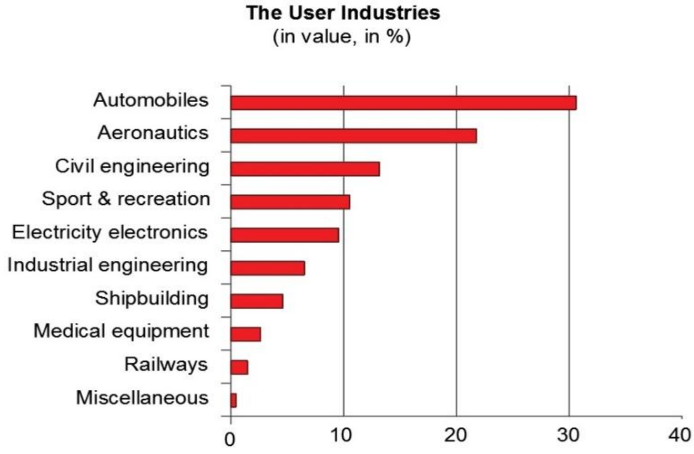

Figure 3: Application of Composite Materials [4]

Polymers are structurally much more complex than metals or ceramics. They are cheap and can be easily processed. On the other hand, polymers have lower strength and modulus and lower use temperature limits. Prolonged exposure to ultraviolet light and some solvents can cause the degradation of polymer properties. Because of predominantly covalent bonding, polymers are generally poor conductors of heat and electricity. Polymers, however, are generally more resistant to chemicals than are metals. Structurally, polymers are giant chainlike molecules (hence the name macromolecules) with covalently bonded carbon atoms forming the backbone of the chain. The process of forming large molecules from small ones is called polymerization; that is, polymerization is the process of joining many monomers, the basic building blocks, together to form polymers.

2.1. Composite Material Classification According To Reinforcement

Composites can be classified according to reinforcement materials. They can also be classified by the geometry of the reinforcement as follows: particulate, flake, fibers and nanocomposites.

a) **Particulate composites** consist of particles immersed in matrices such as alloys and ceramics. They are usually isotropic because the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature, oxidation resistance, etc. Typical examples include use of aluminum particles in rubber; silicon carbide particles in aluminum; and gravel, sand, and cement to make concrete.

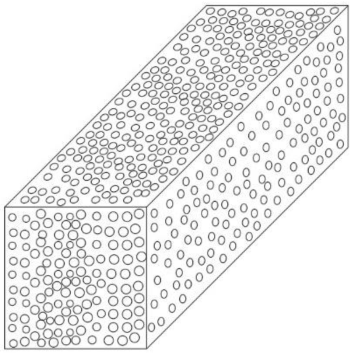

Figure 4: Particles as the reinforcement

b) **Flake composites** consist of flat reinforcements of matrices. Typical flake materials are glass, mica, aluminum, and silver. Flake composites provide advantages such as high out-of-plane flexural modulus, higher strength, and low cost. However, flakes cannot be oriented easily and only a limited number of materials are available for use.

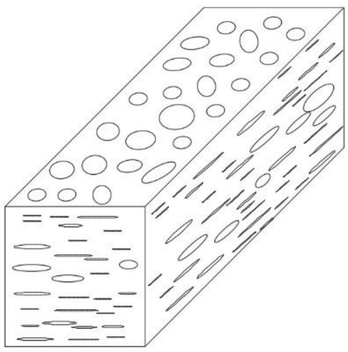

Figure 5: Flat flakes as the reinforcement

c) **Fiber composites** consist of matrices reinforced by short (discontinuous) or long (continuous) fibers. Fibers are generally anisotropic and examples include carbon and aramids. Examples of matrices are resins such as epoxy, metals such as aluminum, and ceramics such as calcium–alumino silicate. Continuous fiber composites are emphasized in this book and are further discussed in this chapter by the types of matrices: polymer, metal, ceramic, and carbon. The fundamental units of continuous fiber matrix composite are unidirectional or woven fiber laminas. Laminas are stacked on top of each other at various angles to form a multidirectional laminate.

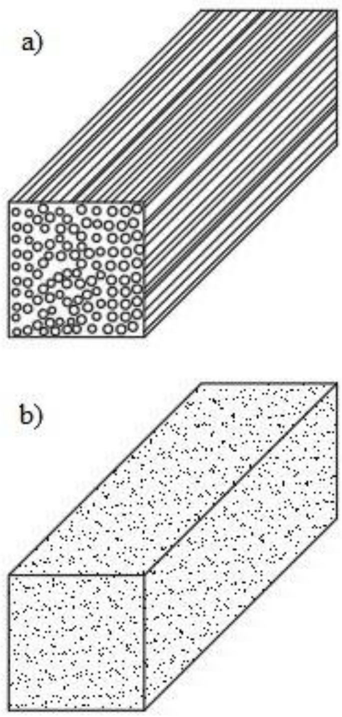

Figure 6: (a) Random fiber (short fiber) reinforced composites, (b) Continuous fiber (long fiber) reinforced composites

d) **Nanocomposites** consist of materials that are of the scale of nanometers (10^{-9} m). The accepted range to be classified as a nanocomposite is that one of the constituents is less than 100 nm. At this scale, the properties of materials are different from those of the bulk material. Generally, advanced composite materials have constituents on the microscale (10^{-6} m). By having materials at the nanometer scale, most of the properties of the resulting composite material are better than the ones at the microscale. Not all properties of nanocomposites are better; in some cases, toughness and impact strength can decrease. Applications of nanocomposites include packaging applications for the military in which nanocomposite films show improvement in properties such as elastic modulus, and transmission rates for water vapor, heat distortion, and oxygen. Body side molding of the 2004 Chevrolet Impala is made of olefin based nanocomposites. This reduced the weight of the molding by 7% and improved its surface quality. General Motors™ currently uses 540,000 lb of nanocomposite materials per year. Rubber containing just a few parts per million of metal conducts electricity in harsh conditions just like solid metal. Called Metal Rubber®, it is fabricated molecule by molecule by a process called electrostatic self-assembly. Awaited applications of the Metal Rubber include artificial muscles, smart clothes, flexible wires, and circuits for portable electronics.

2.2. Composite Material Classification According To Matrix

Composites can be classified by their geometry of the matrix as follows: polymer, metal, ceramic and carbon.

a) **Polymer Matrix Composites:** The most common advanced composites are polymer matrix composites (PMCs) consisting of a polymer (e.g., epoxy, polyester, urethane) reinforced by thin diameter fibers (e.g., graphite, aramids, boron). For example, graphite/epoxy composites are approximately five times stronger than steel on a weight - for - weight basis. The reasons why they are the most common composites include their low cost, high strength, and simple manufacturing principles. The main drawbacks of PMCs include low operating temperatures, high coefficients of thermal and moisture expansion, and low elastic properties in certain directions. The most common fibers used are glass, graphite, and Kevlar. Typical properties of these fibers compared with bulk steel and aluminum are given in Table 1.

Table 1: Typical Mechanical Properties of Fibers Used in Polymer Matrix Composites [5].

Property	Units	Graphite	Aramid	Glass	Steel	Aluminum
System of units: USCS						
Specific gravity	-	1.8	1.4	2.5	7.8	2.6
Young's modulus	Msi	33.35	17.98	12.33	30	10.0
Ultimate tensile strength	ksi	299.8	200.0	224.8	94	40.0
Axial coefficient of thermal expansion	μin./in./°F	-0.722	-2.778	2.778	6.5	12.8
System of units: SI						
Specific gravity	-	1.8	1.4	2.5	7.8	2.6
Young's modulus	GPa	230	124	85	206.8	68.95
Ultimate tensile strength	MPa	2067	1379	1550	648.1	275.8
Axial coefficient of thermal expansion	μm/m/°C	-1.3	-5	5	11.7	23

Glass is the most common fiber used in polymer matrix composites. Its advantages include its high strength, low cost, high chemical resistance, and good insulating properties. The drawbacks include low elastic modulus, (reduces tensile strength), and low fatigue strength. The main types are E-glass (also called "fiberglass") and S-glass. The "E" in E-glass stands for electrical because it was designed for electrical applications. However, it is used for many other purposes now, such as decorations and structural applications. The "S" in S-glass stands for higher content of silica. It retains its strength at high temperatures compared to E-glass and has higher fatigue strength. It is used mainly for aerospace applications. The difference in the properties is due to the compositions of E-glass and S-glass fibers.

b) **Metal Matrix Composites**: Metal matrix composites (MMCs), as the name implies, have a metal matrix. Examples of matrices in such composites include aluminum, magnesium, and titanium. Typical fibers include carbon and silicon carbide. Metals are mainly reinforced to increase or decrease their properties to suit the needs of design. For example, the elastic stiffness and strength of metals can be increased and large coefficients of thermal expansion and thermal and electrical conductivities of metals can be reduced, by the addition of fibers such as silicon carbide. Metal matrix composites are mainly used to provide advantages over monolithic metals such as steel and aluminum. These advantages include higher specific strength and modulus by reinforcing low-density metals, such as aluminum and titanium; lower coefficients of thermal expansion by reinforcing with fibers with low coefficients of thermal expansion, such as graphite; and maintaining properties such as strength at high temperatures. MMCs have several advantages over polymer matrix composites. These include higher elastic properties; higher service temperature; insensitivity to moisture; higher electric and thermal conductivities; and better wear, fatigue, and flaw resistances. The drawbacks of MMCs over PMCs include higher processing temperatures and higher densities. Metal matrix composites applications are:

- Space: The space shuttle uses boron/aluminum tubes to support its fuselage frame. In addition to decreasing the mass of the space shuttle by more than 320 lb (145 kg), boron/aluminum also reduced the thermal insulation requirements because of its low thermal conductivity. The mast of the Hubble Telescope uses carbon-reinforced aluminum.
- Military: Precision components of missile guidance systems demand dimensional stability — that is, the

geometries of the components cannot change during use.27 Metal matrix composites such as SiC/aluminum composites satisfy this requirement because they have high micro yield strength. In addition, the volume fraction of SiC can be varied to have a coefficient of thermal expansion compatible with other parts of the system assembly.

