Selection of Materials and Manufacturing Processes Towards Achieving Green Engineering

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Abstract

Pollution free environment is now-a-day considered as an important criterion of development for almost every country of the world. Thus, selection of materials and manufacturing processes for a particular product becomes very crucial and must pass through numerous regulations to achieve green atmosphere. In order to achieve this goal, close coordination among the designer, material scientist, manufacturing engineer and environmental expert is needed. Starting from the design to the final product including the recyclability and waste disposal, each and every step must be carefully considered, planned and coordinated before manufacturing starts. This is because; any change in design or material and associated technique during manufacturing becomes more and more expensive as work progresses. Agro-based and industrial nations of the world have started to show their interest on health hazard, recyclability and to generate clean and environment friendly energy. At the same time, emphasis must be given on pollution free green environment so that man-made disaster may not occur.

1. Introduction

Environmental aspects are now considered as one of the most important concerns for many countries of the world including Malaysia. Clearly, environmental regulations have given a new dimension and direction towards the selection of materials and manufacturing processes for a particular application. The overall exercise of environment friendly design, material selection and manufacturing is simply known as Green Engineering [1]. It is the design, commercialization, and the application of processes and products, which are feasible and economical in minimizing the generation of pollution at the source and the risk to human health and environment. Thus, it embraces the concept that decisions to protect human health and environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process for any product. This is categorized as 'Business Issues' and in some of the business issues most designers and engineers select materials on the basis of recyclability, health hazard, emissions, waste disposal, product liability and code compliance [2].

In Malaysia, a Dow Chemical Group of Company implemented the ISO 14000 standards and other initiatives at Dow are Eco-labeling, Green partners and Implementation of 4R (Reduce, Reuse, Recycle and Regenerate) approach [3]. Dow is a leader in science and technology, providing innovative chemicals, plastics and agricultural products and services to many essential consumer markets. In USA, the Environmental Protection Agency (EPA) has numerous regulations regarding environmental performance. Every designer and manufacturer must follow these regulations. An environmental impact assessment (EIA) is related to the life cycle assessment (LCA) and is intended to structure a study of the impact of emissions so that potential major problems are identified [4]. In order to achieve this objective, an engineering component must be manufactured using appropriate technique from selected engineering materials so that it can withstand the service environment, avoiding any atmospheric pollution and health hazard to living beings.

The main health hazard, especially in the foundry industry (one of the manufacturing industries) arises from silica particles in the size range below 2 µm, which are active in inducing pneumoconiosis. Airborne industrial dust consists predominantly of particles below 2.5 µm with a median size of about 1 µm. A particle of this size has a free falling velocity of only 18 mm/min and so stays airborne indefinitely in normal environments [5]. In order to maintain a good and healthy environment in any manufacturing industry, the following essential steps need to be taken:

(a) Proper and adequate ventilation system must be provided so that the materials carrying contaminants from various sections cannot pollute the environment.
(b) In order to expel the smelly and hot air easily from the industry, sufficient exhaust fans must be provided.
(c) Spreading of sand dust, saw dust, coke dust, lime powder, rusts, scales or metallic oxides, fly ash, etc. to the surrounding must be controlled from various sections of the industry by providing arrangements as shown in Figs. 1 and 2.

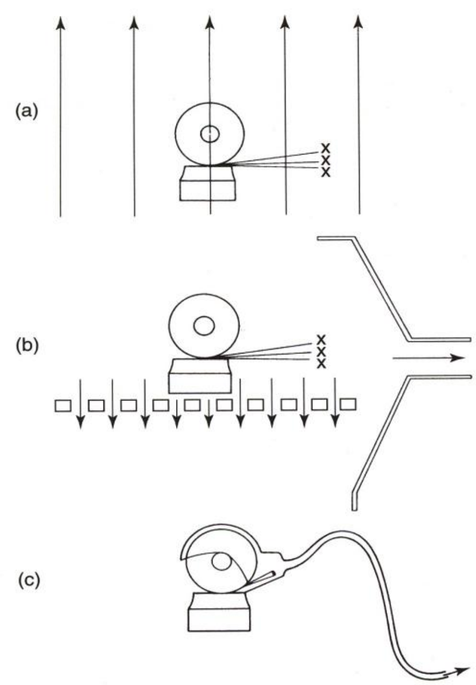


Fig.1, System of dust extraction, (a) General ventilation of work-space, (b) Local extraction adjacent to work-place and (c) Local extraction at tool-position.

