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Opportunities for the Recycling of Fiber Reinforced Plastics under Technical, Economic and Social Aspects

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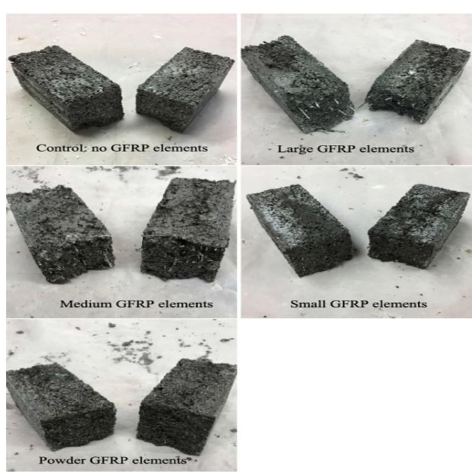
Abstract: This paper is based study about different methods of FRP recycling and their advantages and disadvantages. This paper largely focuses on finding best possible method for recycling of Fibre Reinforced Polymer based on various factors such as technical analysis, economics of method and it's environmental impacts. Various methods are speculated on technical background to find out mechanical constraints while performing particular recycling process and then emissions and social impacts are analyzed to figure out suitability and workability of the process. This way various methods are studied and an attempt has been made to figure out detailing of every recycling method which will throw light on some unexplored regions for better understanding of recycling of FRP.
Keywords: FRP, EuCIA, recycling, economics, Pyrolysis, Solvolysis, recyclats, Combustion, Calorific value.

I. INTRODUCTION

The composites industry is producing plethora of products due to the properties FRP possess. But FRP's poor waste management has left many issues waiting to be solved. In today's world, landfills remain the most popular way of disposing waste. Cutting edge technology demands research and innovation in these areas. So we have some good methods to recycle FRP presently available with only one demerit. That is nothing but lack of analysis. Proper recycling method will yield much more than expected but also new horizon of business will be open for all. It is very critical to study all aspects of a recycling process. We are introducing you some useful comparison and analysis to find out most suitable method of FRP recycling.

II. BACKGROUND

The usage of Fiber Reinforced Plastics (FRPs) has substantially increased in the past few decades. The lightness, high strength to weight ratio, corrosion resistance and low cost naturally make FRPs a better alternative to traditional usage of Metals and Alloys. The major applications of FRPs are composite seat frames, front fenders, fuel tanks, etc. in Auto-mobiles, outer wings, flaps, vertical stabilizers, radome, tail, etc. in Aerospace applications, Blades in Wind Turbines. The global market value of thermoset plastics was estimated at US$41.98 billion in 2017 and is expected to increase to US$57.98 billion by 2021. The annual demand of FRPs has now reached to 72,000 tonnes. A major problem is these composites are non biodegradable in nature. Naturally, the production and End-of-Life waste of FRPs is estimated to be 6200 tonne and 75,000 tonne yearly in UK. Hence recycling FRPs by different alternative methods is a must. These recycling methods tend to have environmental and financial impacts that need to be reviewed so as to decide the best possible alternative that can be implemented on a large scale.



III. METHODS OF RECYCLING

According to Waste Framework Directive (Art. 3 (17)) and EuCIA 'Recycling' is defined as "Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations".

Taking in consideration, the above definition there are four main types of Recycling of the FRPs namely:

A. Mechanical Recycling.

In Mechanical Recycling of FRPs the waste products go through a size reduction process generally by grinding and milling. The reduction takes in two steps where the initially the composites are reduced to 50-100 mm size. This process is generally done by the slow crushing mills and aids the removal of metal inserts. Later on, in the second stage, the composites are grinded to a 10-50 mm size using high speed mills or hammer mills. Finally, these particles are separated using cyclone separators and segmented as Finely Powdered, Coarse or Fibrous. This type of FRP is generally used as filler or reinforcement materials. Some of the successful applications for mechanically recycled FRPs include furniture manufacture, man hole covers and utility boxes. Apartfrom these, Mechanically Recycled FRPs are also used as a dampening material for noise insulation and sound proofing.