- Transportation: Metal matrix composites are finding use now in automotive engines that are lighter than their metal counterparts. Also, because of their high strength and low weight, metal matrix composites are the material of choice for gas turbine engines.

c) **Ceramic Matrix Composites:** Ceramic matrix composites (CMCs) have a ceramic matrix such as alumina calcium alumino silicate reinforced by fibers such as carbon or silicon carbide. Advantages of CMCs include high strength, hardness, high service temperature limits for ceramics, chemical inertness, and low density. However, ceramics by themselves have low fracture toughness. Under tensile or impact loading, they fail catastrophically. Reinforcing ceramics with fibers, such as silicon carbide or carbon, increases their fracture toughness because it causes gradual failure of the composite. This combination of a fiber and ceramic matrix makes CMCs more attractive for applications in which high mechanical properties and extreme service temperatures are desired. Ceramic matrix composites are finding increased application in high-temperature areas in which metal and polymer matrix composites cannot be used. This is not to say that CMCs are not attractive otherwise, especially considering their high strength and modulus, and low density. Typical applications include cutting tool inserts in oxidizing and high-temperature environments.

d) **Carbon–Carbon Composites:** Carbon–carbon composites use carbon fibers in a carbon matrix. These composites are used in very high-temperature environments of up to 6000°F (3315°C), and are 20 times stronger and 30% lighter than graphite fibers. Carbon is brittle and flaw sensitive like ceramics. Reinforcement of a carbon matrix allows the composite to fail gradually and also gives advantages such as ability to withstand high temperatures, low creep at high temperatures, low density, good tensile and compressive strengths, high fatigue resistance, high thermal conductivity, and high coefficient of friction. Drawbacks include high cost, low shear strength, and susceptibility to oxidations at high temperatures. The main uses of carbon–carbon composites are the following:

- Space shuttle nose cones: As the shuttle enters Earth's atmosphere, temperatures as high as 3092°F (1700°C) are experienced. Carbon– carbon composite is a material of choice for the nose cone because it has the lowest overall weight of all ablative materials; high thermal conductivity to prevent surface cracking; high specific heat to absorb large heat flux; and high thermal shock resistance to low temperatures in space of –238°F (–150°C) to 3092°F (1700°C) due to re-entry. Also, the carbon–carbon nose remains undamaged and can be reused many times.
- Mechanical fasteners: Fasteners needed for high temperature applications are made of carbon–carbon composites because they lose little strength at high temperatures [5].

2.3. Common Thermoplastic Matrix Materials

Thermoplastics are characterized by linear chain molecules and can be repeatedly melted or reprocessed. It is important to note that in this regard the cool-down time affects the degree of crystallinity of the thermoplastic. This is because the polymer chains need time to get organized in the orderly pattern of the crystalline state; too quick a cooling rate will not allow crystallization to occur. Although repeated melting and processing are possible with thermoplastics, it should be recognized that thermal exposure (too high a temperature or too long a dwell time at a given temperature) can degrade the polymer properties such as, especially, impact properties.

Common thermoplastic resins used as matrix materials in composites include some conventional thermoplastics such as polypropylene, nylon, thermoplastic polyesters (PET, PBT), and polycarbonates. Some of the new thermoplastic matrix materials include polyamide imide, polyphenylene sulfide (PPS), polyarylsulfone, and polyetherether ketone (PEEK). Figure 7 shows the chemical structure of some of these thermoplastics. PEEK is an attractive matrix material because of its toughness and impact properties, which are a function of its crystalline content and morphology. It should be pointed out that crystallization kinetics of a thermoplastic matrix can vary substantially because of the presence of fibers [6]. In order to make a thermoplastic matrix flow, heating must be done to a temperature above the melting point of the matrix. In the case of PEEK, the melting point of the crystalline component is 343 °C. In general, most thermoplastics are harder to flow in relation to thermosets such as epoxy! Their viscosity decreases with increasing temperature, but at higher temperatures the danger is decomposition of resin.

Thermoplastic resins have the advantage that, to some extent, they can be recycled. Heat and pressure are applied to form and shape them. More often than not, short fibers are used with thermoplastic resins but in the late 1970's continuous fiber reinforced thermoplastics began to be produced. The disadvantages of thermoplastics include their rather large expansion and high viscosity characteristics [7].

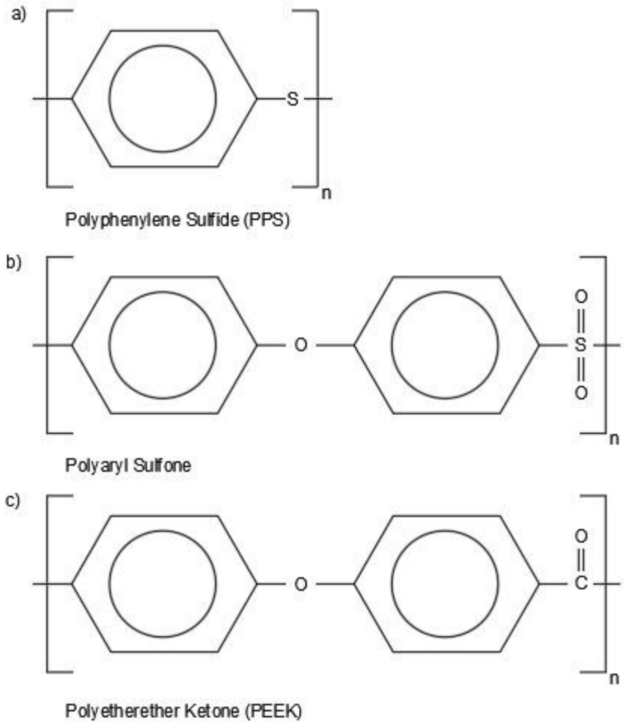

Figure 7: Chemical structure of (a) PPS, (b) polyarylsulfone, and (c) polyetherether ketone (PEEK)

An important problem with polymer matrices is associated with environmental effects. Polymers can degrade at moderately high temperatures and through moisture absorption. Absorption of moisture from the environment causes swelling in the polymer as well as a reduction in its T_g. In the presence of fibers bonded to the matrix, these hygrothermal effects can lead to severe internal stresses in the composite. The presence of thermal stresses resulting from thermal mismatch between matrix and fiber is, of course, a general problem in all kinds of composite materials; it is much more so in polymer matrix composites because polymers have high thermal expansivities.

2.4. Matrix Toughness

Thermosetting resins (e.g., polyesters, epoxies, and polyimides) are highly crosslinked and provide adequate modulus, strength, and creep resistance, but the same cross-linking of molecular chains causes extreme brittleness, that is, very low fracture toughness. By *fracture toughness*, it is meant resistance to crack propagation. It came to be realized in the 1970's that matrix fracture characteristics (strain to failure, work of fracture, or fracture toughness) are as important as lightness, stiffness, and strength properties. Figure 8 (note the log scale) compares some common materials in terms of their fracture toughness as measured by the fracture energy in J/m^2 [8]. Note that thermosetting resins have values that are only slightly higher than those of inorganic glasses. Thermoplastic resins such as PMMA have fracture energies of about 1 kJ/m^2, while polysulfone thermoplastics have fracture energies of several kJ/m^2, almost approaching those of the 7075-T6 aluminum alloy. Amorphous thermoplastic polymers show higher fracture energy values because they have a large free volume available that absorbs the energy associated with crack propagation. Among the well-known modified thermoplastics are the acrylonitrile-butadiene-styrene (ABS) copolymer and high-impact polystyrene (HIPS). One class of thermosetting resins that comes close to polysulfones is the elastomer-modified epoxies. Elastomer-modified or rubber-modified thermosetting epoxies form multiphase systems, a kind of composite in their own right. Small (a few micrometers or less), soft, rubbery inclusions distributed in a hard, brittle epoxy matrix enhance its toughness by several orders of magnitude [9-13].

Epoxy and polyester resins are commonly modified by introducing carboxyl-terminated butadiene-acrylonitrile copolymers (ctbn). The methods of manufacture can be simple mechanical blending of the soft, rubbery particles and the resin or copolymerization of a mixture of the two. Figure 9 shows the increase in fracture surface energy of an epoxy as a function of weight % of ctbn elastomer [13].