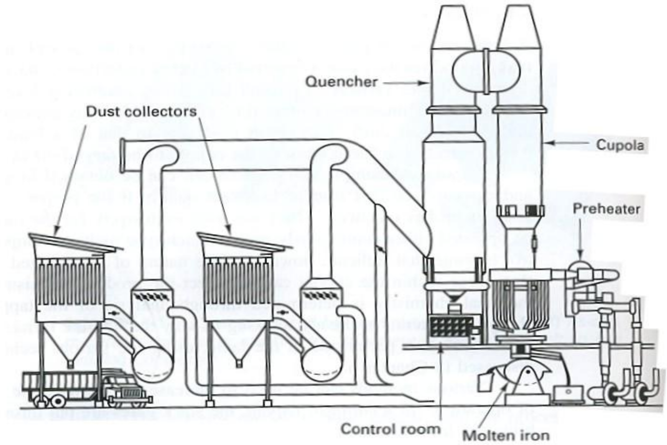


Fig. 2, Modern cupola with preheated blast, sparks quencher and dust collector [6].

(d) Evolution of hazardous gases such as CO and SO_2 in the melting section of a foundry must be controlled. In order to control the formation of CO, sufficient supply of air or oxygen must be provided in the burner. At the same time, in order to control the amount of SO_2 in iron and steel manufacturing industries, the raw materials such as pig iron, foundry grade coke, etc. must contain minimum level of sulphur.

(e) During heat treatment of some engineering components, cyanides in the salt bath make the environment seriously polluted. So, cyanide free salt must be used or other types of heat treatment procedure must be adopted.

However, during last sixty years, dynamic changes have occurred in the world of materials. Concerns regarding environmental pollution, recycling, and workers health and safety factors have imposed new restrictions in selecting proper engineering material for a particular application. At the same time, desires for weight reduction, energy savings and improved corrosion resistance also motivate this selection. Thus, the selection of engineering material and appropriate processing technique has become an extremely important criterion, which requires constant re-evaluation. The design engineer will, therefore, frequently work in conjunction with material specialists to select the materials that will be useful to convert the designs into reality. A key function of material engineer is to synthesize the applicable materials and produce them in bulk quantities. On the other hand, mechanical and manufacturing engineers must frequently select materials (in consultation with material scientists) and manufacturing processes to implement the designs for the new products. This is to improve the existing products by substituting the old ones and to face the challenges for requiring the replacements. Thus, a close coordination among them is essential at every stages of manufacture for a simple product, if economy is to result.

2. DESIGN, MATERIAL SELECTION AND MANUFACTURING

There is a close interdependent relationship among the design of a product, selection of material, and selection of processes and equipment or tooling. Each of these steps must be carefully considered, planned and coordinated before manufacturing starts. Close coordination of all the various phases of manufacture is essential if economy is to achieve. All wrongdoings and bugs must be eliminated carefully during preliminary phases. This is because; any change during manufacturing becomes more and more expensive as work progresses [6]. Most designers and engineers create value for their employers by designing machines to make products and by designing new products, processes and facilities. The common thread throughout engineering is design. The marriage between design and material selection should start early in the design process [2]. Thus, the first step in the manufacture of any product is the 'design', which usually takes place in various distinct stages.

The selection of an appropriate material and its subsequent conversion into a useful product with desired shape and properties is a complex process. Nearly every engineering product goes through the following sequence of activities: Designing --- Material Selection --- Process Selection --- Manufacturing --- Evaluation --- Possible Redesign. Thus, a number of engineering decisions are made along the way.

2.1 Conceptual Design

During the conceptual-design stage, the designer is concerned primarily with the functions that the product is to fulfil. Several ideas are considered, but the determination is made on basis of its applicability. Here, the only concern about materials is that whether the existing materials can provide the desired properties of the product or not.

2,2 Functional Design

At the functional or engineering-design stage, a workable design is developed including a detailed plan for manufacturing. Geometric features and dimensions are specified, and specific materials are selected for each component. Consideration is given to appearance, cost, reliability, producibility, and serviceability, in addition to various functional factors. Very often, a prototype or working model is constructed to permit a full evaluation of the functions and performance requirements of each component. A few examples can be cited in this context. In designing a windsurfer mast (Fig. 3), which controls the sail shape, performance index and mass, the thin-walled tube of carbon fibre reinforced polymer (CFRP) is the best solution for the windsurfer mast material [7].