Toughening of glassy polymers by elastomeric additions involves different mechanisms for different polymers. Among the mechanisms proposed for explaining this enhanced toughness are triaxial dilation of rubber particles at the crack tip, particle elongation, and plastic flow of the epoxy. Ting [8] studied such a rubber-modified epoxy containing glass or carbon fibers. He observed that the mechanical properties of rubber-modified composite improved more in flexure than in tension. Scott and Phillips [13] obtained a large increase in matrix toughness by adding ctbn in unreinforced epoxy. But this large increase in toughness could be translated into only a modest increase in carbon fiber reinforced modified epoxy matrix composite. Introduction of a tough elastomeric phase, for example, a silicone rubber with good thermal resistance in a polyimide resin, produced a tough matrix material: a three- to fivefold gain in toughness, G_{Ic} without a reduction in T_g [12].

Continuous fiber reinforced thermoplastics show superior toughness values owing to superior matrix toughness. PEEK is a semicrystalline aromatic thermoplastic [14, 15, 16] that is quite tough. PEEK can have 20–40 % crystalline phase. At 35 % crystallinity, the spherulite size is about 2 μm [15]. Its glass transition temperature T_g is about 150 °C, and the crystalline phase melts at about 350 °C. It has an elastic modulus of about 4 GPa, a yield stress of 100 MPa, and a relatively high fracture energy of about 500 J/m^2. In addition to PEEK, other tough thermoplastic resins are available, for example, thermoplastic polyimides and PPS, which is a semicrystalline aromatic sulfide. PPS is the simplest member of a family of polyarylene sulfides [17]. PPS (trade name Ryton), a semicrystalline polymer, has been reinforced by chopped carbon fibers and prepregged with continuous carbon fibers [17].

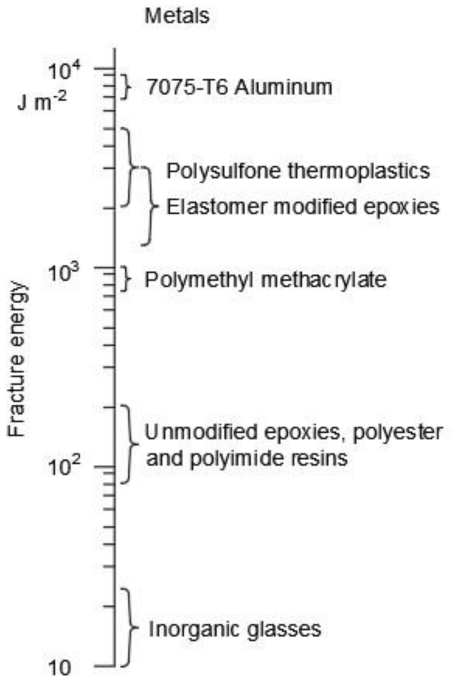

Figure 8: Fracture energy for some common materials

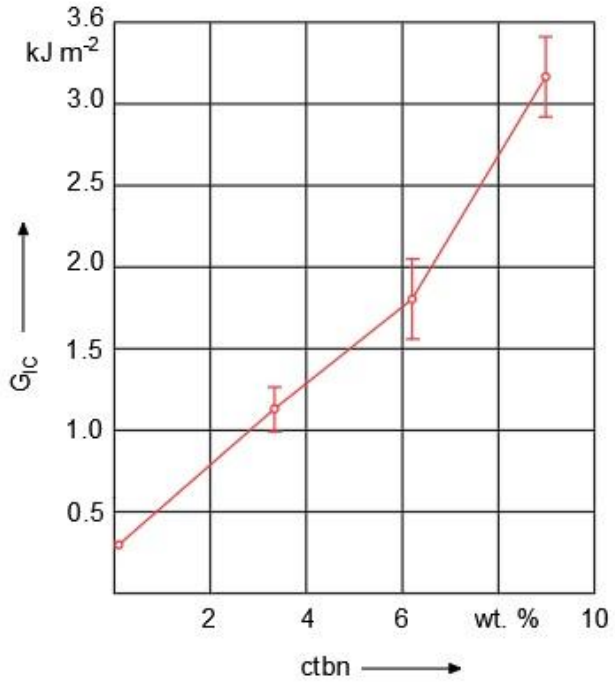

Figure. 9: Fracture surface energy of an epoxy as a function of weight % of carboxyl-terminated butadiene-acrylonitrile (ctbn)

Conclusions

The purpose of this review article is to investigate about the matrix toughness of thermoplastic polymers. After the literature researches completed, some observations have been come up;

1. The mechanical properties of rubber-modified composite improved more in flexure than in tension.
2. It is obtained a large increase in matrix toughness by adding ctbn in unreinforced epoxy. But this large increase in toughness could be translated into only a modest increase in carbon fiber reinforced modified epoxy matrix composite.
3. A silicone rubber with good thermal resistance in a polyimide resin, produced a tough matrix material: a three- to fivefold gain in toughness, G_{Ic} without a reduction in T_g.
4. Thermoplastic polyimides and PPS, which is a semicrystalline aromatic sulfide, are available as tough thermoplastic resins. PPS is the simplest member of a family of polyarylene sulfides. PPS, a semicrystalline polymer, has been reinforced by chopped carbon fibers and prepregged with continuous carbon fibers.

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Metallographic Procedures and Analysis – A review

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Abstract

The purpose of this research is to give readers general insight in what metallography generally is, what are the metallographic preparation processes, and how to analyse the prepared specimens.

Keywords: metallography; metallographic specimens; metallographic structure

1. Introduction

Metallography is the study of the microstructure of various metals. To be more precise, it is a scientific discipline of observing chemical and atomic structure of those materials, and as such is crucial for determining product reliability.

Not only metals, but polymeric and ceramic materials can also be prepared using metallographic techniques, hence the terms plastography, ceramography, materialography, etc.

Steps for preparing metallographic specimen include a variety of operations, and some of them are: documentation, sectioning and cutting, mounting, planar grinding, rough polishing, final polishing, etching, etc.

1.1. Documentation

As previously mentioned, metallographic analysis is very valuable. If the analysis is properly conducted, it can provide a researcher with high quality control, and can serve as an investigative tool.

2. Metallographic Procedures

2.1. Sectioning and cutting

Most of the metallographic samples need to be sectioned for easier handling. The way of sectioning depends generally on the type of material, and so you can clearly differentiate abrasive cutting (metals), thin sectioning with a microtome (plastics), and diamond wafer cutting (ceramics).

These processes are mostly used in order to minimize the damage which could alter the microstructure of the material, and the analysis itself.

2.2. Mounting

This process protects the material's surface, fills voids in damaged (porous) materials, and improves handling of irregularly shaped samples. There are plenty of ways to conduct this operation, and all of them depend on the type of material that is being handled. So, there are: compression mounting used for metals, and castable mounting resins used for electronics or ceramics.

2.3. Planar grinding

This operation is mainly used to reduce the damage caused by previously done sectioning. Generally talking, this means reducing the size of the particles in such way that the surface of the material is ready for polishing. It goes without saying that, in this step, it is necessary to be cautious in order not to produce greater damage than the one caused by cutting.

2.4. Rough polishing

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The purpose of this process is to remove the damage caused by cutting and planar grinding. This is usually done using diamond abrasive because of its multiple smaller cutting edges which produce minimal surface damage. If done right, rough polishing serves as a reason to spend minimal amount of time on further (final) polishing.

2.5. Final polishing

Final polishing is used to remove the surface damage, and not the damage caused by cutting and/or planar grinding. If the damage from those two steps is not removed completely, the rough polishing should be repeated before moving on to the final polishing step.

2.6. Etching

The reason why etching is done is to optically enhance microstructural features of the material (grain size, phase features, etc.). The most common technique used is chemical etching, but other techniques include: molten salt, electrolytic etching, thermal etching, and plasma etching.

3. Metallographic analysis

The metallographic analysis provides the scientist with information about grain size, phase structure, solidification structure, etc. For example, Fig. 1 shows how the grain size of the tough pitch copper, while the Fig. 2 represents aluminum and titanium couple bonded by diffusion welding method.

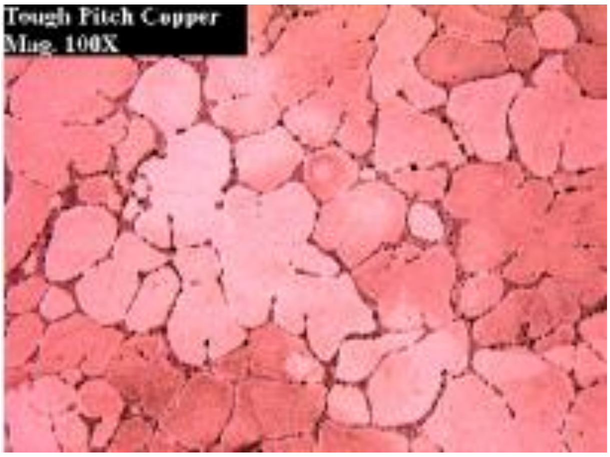

Figure 1. Tough pitch copper

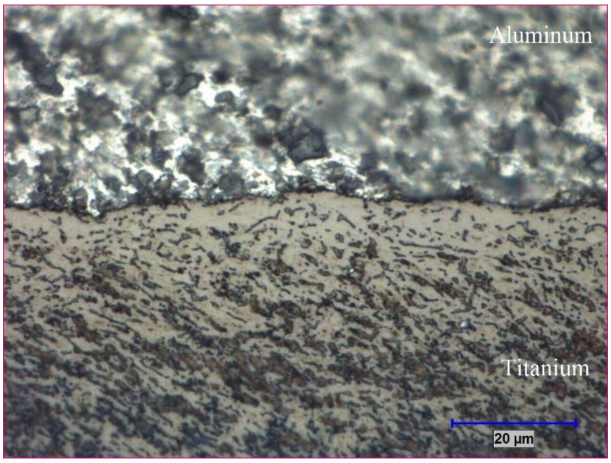

Figure 2. Aluminum-titanium diffusion couples

4. Microscopic analysis

The most common way of conducting the metallographic analysis.

4.1. Bright Field (BF) illumination

It counts as the most common illumination technique for metallographic analysis. The light path for BF illumination is from the source, through the objective lens, reflected off the surface, returning through the objective, and back the the eyepiece/camera. This way, non-flat surfaces (cracks, pores, etc.) appear darker compared to the flat surfaces which produce the bright background.

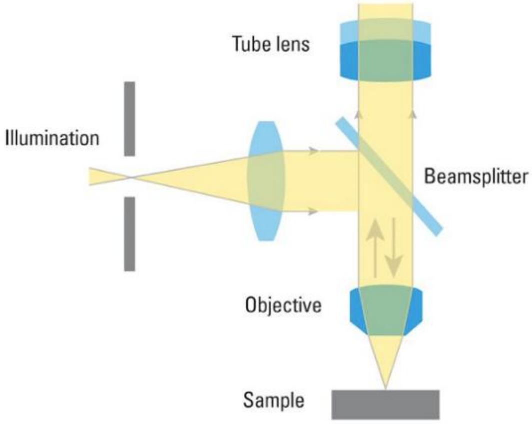

Figure 3. BF illumination

4.2. Dark Field (DF) illumination

This type of illumination is not as known as BF illumination, but nonetheless is a powerful illumination technique. The light path for the DF illumination is from the source, down the outside of the objective, reflected off the surface, returning through the objective, and back to the eyepiece/camera. What

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happens with this type of illumination is the exact opposite of the BF illumination, because here the flat surfaces serve as dark background to the non-flat surfaces which appear brighter.

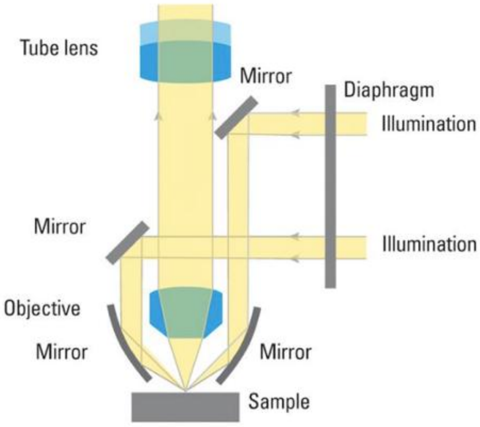

Figure 4. DF illumination

4.3. Differential Interference Contrast (DIC)

This type of microscopic analysis is also known as *Nomarski* Contrast. It helps to visualize small height differences on the surface of the observed material. The mentioned height differences are visible as variations in color and texture.

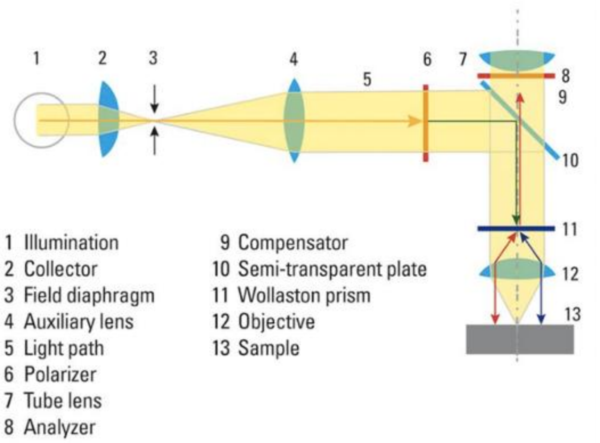

Figure 5. DIC

5. Hardness testing

This step provides the scientist with useful information which refer to the tensile strengtj, wear resistance, ductility and various other physical characteristics. Hardness testing is therefore very useful for monitoring quality control, and for the material selection process.

5.1. Microhardness

Microhardness is determined with Knopp hardness number (HK) and Vicker hardness number. It is used to determine the hardness of specific phases, small particles, etc.

5.2. Rockwell hardness (HR)

This type of harness is determined with a spheroconical penetrator (hard steel ball forced into the material surface).

6. Conclusions

Microstructural analysis is extremely important in today's day and age because materials such as metals, ceramics, polymers, and others are used to improve our everyday lives in terms of insuring reliability, safety, etc. In order to successfully conduct the microanalysis of the metallographic structures, it is necessary to do a proper specimen preparation. The key to the mentioned proper specimen preparation is knowing as much physical properties (hardness, fracture toughness, and other) of the observed material as possible. Generally, the point is to minimize the damage early in the microstructural preparation stage, and to follow the guidelines outlined in this paper with the goal of obtaining accurate results from the analysis.

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The importance of interlayers in diffusion welding - A review

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Abstract

During the last few years diffusion welding has become significant attention regarding its suitable applications in comparison to traditional welding techniques. Bonding of dissimilar materials has always been a challenging task due to poor control on grain size and sensitive mechanical properties that could have been made by joining with traditional welding techniques. Moreover, joining dissimilar materials such as Aluminum/steel, metal/glass, Aluminum/copper had been achieved with the usage of diffusion welding. This work presents a review of literature regarding the importance of diffusion welding and influence of interlayers in diffusion welding. Additionally, this paper provides different examples and applications of diffusion welding. Main advantages of this technique are, clean and undamaged exterior parts of weld, power savings, stable and strong bond, time efficiency.

Keywords: Diffusion welding; Copper interlayer; Silver interlayer; Nickel interlayer; Titanium interlayer

1. Introduction

Diffusion Welding is a solid-state welding process, and it provides a novel joining process for similar and dissimilar metals. However, joining of dissimilar metals provides significant advantages in the design and manufacturing of many products. Pressure is applied on two metals with cleaned surface at a temperature below the melting point of the metals. Thus, bonding can occur in their interface atoms [1,2].

Joining and face contacts are improved by interlayers. Electrolysis, thermal spraying and thin foils deposit as interlayers. Mostly Ni and Cu are used, because of diffusivity properties; however interlayers do not have to be used. [3,4]. This article focuses on the importance of interlayers in diffusion welding. Interlayer mechanism is shown in Fig. 1.

Recently, interlayers are getting more useful in diffusion welding applications. Although interlayers give advantages in joints, wrongly chosen interlayer can significantly decrease strength of joints. Main reasons for the use of interlayers are given as; to minimize the formation of intermetallics at the weld interface and to increase the compatibility for joining dissimilar metals.

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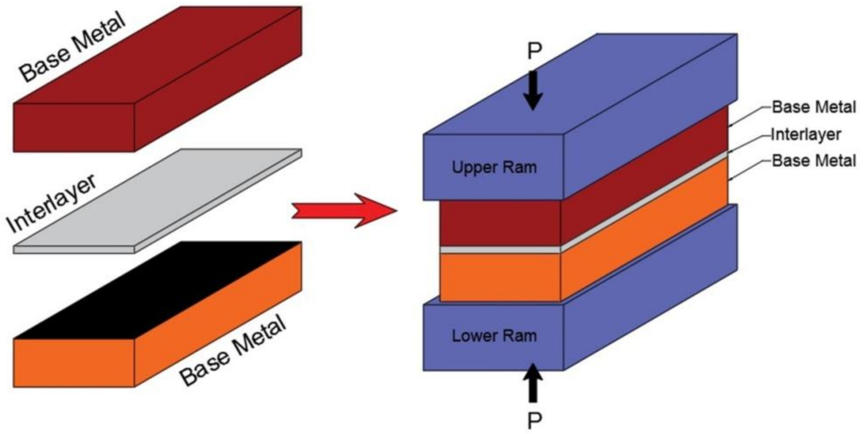

Figure 1: Processing system of diffusion welding

2. Theoretical background

Diffusion welding is getting more applicable for aerospace industry, and it is also used for different applications which are still in advanced development, such as fabrication of honeycomb, turbine components, rocket engines, structural members, composites and laminates [5,6]. The applications of diffusion welding should increase in the next years thanks to additional research and education of process engineers.

Diffusion welding is also known as a recent, non-conventional joining process that has attracted considerable interest of researchers in recent times [6], and it is one of the *Solid State Welding (SSW)* process [7]. According to literature research, many dissimilar metals have been welded by SSW, as well [8,9,10].

There are also some parameters which affect the bonding during diffusion welding process. Diffusivity can be expressed as a function of temperature as follows:

$$D = D_o e^{-Q/kT}$$

where

D = *Diffusivity*, the diffusion coefficient at temperature T;

D_o = A constant of proportionality;

e = An exponential value defined mathematically;

Q = Activation energy for diffusion;

T = Activation temperature;

k = Boltzmann's constant.

It is apparent from the above equation that the diffusion-controlled processes vary exponentially with activation energy and temperature for diffusion.