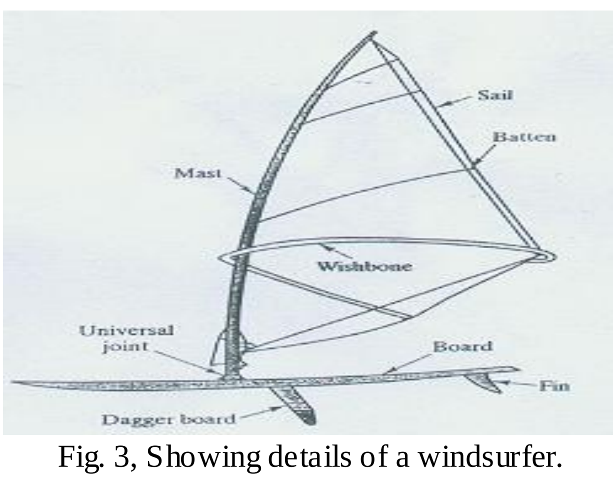
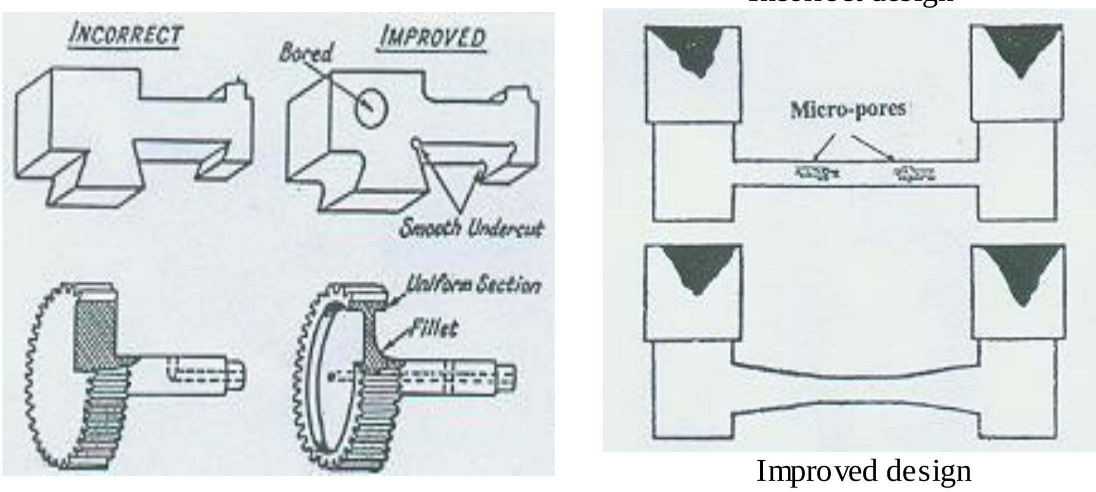


Fig. 3, Showing details of a windsurfer.

Again, if heat-treatment is required for an engineering article to improve the properties, then its design may need to change in order to get full benefit of the process as can be seen from Fig. 4(a). Similarly, an article produced by casting process, may need to change the design slightly in order to obtain a sound casting as shown in Fig. 4(b).

Incorrect design



Improved design

(a) (b)

Fig. 4. Relation of design to (a) Heat-treatment and (b) Casting operations.

At the same time, the ductile-to-brittle transition temperature (DBTT) is a design criterion of great importance for some structural materials. The alloy that exhibits a DBTT loses toughness and is susceptible to catastrophic failure below this transition temperature. Several disastrous failures of Liberty ships occurred during World War II because of this phenomenon [8]. The low carbon steels that are ductile at room temperature become brittle when they are exposed to lower temperature ocean environments. Therefore, data on DBTT for some engineering materials are of great practical importance in functional design and material selection.

2.3 Production Design

In the production-design stage, materials concerns should be directed to whether the specified materials are compatible with the manufacturing process and equipment used for their processing. Example can be cited regarding the biocompatibility of a material, say mercury – when ingested into the body, it is poisonous. However, when it is amalgamated with gold, silver and copper for dental fillings, which have high mercury contents, are found to be very biocompatible [9]. Again, it should be considered that whether the materials can be processed economically or not as well as their availability in terms of quality and quantity. They must be assessed carefully so that there should not be any shortage of materials during manufacturing.