Table 1: diffusion welding parameters for dissimilar metal couples [11]

Metal 1	Metal 2	Interlayer	Temperature (°C)	Pressure (N/mm^2)	Time (minutes)
Copper	Molybdenum	-	900	7.35	10
Copper	Steel	-	900	04.9	10
Copper	Nickel	-	900	14.7	20
Copper	Copper	-	800-850	4.9-6.9	15-20
Titanium	Nickel	-	800	09.8	10
Titanium	Copper	Molybdenum	950	04.9	30
Titanium	Copper	Niobium	950	04.9	30
Titanium	Copper	-	800	04.9	30
Molybdenum	Molybdenum	Titanium	915	6860	20
Molybdenum	Steel	-	1200	04.9	10
Tungsten Tantalum	Tungsten	Niobium	925	6860	20
Niobium	Tantalum	Zirconium	870	-	-
Zircalloy-2	Niobium	Zirconium	870	-	-

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Steel	Zircalloy-2	Copper	1040	20.6	30-120
Beryllium	Aluminum	Copper	550	04.9	10
Copper	Beryllium	68-Ag-27	800	-	30
Kovar	Copper	Cu-10-ln	-	-	-
Steel	Kovar	-	1000-1110	24.5-10.6	20-25
Steel	Cast-iron	-	850-950	14.7	5-7
	Aluminum	-	500	7.35	30

In Table 1, diffusion welding parameters for metal couples have been established. The parameters include temperature, pressure and time. Also, interlayers for different metals were given.

2.1 Dissimilar metals bonded by diffusion welding

Bilgin [12] bonded Ti-6Al-4V/304L stainless steel using *copper interlayer* by diffusion welding at 830, 850 and 870°C temperature, 1 MPa pressure, for 50, 70 and 90 minutes under the argon gas shielding. Mechanical properties and microstructure analyses were carried out on the bonded samples.

Kundu [13] bonded Ti/304 stainless steel using *copper and nickel interlayers* by diffusion welding. As a result of experimental studies, bonded samples using copper interlayer obtained strength of 318 MPa, however bonded samples using nickel interlayer obtained strength 302 MPa.

Kejanli [14] studied on bonding $Ti_{45}Ni_{49.6}Cu_{5.4}$ composite using *Cu-Ni interlayer* by diffusion welding. Composite materials were produced with approximately 45 µm powders.

Berrana [15] investigated on bonding aluminum and titanium using *copper and silver interlayers* by diffusion welding at 750°C, 3 MPa pressure, and for 10 and 60 minutes. Maximum hardness measurement was obtained at 750°C for 60 minutes. Berrana [16] studied on bonding WC-Co and Ti-6Al-4V alloy using *silver interlayer* by diffusion welding. 825 and 850°C temperature, 15 and 30 minutes and 2 MPa pressure were chosen as diffusion parameters. Bonded samples were subjected to shear test, microhardness and microscopic analyses. The best bonding occurred in the sample processed at 850°C for 30 minutes.

Sabetghadam [17] bonded stainless steel and copper using *nickel interlayer* by processing at 800-950°C, 12 MPa pressure for 60 minute. The interlayers of bonded samples were subjected to SEM, optic microscope, X-Ray and EDS analyses. As a result of this study, Fe-Ni, Fe-Cr-Ni and Fe-Cr were obtained in the diffusion interlayers.

He [18] studied on bonding Ti-6Al-4V and stainless steel (X8CrNi 18 10) using *nickel interlayer* by diffusion welding. TiFe, $TiFe_2$ and TiC which are brittle and tough compounds can be reduced by using nickel interlayer. In high temperatures, it is observed that some brittle intermetallic phases (TiNi, Ti_2Ni, $TiNi_3$, etc.) occurred in Ti and Ni interfaces. In low temperatures, TiNi layer obtained and joining of interface are determined to be weak.

Kliauga [19] bonded Al_2O_3 and 304 stainless steel using *Ti interlayer* by diffusion welding, and investigated on microstructure of interfaces. In this study, 50 µm thickness of α-Ti insisted on diffusion of Al and O into titanium in Al_2O_3 and Ti interfaces.

Travessa [20] bonded Al_2O_3 and 304 stainless steel using *Ti interlayer* by diffusion welding at 700-900°C. They observed that Ti_3Al is obtained in the interface between Ti and Al_2O_3. Maximum shear strength obtained by using Ti interlayer with a thickness of 0.5 mm is closed to 20 MPa.

Ghosh [21] succeeded to bond pure titanium to 304 stainless steel at temperatures of 850, 900 and 950°C for holding time of 2 hours by applying 3 MPa pressure without using interlayer. Maximum strength (222 MPa) is obtained in the samples processed at 850°C. In the higher temperatures, lower strength is obtained due to extreme growth of grain size.

Akca [22] studied on bonding Ti-6Al-4V alloy and pure aluminum by diffusion welding without using interlayer. Samples were processes at 520-680°C for 30, 45 and 60 minutes under the argon gas shielding. The processed samples were subjected to SEM, optic microscope, tensile and microhardness analyses.

Fidan [23] bonded aluminum and copper couples by diffusion welding under the argon gas shielding. Bonded and obtained interphases are investigated by using determined optimum bonding conditions.

Rahman and Cavalli [24] have diffusion bonded commercially pure titanium using silver and copper interlayers and without any interlayer. The maximum tensile strength achieved was 160 MPa, 502 MPa, and

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382 MPa when Ag, Cu and no interlayer were used, respectively.

2.2 Copper interlayer

Copper is important commercial material which often is used at temperatures where diffusion processes strongly affect their properties. Significant changes in mechanical properties can occur through surface alloying, compositional changes at interfaces, and interface degradation resulting directly from diffusion.

Copper is a good conductor of heat. This means that if one end of a piece of copper is heated, the other end will quickly reach the same temperature.

Many metallurgical processes such as creep, precipitation, ageing, and corrosion are diffusion-limited. Other important diffusion effects include homogenization of alloys, diffusional breakdown of protective films, permeability of thin-walled tubing, and diffusion bonding.

3. Conclusions

The purpose of this review article was to investigate about effect and importance of interlayer in diffusion welding. In dissimilar metal combinations, such as different aluminum alloys welded to one another or to metals such as copper or steel, a brittle intermetallic layer can form at the weld interface. In order to minimize the formation of these intermetallics a thin-layer of Ti, Ag, Cu and Ni is mostly used according to the literature researches. In some circumstances, other interlayers can be used; however the best results were obtained with Cu interlayer. The main advantage of copper interlayer lies in its high thermal conductivities and diffusivity, which allows for higher heat fluxes. It is also observed that bonding of dissimilar metals is possible without using interlayers in diffusion welding. In the industry, it is important to take care of reducing cost of processes. Thus it is thought that using of interlayer is not vitally necessary.

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Green Materials and Applications

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Abstract

A green material suits most tunefully within ecosystem practices and donates to the achievement of a service-based economy. Due to the properties of non-toxic, organic and recycling, green materials are widely used in various industrial applications. Green materials can be categorized as natural materials, plastics, ceramics and composite materials, and they are extensively utilized in building materials. In this study, green materials are briefly introduced and their applications are shortly reviewed.

Keywords: Green materials, green technology, building, polymer

1. Introduction

Materialsare the stuff of economic life in our industrial world. They include the resource inputs and the product outputs of industrial production. How we handle them is a major determinant of real economic efficiency, and also has a major impact on our health and the health of the natural environment.

A green material is one that simultaneously does the most with the least, fits most harmoniously within ecosystem processes, helps eliminate the use of other materials and energy, and contributes to the attainment of a service-based economy.

Green materials can be classified as natural materials (such as wood), plastics (e.g.plexiglass), ceramics (e.g. kaolin) and composite materials (e.g. wood based composites). Green materials are classified in Figure 1 and Table 1.

Green materials can be used in different places such as environmental area, chemical industry as well as building materials. In this study, green materials are reviewed and then their usage in building and other applications are reported.

2. Elements of Material Solutions in Building

John Young (2000) lately reviewed the materials competence that can be applied to construction materials with a requirement [1]:

a. Materials utilize prevention: It contains a focus on selling services, sooner than products. The great efficiencies resulting from ecological urban design and mixed-use development are in this group.
b. Improved intensity of product employ: Co-housing developments with shared facilities, for instance, can considerably decrease the volume of materials employ.
c. Extended product life: Repair, reuse and remanufacturing are in this group, and in building there is huge potential for deconstruction and the reuse of building materials.
d. Materials recycling: This tends to need more energy, but some form of recycling will be essential for each material at a point in its life cycle.

Although this classification is not adequate in itself to manage all the main dimensions of transforming materials use in building, it provides a structure that can be built upon.