However, new processes are frequently associated with new materials and their implementation can often reduce production costs and improve product quality. Therefore, a change in material may well require a change in the manufacturing process or improvements in processing and may lead to re-evaluation of materials being processed.

Improper processing of a well-chosen material can often result in a defective product. Thus, proper implementation of the processing technique is also important to achieve desired goal or output. Fig. 5 shows the correct method of introducing some articles into the quenching medium in order to get full benefit of heat treatment operation. If it is not carried out properly, all efforts will be in vain.

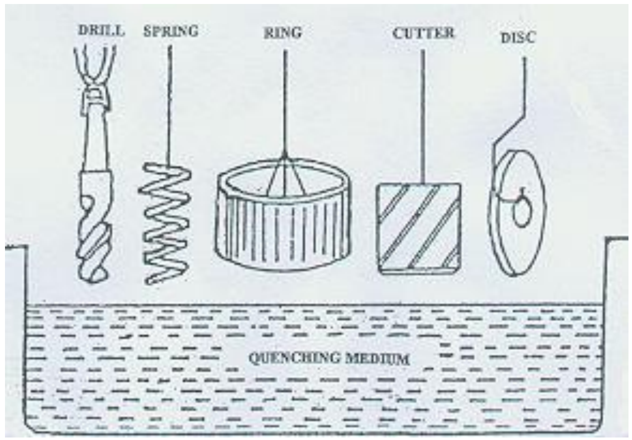


Fig. 5, Correct methods of introducing engineering articles into quenching bath.

Therefore, in order to obtain satisfactory service performance from an engineering component, considerable care must be exercised in selecting optimum or improved design, proper engineering material and appropriate manufacturing technique to produce it.

3. Development of Advanced Materials and Manufacturing Processes

After the 1973 oil embargo, market pressures arose to substitute traditional materials for aerospace and automotive industries. Quite often, the substitution must bring about improved quality, reduced cost, ease of manufacturing, simplified assembly with enhanced service performance. However, it is important that the responsible engineer should consider the total picture and be aware of any possible compromises. Design modifications would also be necessary to accommodate the new material.

Considering the efforts that relate to the production of a lighter-weight, more-fuel-efficient automobile, the development of high-strength-low-alloy (HSLA) steel sheets provided this facility to match the strength of traditional body panels with thinner-gauge material. Ductile cast iron crankshafts have replaced forging steels, saving energy, processing time and production cost. Cast iron engine blocks do an excellent job for damping out vibration and noise. Similarly, polymeric materials have been used successfully for body panels, bumpers, fuel tanks, pumps and housings. Composite materials have been used in place of metal. Cast metal, powder metallurgy and composite materials have all been used for connecting rods. Ceramic and reinforced plastic components have been used on engines.

The increasing trend of replacement of metal parts by engineering polymers has been emphasized because of lightness, high toughness and impact strength, and increased resistance to corrosion and wear. At one time, bicycle frames were constructed almost exclusively from welded steel tubing, but now, companies offer frames in a wide range of engineering materials. One top-of-the-line carbon fibre frame now weighs only 2.5 lbs. Also the manufacturer uses a sophisticated software package utilizing 'finite element analysis (FEA)' to analyse how the frame will respond to stress, allowing the engineers to tailor the frame stiffness to the individual rider. At the same time, the body panels of smart car are made from recyclable thermoplastic alloy called Xenoy that is several times lighter than steel and helps the car to get up to 28 km/l [10].

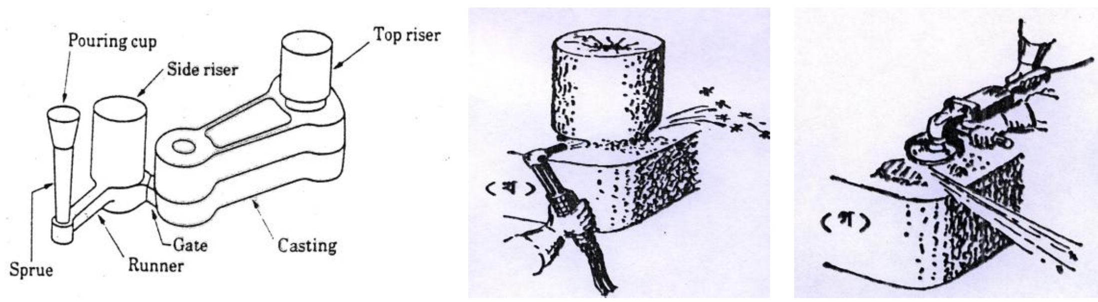
A key example of the driving force for replacing metals with lower density composites is in the commercial aircraft industry. Competition is intense and the material substitutions are frequent. This is because; one kilogram of 'dead weight' on a commercial jet aircraft can consume 830 litres of fuel per year [8]. An early response to the need for materials substitution for fuel savings was the use of over 1100 kg of Kevlar-reinforced composites in the Lockheed L-1011-500 long-range aircraft. The result was a net 366 kg weight saving on the secondary exterior structure. Similar substitutions were made later on all L-1011 models. An excellent example of this effort is the design of Boeing 767. A significant fraction of the exterior surface consists of advanced composites, primarily with Kevlar and graphite reinforcements and resulting weight savings is 570 kg.