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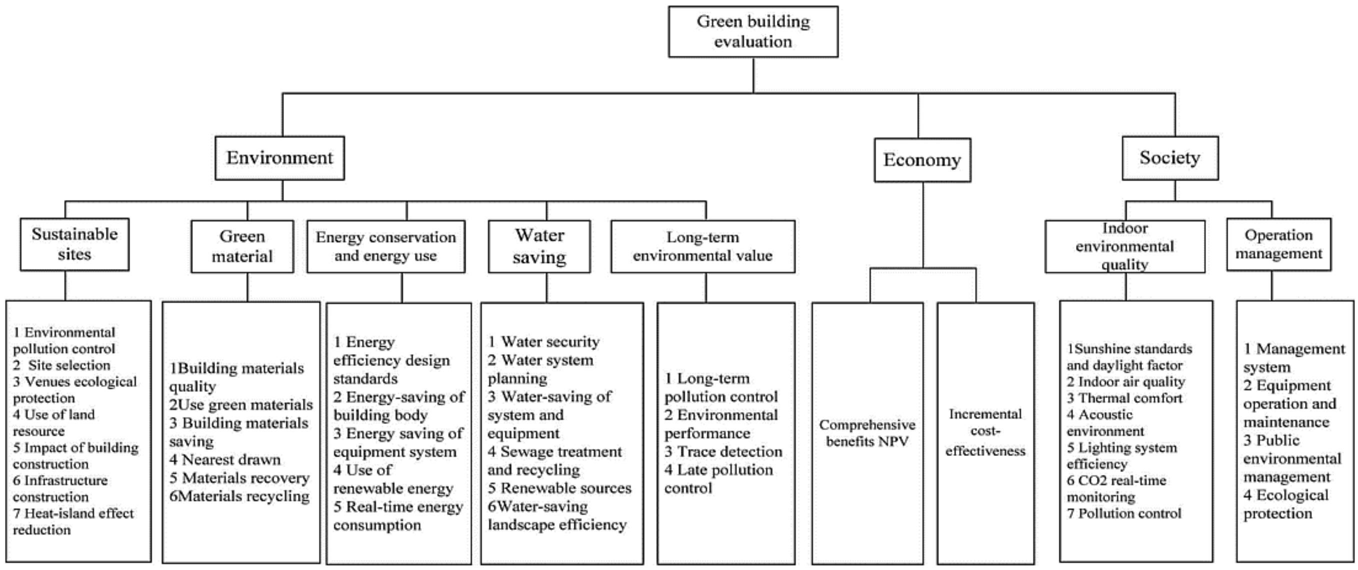

Figure 1. Classification of green materials

Table 1. Triple objective evaluation system of green building.

Item	Indicator	Weight
Environment		
Sustainable sites 22.5%	Venues ecological protection	0.0788
	Use of land resource	0.0562
	Infrastructure construction	0.0338
	Impact of building construction	0.0337
	Heat-island effect	0.0225
Green material 22.5%	Use green materials	0.0900
	Building materials saving	0.0450
	Materials recovery	0.0450
	Nearest drawn	0.0225
	Materials recycling	0.0225
Energy conservation and energy use 22.5%	Energy-saving of building body	0.0675
	Energy saving of equipment system	0.0675
	Use of renewable energy	0.0450
	Real-time energy consumption	0.0450
Water-saving	Water system planning	0.0563
	Water-saving landscape efficiency	0.0338
Water-saving 22.5%	Water-saving of system and equipment	0.0562
	Renewable sources	0.0450
	Sewage treatment and recycling	0.0337
Long-term environmental value 10%	Trace detection	0.0600
	Late pollution control	0.0400
Economy		
Comprehensive benefits NPV 50%		0.5000
Incremental cost-effectiveness 50%		0.5000
Society		
Indoor environmental quality 60%	CO_2 real-time monitoring	0.1500
	Thermal comfort	0.1200
	Acoustic environment	0.1200
	Lighting system efficiency	0.1200
	Pollution control	0.0900
Operation management 40%	Equipment operation and maintenance	0.1400
	Public environmental management	0.1400
	Ecological protection	0.1200

Key areas that are vital to accomplish this materials transformation are:

- Product Evaluation: “What is a green material”?

- Deconstruction and Reuse
- Alternative Materials: the intelligent use of local materials—both natural materials (Rammed earth, straw bale, etc.) provided by the waste stream: tires, cans, etc.
- Eco-industrial production: parks, networks and secondary materials industry.
- Regulation & the State: altering the rules of the game
- Consumption and consumerism

3. Practical Applications

3.1. Kitchen utensils, Green Street™(Fig.2)

Application details:
Application name Kitchen utensils, Green Street™
IndustryHouse / Garden
Manufacturer Robinson Home Products
Material name Valox IQ
Material abbreviation PBT

Figure 2. View of several green kitchen utensils [2]

Kitchenware industry leader Robinson Home Products has tapped SABIC Innovative Plastics' eco-engineered ValoxiQ* resin for its new Green Street™ line of plastic kitchen utensils. A more sustainable, higher-performance material than traditional resins, ValoxiQ resin utilizes up-cycled polyethylene terephthalate (PET) water bottles, diverting them from already bulging landfills. Equally important, this innovative product delivers the exceptional performance and quality that consumers demand in kitchenware, including heat and chemical resistance, U.S. Food and Drug Administration (FDA) approval for food contact, and attractive appearance.

3.2. Housing, medical imaging system (Fig.3)

Application details:
Application name Housing, medical imaging system
Industry Medical Engineering
Manufacturer Grimm Brothers Plastics Corp.
Material name RTP 300 Series
Material abbreviation PC

Cross-Functional Team of Engineering, Sheet, and Color Solve Challenges in Medical Housing. The housing was particularly challenging. The sheet product required a V-0 flame rating, coupled with translucency and a critical color match to the desired translucent mint green color. A custom RTP 300 Series polycarbonate flame retardant sheet was created for the housing that met all the application challenges. The Symbia Medical Imaging System went on to receive global recognition for its overall design, including winning a Gold Industrial Design Excellence Award in 2006. Siemens has since changed the Symbia system and the housing material has evolved away from this formulation.

Figure 3. View of a green housing and medical imaging system [2]

3.3. Housing, lawnmower, Husqvarna(Fig.4)

Application details:
Application name Housing, lawnmower, Husqvarna
Industry House / Garden
Manufacturer Husqvarna
Material name Luran® S
Material abbreviation ASA

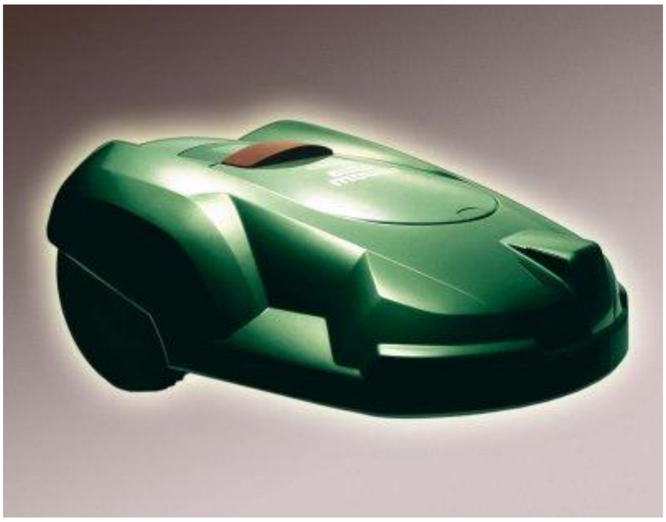

Figure 4. View of a green lawnmower [2]

Automatic lawnmower made by Husqvarna shines with BASF's dark-green Luran®. The first automatic lawnmower made by the Swedish outdoor equipment manufacturer Husqvarna is designed for continuous operation. Once it has been programmed, the battery-powered Automower™ can mow lawns of up to 1800 square meters, needing about one hour for an area of 75 square meters. A housing made of Luran® S, a highly weather resistant material made by BASF on the basis of Acrylonitrile-styrene-acrylate copolymer (ASA), protects the robotic garden helper against heat and rain.

3.4. Handle, disposable applicator, Resofix® Plus(Fig.5)

Application details:

Application name	Handle, disposable application Resofix® Plus
Industry	Medical Engineering
Manufacturer	Resoimplant
Material name	Ultraform® PRO
Material abbreviation	POM

Development of the Resofix® Plus by the company Resoimplant in Regensburg, Germany took only about one year. During an operation for a torn cruciate ligament, the disposable applicator ensures safe and gentle attachment of a new tendon in the knee. The handle (blue) and the various versions of the handle's tip (white, yellow, green) are molded out of Ultraform® PRO from BASF, and colored with masterbatches from BASF Color Solutions produced specifically for this application. The custom-formulated POM (polyoxymethylene) grades for the medical device market offer, in addition to the classical material properties of the engineering plastic, a comprehensive service package for the user that includes Drug Master Files, compliance with medical device standards and tests, biocompatibility tests and most consistent formulations.

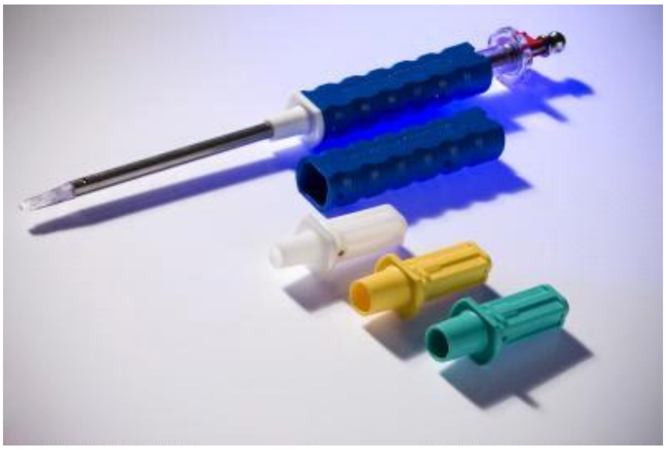

Figure 5. View of a green disposable applicator [2]

4. Suspension spring, Audi

Application details:

Application name	Suspension spring, Audi
Industry	Automotive
Manufacturer	Sogefi
Material name	-
Material abbreviation	EP-GF

The lightweight suspension springs made of glass fiber-reinforced polymer (GFRP), which Audi developed in collaboration with an Italian supplier, even looks different than a steel spring. It is light green, the fiber strand is thicker than the wire of a steel spring and it has a slightly larger overall diameter with a lower number of coils. The core of the springs consists of long glass fibers twisted together and impregnated with epoxy resin. A machine wraps additional fibers around this core — which is only a few millimeters in diameter — at alternating angles of plus and minus 45 degrees to the longitudinal axis. These tension and compression plies mutually support one another to optimally absorb the stresses acting on the component. In the last production step, the blank is cured in an oven at temperatures of over 100 degrees Celsius. The GFRP springs can be precisely tuned to their respective task, and the material does not corrode, even after stone chipping, and is impervious to chemicals such as wheel cleaners. Last but not least, productionrequires far less energy than the production of steel springs.

5. Plastics

5.1. Geon™ E7790 Green | PVC

Composition
Polymer class Thermoplastics
Polymer code PVC
Polymer type PVC

Characteristics
Processing Compression Molding, Other Extrusion
Delivery form Powder
Special Characteristics U.V. stabilized or stable to weather
Applications Electrical and Electronical

5.2. DSM Somos® 7110 UV Postcure | EP

Composition
Polymer class Thermoplastics
Polymer code EP
Polymer type EP

5.3. P84® NT1 15G conditioned | PI-CD

Composition
Polymer class Thermoplastics
Polymer code PI-CD
Polymer type PI
Filler Type Carbon Fines/Powder

Characteristics
Delivery form Granules, Powder
Special Characteristics Heat stabilized or stable to heat
Additives Lubricants

Product information notes

Polyimid P84® NT - at a glance Excellent performance at high temperatures High strength and excellent shape stability Very good impact resistance High heat deflection temperature Very good creep resistance even at elevated temperatures Machinable with standard tools Low wear and friction behavior Processing by Hot compression molding or Direct forming Application examples bushings, seals, bearings components, guides, gear wheels, and valve parts in the automotive and aerospace industries and in industrial equipment.

Processing notes, Compression Molding

Hot compression molding Production of big semi-finished parts (plates, rods, tubes) High pressure 400 kg/cm² and temperature above Tg (350-380 °C) Cycle time = hours Processing of precise parts by machining Best mechanical properties Direct forming High number of small parts Production of green parts at ambient temperature and very high pressure of 3 t/cm² Cycle time = seconds Subsequent sintering above Tg (350-380 °C) No or little machining necessary.

5.4. PLEXIGLAS® Resist AG 100 | PMMA-I

Composition

Polymer class Thermoplastics
Polymer code PMMA-I
Polymer type PMMA
Additional components Impact modifier

Characteristics

Processing: Film Extrusion, Injection molding, Other Extrusion, Profile Extrusion, Sheet Extrusion, Thermoforming
Delivery: form Pellets
Special Characteristics: High impact or impact modified, Light stabilized or stable to light, Transparent, U.V. stabilized or stable to weather
Additives: Release agent

6. Alternative Materials

The assessment and promotion of green building materials should start with conservative materials (Fig. 9) because these are the most utilized. However, in a transition to sustainability, we must start to consider more and more of materials that fit within ecosystem processes. These are the alternative materials. They differ from place to place, bioregion to bioregion, but some of the better known, and increasingly popular, in North America are straw bale, rammed earth, adobe, cob, cordwood, stone and "earthship" buildings made of old tires and other garbage [3,4].

Figure 6. Green building materials made of old tires and other garbage.

They all make outstanding employ of local resources and are shaped with little energy. Their building processes tend to be labor-intensive and resource-saving. Most are natural drying and eminently recyclable or even reusable. They are also non-toxic and engender little pollution. Some, like earthships (built from old tires) and straw bale construction, make good use of a waste product [5].

Most of the alternative building techniques are modernized versions of traditional building methods that were swept aside by the industrial revolution. Many of the materials are almost ideal materials for the climates where they are found. Materials like straw are natural insulators—one of the totally non-toxic forms of insulation (Fig. 7). Other materials like earth have great thermal mass, keeping warmer in winter and cooler in summer. Whereas many people connect these materials with rural settings, this is mainly since the countryside has been more conducive to experimentation. There is no reason why rammed earth, earthships and even straw bale couldn't be utilized as easily in cities. The future of sustainable cities lay in low-rise, high- and medium-density settlements, featuring lots of plant growth that can offer food, climate-control, energy and water eco-infrastructure, and along with neighborhood employment.

If green cities are to value the natural productivity of the landscape, they must also harness the social productivity of vernacular building and design, and of the informal economy [6]. Economies must find ways of supporting the gardening, preventive health care and self-help building. Alvin Toffler (1972, 1980) first called these emerging informal activities "prosumption"[7]. Toffler was totally ignorant to the ecological dimension, but writers like Schumacher, Illich, Winner, Mumford and Goodman have not only called attention to the importance of these sectors, but also to the need to design and implement technologies to support them [8].

Figure 7. A house built by mud-brick and straw, a natural and non-toxic insulator green material.

The alternative materials are highly suited to "prosumptive" activities. Rammed earth, for instance, takes soil right from the building excavation, eliminating most of the huge processing industry dedicated to wood frame or concrete construction [9]. Most of the techniques can be learned by the people who will live in the buildings. They can contribute in the design. They can see and feel how nature supports them, and understand what they must do to return that support.

The implications of greater use of alternative materials cannot consequently be fully understood with a life cycle analysis. They also occupy social relationships that are essential to creating sustainable communities and economies. They can assist to undermine the forms of hostility of producer from consumer, of professional from client, of design from execution, and of individual from community, that so underlie unsustainable practices.

7. Conclusion

1. The greening and dematerialization of building engage the whole economy. It must take place on every level—production, expenditure and regulation. Green plans have to begin everywhere, but the area of expenditure may be the place where fundamental initiatives have the utmost space for movement. Grassroots action is maybe the most complex since, by description, it is moving from the dominion of the marginalized and fragmented. But it also can request straight to real felt needs and also construct incrementally.
2. The dominion of expenditure is severely rooted in civil society. It not only includes voluntary presumption but is intimately linked to the dominion of small business. This level of business is where most environmental economic options are realized: eco-construction firms, community-supported agriculture networks, auto-sharing networks, green power co-ops.

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A University Emblem Die Design and Molding

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Abstract

To decrease the price of materials is very important. It is possible to make cost effective products by means of method that without machining i.ekitchen appliances, electronic devices and even plastic producsts. In this study one of the branch of design compression dies are investigated and a university emblem is studied using that kind of die. By compression dies any letters, numbers, figures and patterns can be produced on the metallic sheet. Frequently some problem such as cracking of punches and uniforming of the figures and patterns may be occurred. The advised solutions for those problems are enough compressing force and working materials hardness. Furthermore the hardness of the punch surfaceshould be among 58-64 Hrc.

Keywords: compression dies; emblem printing; design

1. Introduction

Manufacturing of products that are used in daily life in an economic way has importance in modern competitive age. Decorative products, kitchen utensils, electronic as well as polymer products etc. should be manufactured by such method that does not require machining, quick and convenient for mass production. Compressing molding is one of the well-known production method that satisfy these requirements.

In compression molding work pieces are soft and limited to certain thicknesses. The figures or patterns that are need to be printed on a work piece are processed on to mold punch. Punch surfaces are exposed to high wearing during operations, its surface is coated with chrome or nickel to reduce wearing rate. Pattern or figure on punch is transmitted to work piece by means fast strokes and with high compression force on punch. Bending or breaking of punches are frequently observed during manufacturing which leads undesired miss forming of materials. To overcome this problem suggested method is to apply correct compression force on punch and made punch from a material that 58-64 Hrc hardness level.

Coins, medallions etc. which are contains precious metals are also produced with compressing molding method. For instance, figures on front and back side of a coin is created by two punch stroke in once. Certainly manufacturing of these products needs careful selection of material and manufacturing process. In this paper, an emblem is going to be designed which is having print of “International University of Sarajevo (IUS)” on one side and flat on the other side.

2. Compression Molding

The process of molding a material in a confined shape by applying pressure and usually heat. Compression molding process is followed by two step first one preheating and pressurizing. Sheet-like materials are maintained betweenmale and female punch, subject to pressure to shape workpiece to desired figure or pattern [6].

In the pressing process of workpieces to find enough compressive force following formulation is used:

$$P = A * \sigma_b \quad \text{(kg)} \quad (1)$$

where,

$$A = surfacearea(mm2)$$

$$\sigma_b = compressionforceperunitsurfarcearea$$

To find value of σ_b one should look at in Table 1.