At the same time, the development of amorphous metals in recent decades has provided an attractive new choice for transformer cores. A key to the competitiveness of amorphous metals is the absence of grain boundaries, allowing for easier domain wall motion. Ferrous glasses are among the most easily magnetised of all ferromagnetic materials. These ferrous alloys have especially low core losses. As manufacturing costs for the amorphous ribbons and wires were reduced, the energy conservation due to low core losses led to commercial applications. The replacement of grain-oriented silicon steel with amorphous metals [8] in transformer cores reduced core losses by 75%. Thermal stability has proven to be a primary design consideration in commercialisation of amorphous alloys for electric power distribution. As a result, amorphous $Fe_{80}B_{11}Si_9$ alloy is the most commonly used amorphous alloy in power applications, since this alloy offers the best thermal stability having highest critical temperature. Distribution transformers step down electrical voltages from 5-14 kV range used for local transmission to the 120-240 V used in homes and businesses. Given the thinner geometry and more brittle mechanical behaviour of amorphous alloys, the specific design of the transformer core has been modified somewhat in comparison to the conventional grain-oriented silicon steel.

4. Sources of Industrial Pollution and their Controls

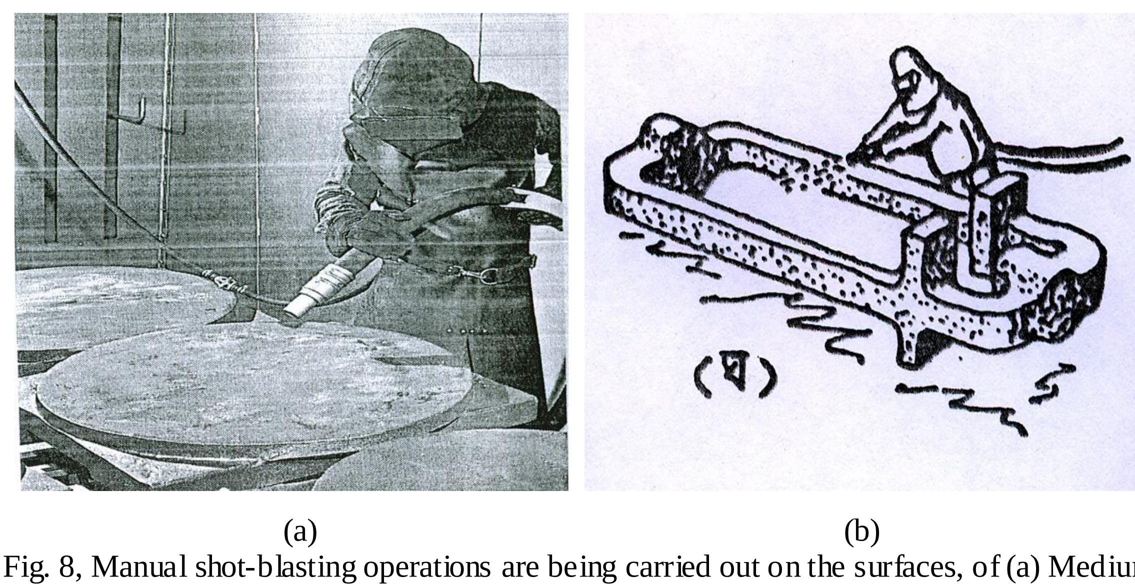
The main activities of any industry are usually related with handlings of metallic materials, sand, clay, water, hazardous chemicals, fire, etc. The limitations to any foundry industry are the safety hazards to human beings, especially when hot metal and alloys are handled (Fig. 6) and also produce some environmental problems. During knockout of the mould to take the casting out, silica dust, smelly smoke and moisture polluted the whole environment. Similarly, during cutting the gating system from the casting, metallic spark, dust as well as annoying sound from grinding action make the environment polluted and noisy (Figs. 7-9).