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Compression Molds

These kind of molds are working under high pressing forces due to that fracture of mold punch, or mold itself is likely. To overcome that, low pressing force and soft material for work piece should be considered. Another issue is adhesion; this can lead certain damage on mold [7]. Failure of mold due to high pressing load or because of workpiece usually reasons are listed below:

a) molding of very elaborate design.
b) large are of punching requires too much pressure
c) rich feature patterns or figure printing [8].

If pressed to the desired shape and trimmedworkpiece on a piece, but the opposite is not properly designed as smooth metal flow is disrupted. As a result of my dispersed mass to be designed right on the part working on it is required. Because otherwise it will reduce the life of the mold and achieve desired shapes or motifs in a not good way.

Table 1 Compressive Stress of some mostly used emblem material. [11]

Type of Material	Compressive Stress (kgf/mm^2)
Aluminum	64-112
Brass	84-180
Copper	40-112
Steel (Ç 1010)	80-264

3. Preparation of work piece

Printing should be defined for a contact between the mold surface of the material. These contacts are in the process of thermoforming or extrusion requires the re-distribution of wealth in the metal's crystalline structure.

After, emblem material composition defined, casting begins for that composition. Composition contains 69.5 % Cu, 12 % Ni, 18% Zn, and 0.5% Mn. Recommended hardness level for this composition should be around 50 Rc. Composition is obtained by melting raw materials around 870 C°. Composition is poured into mold that is in form of small ingots, here end product size and cutting clearances calculated to design size of these ingots. To ensure identical weight of work piece rolling process is used to form ingots into desired from of sheet metal. Thereafter, the sheet metal cuts in strips to get ready for punching into final shape before compression molding of work piece [1,2,9].

3.1. Coin and medallion molding preparation

Two-step meticulous work, including artistic and technical part. Firstly, emblem material and dimensions is decidedthen artistic part of it starts. It prepared utilizing the graphic pattern image classification miniature and calligraphy. After determining the pattern switches to model preparation with engraving and sculpture work.
Male acrylic pattern is prepared by using pantograph machine from previously created model. After that, punches are heat treated and hardening process done in oil with barium salt having temperature between 960-1020.

Punches are made of from 2550 oil steel and 2770 water hardened tool steel. After hardening (quenching) tempering process is done to reduce hardness and increase toughness of the material. Punch hardness are chosen between 55 to 59 Rc based on work piece (coin, emblem, medallion etc.) material. For instance, punch for brass (Cu 70 %+ Zn 30 %) and gold (Au) work piece should be 55 Rc and 59 Rc respectively.

3.2. Dimensional accuracy and work piece shape

To have good printing quality, design and mold accuracy should be considered carefully. Finishing is generally done on the latest stage. It gives accurate results as a result of a good machine labor.There are practical limits on workpiece shape. All this may be summarized as of press capacity and characteristics of the material to be molded [1]. For example, a material which has compressive load of 1,000,000 kgf/mm^2 with a 250 tones press, maximum a surface area of 50 m^2 can be pressed.

4. Printing Coin and medallions

Coins and medallions are produced in process which quantities more than 100,000 pieces. Banknotes are generally high-speed hydro - pneumatic and pneumatic press is manufactured using molds comprising an impact with less embossing on the back side.

Steel blanks and surface electro-coating process is performed to punch surface quality problems seen as a problem in recent years has declined. Covering the cost of cheap increased the applicant is through use of the common stereotypes in this method. Electro-plating industry is already developed. Very big efforts in recent years for the industry to print money is spent.

5. Formability of metals

5.1. Steels and Irons

The easiest pressed steels are defined as the alloys that contains 0.3 % carbon. Formability decreases when carbon content increases, more 0.30 % carbon content in alloy usually makes it brittle and difficult to form under press. Nevertheless, material that contain sulfur are not recommended due to their brittle structure.

Metal coins and medallions are manufactured with compression molding method. In this method, work piece if feed in to mold cavity, and pressed with mold punch. Therefore, volume of work piece must be equal volume of mold cavity [1,2,3,4].

5.2. Production of silver alloy medallions

To manufacture medallion from 0.84 g silver alloy (95 % Ag, 5% Cu) necessary compression mold and its component shown in the Mold material

O1 toll steel

Mold hardness	*rock well C-60*
Compressive force	*150 ton*
Oilier no	
Formation time	*0.25 hour*
Production ratio	*48 piece/hour*
Total service life of the mold	*1000 to 10,000 piece*
Cost of tools	*$600*

Figure 1. Cutting and forming is done with a 140-ton press. There is no need for flanging in the process of medallions often. However, if design includes thick embossing, it would quire second press stroke to complete pressing. Before, the second pass previously pressed area tempered to increase toughness due to strain hardening of work piece [1,2,3,7].

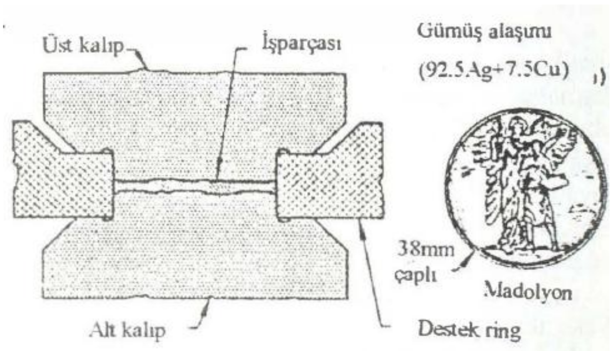

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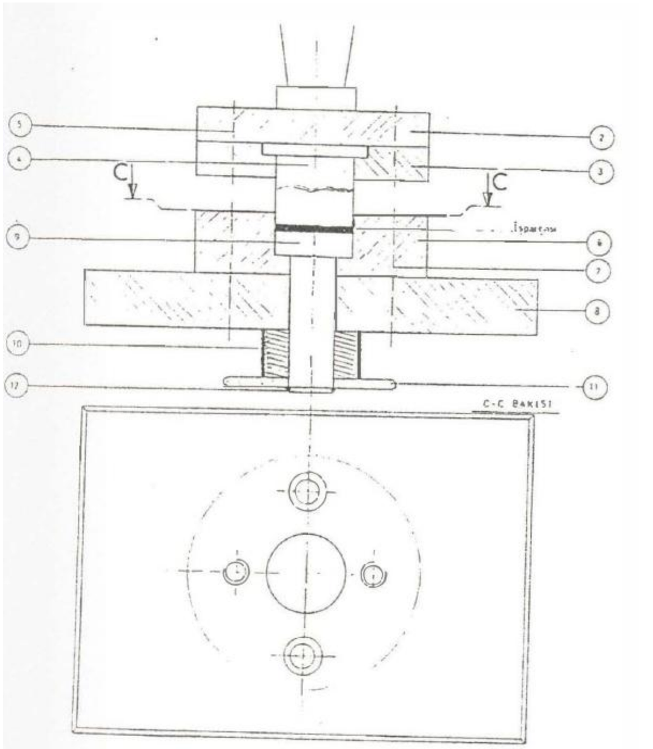
Figure 1Compressing mold used in Ag (Silver alloy) medallion pressing [1].

6. Analysis of problems and solutions

An appropriate mold cavity clearing is necessary to have good result from the molding. In the preparation of mold cavity, size of the work piece should be taken in to account. Details on a mold cavity should be formed in to work piece in once stroke of press or as much as minimum number of press stroke to reduce required time for molding.

Failure in the molding might be caused due to dirty mold cavity surfaces. While molding process airflow is used to prevent dust and other contaminant from mold



cavity to over this problem. A careful examination of molded products to detect possible problematic cases like oiling or sticking of material pieces to mold punch or cavity saves next coming work pieces being damaged.

Another source of failures is wrong sequence of materials based on their geometric tolerances and properties. Sequencing should be done considering following point; in a way that expected tolerance level from work piece to be produced.

Figure 2 Technical drawing of the mold assembly

7. Case study: IUS emblem design and molding

IUS (International University of Sarajevo) emblem mold design is studied in this section. Mold consists of lower and upper group; in the upper group fastening stalk, holder plate and upper punch are placed. The university emblem (see *Figure 3*) should be pierced via pantograph bench on the upper punch which made of from SPK 2080 steel material advisably. The punch should be polished to remove possible burrs and hardened at least HRC 58. Lower group, might any faculty or program name would be pierce, in this study it is considered as shiny flat surface without any printing.

Figure 3 IUS emblem (front face only)

Technical drawing of press and mold is given in *Figure 2*. After the mold montage, a 35-ton eccentric press would be enough to print the emblem. Emblem material for the print are selected as copper, aluminum and brass with 25 mm diameter and 2 mm thickness. From previous studies, it is reported that soft materials like copper and aluminum gives better results. This is due to high formability of soft materials.

8. Conclusions

Molding: a process which includes pressing circular /strip shaped workpiece once or in couple of sequence between two die which predesigned and manufactured to print certain figure on the material. Workpiece is trapped between die plates and by pressing appropriate pattern obtains.

Reasonably accurate process and oversensitive tolerances are required by the pressing. Cost is high for this process, however cost per piece relatively low since it is mass production capability. In order to reduce cost of the process die failures in terms of material selection needs to be considered. Recent findings showed that pressing coins, medals, emblems and similar products with electroplated die punches with bronze is improved service life and printing quality significantly. Currently, common coating material for the dies are pure nickel.

In this study, pressing the emblem of the university has not only cost problem but also design and material selection are another important problem to solve.

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