Fig. 6, Casting- pouring molten metal into mould is risky to human being and environment.



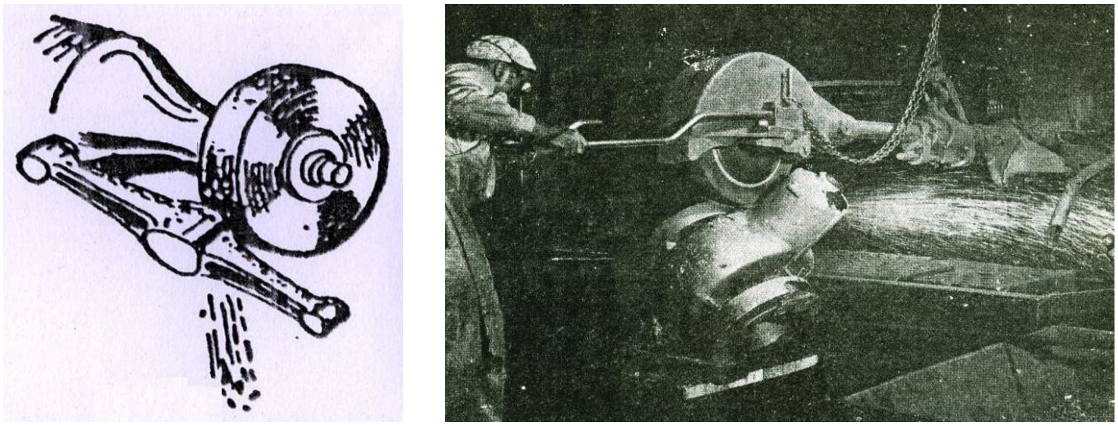
(a) (b) (c)

Fig. 7, Showing (a) Casting with gating system, (b) Riser is being cut by flame and (c) After cutting, the surface is being smoothened by hand grinder.



(a) (b)

Fig. 8, Manual shot-blasting operations are being carried out on the surfaces, of (a) Medium sized and (b) Large sized castings.



(a) (b)

Fig. 9, Showing surface cleaning operations of some products by using (a) Simple hand grinding machine and (b) Swing grinding machine.

At the same time, during heat treatment operation of any product, especially during carburizing and nitriding, the copious fumes, CO, CO_2, SO_2, etc. are produced together with oil vapour, moisture and poisonous cyanide gas, which make the environment polluted and health hazardous. Similarly, other manufacturing industries such as welding, petrochemical, etc. are also hazardous to human beings and the surrounding atmosphere as shown in Fig. 10.

(a) (b)

Fig. 10, Showing (a) Arc welding spreading the sparks and fumes and (b) Industrial smokes and gases polluting the atmosphere.

Under these circumstances, if the above mentioned items are not controlled properly, the working labours, technicians, machine operators and the staff who have been servicing in the factory environment for years together may suffer with various diseases. If infected, the family members and the relatives of infected person may also be affected.

For these reasons, the people who are working in the manufacturing industries need to wear insulating gloves, aprons, shoes, goggles, ear plug or muff, mask, cap or hood, etc. to protect themselves from the injurious effects of their working environments. However, it is the duty and responsibility of the administration or management to supply all sorts of personal safety items to the working staff. At the same time, administration must supervise that these safety items are being used properly or not by the working staff, especially during operational period. The health and safety executive is charged with direct enforcement of the relevant laws and acts as a source of advice and information on all matters relating to occupational health and safety [5].

5. CONCLUDING REMARKS

On the basis of foregoing discussion, following conclusions can be drawn:

(a) It is apparent that those who select engineering materials and manufacturing processes should have a broad and basic understanding of the nature and properties of materials, and their processing techniques so that both can be chosen as environment friendly.
(b) Efforts are to be made for the conversion of renewable energy to electricity generation so that all kinds of manufacturing industries can be operated smoothly with clean and pollution free environment.
(c) The administration must be careful to implement the laws and acts relating to occupational health and safety for the respective industry, and must supervise that the safety items have been provided by the management and are being used properly for the cause of safety during working time.
(d) Emphasis must be given on green engineering towards the selection of materials and manufacturing processes so that man made environmental disaster may not occur in any country either developed or underdeveloped.

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