B. Thermal Method

The Second type of recycling of FRPs is by using Thermal Methods. Thermal recycling of FRPs is generally done by mainly three categories namely: Combustion, Fluidized Bed and Pyrolysis.

1) *Combustion Process:* In the combustion recycling of FRPs, the wastes are used as fuels to generate energy. All Polymers have a calorific value of around 30,000 KJ/kg. The calorific value of FRPs is highly dependent on the type and proportion of polymers used. This type of recycling generally gives the energy recovery but on the other hand the residual waste is a major issue which is ultimately used as land fill. This again has a severe on the soil ecosystem and hence is not preferable. On the other hand, leftovers of combustions can be used as filler materials.
2) *Fluidized bed Process:* Fluidized bed is the second thermal alternative used for the recovery of reinforcements like Glass Fiber or Carbon Fiber. In this method, FRPs are reduced to 25mm size and then fed to the fluidized bed of silica sand. The hot air at 0.4 m/s to 1.0 m/s passed to a hot bed at around 450-550 deg C. This interaction volatilizes the polymers which lead to separation of polymers from the fibers. Later on, the residual mixture is moved to the final chamber where the complete oxidation of polymer takes place. It is observed that the glass fibers recycled from such process possess have 50% reduction in tensile strength whereas for carbon fibers the reduction is 20%.
3) *Pyrolsis:* Pyrolysis is the most studied and performed thermal recycling process. This process is performed in the absence of oxygen. The FRPs are burned at the temperatures of about 450-550 deg C. This leads to matrix degradation and produce oil and gasses of the polymer and the solid products having fibers as the main constituent. Generally, in case of carbon fibers, they are post treated at the temperatures of about 450 deg. In this process a loss of 15% in mechanical properties of carbon fibers was observed. As the energy requirements of conventional pyrolysis process are high, Microwave assisted pyrolysis was developed where microwave radiation was used to heat the substances. This has the main advantage saving almost 80% of energy (from 25 MJ/kG for conventional pyrolysis to 5 MJ/kG for microwave pyrolysis) as the FRP wastes get heated up in the core thereby increasing the heat transfer.
4) *Solvolysis:* Solvolysis or Chemical Recycling is one of the most suitable FRP recycling technique as almost all the mechanical properties of FRP is recovered. This process is basically a chemical treatment of epoxy resins using solvents. Water with other liquids like alcohol, phenol and amine are used as solvents. Acidic catalysts are generally used highly resistant to degradation resins. Meng et al. used the high concentrated nitric acid to effectively break down polymer resin of carbon FRP at a processing temperature of 90 deg C. The fiber thus retrieved from the process was found to have lost a mere 1.1% of its tensile strength.

C. Chemical Process

Chemical process for recycling of FRPs is the most effective way to recycle the glass fibers as both resins and fibers are retrieved. This was the main limitation of Thermal recycling of FRPs. The second main advantage of using Chemical process is that the fibers regenerated from this process almost no loss in mechanical properties.

D. Co-Processing

Another method that is similar to Mechanical recycling of FRPs is Co-processing of FRPs.This method is considered as the best alternative by the EuCIA. In this method, the waste material is used as an alternative to primary fuel for the cement kiln process. Almost 1/3rd part of the waste is converted into useful energy. Remaining 2/3rd part of the waste is then fed into the cement as a filler. It is found that there is no deterioration in the quality of cement produced. Moreover the carbon foot-print produced by burning of FRP waste is also very low.

IV. DISCUSSION

A. After reviewing all the recycling processes technologically, it can be interpreted that Chemical processing of the FRP wastes gives the best retrieval both quantity and quality wise among all the alternatives reviewed. An economical and environmental viewpoint needs to be checked so as to have a better conclusion.

B. Mechanical recycling of FRP is one of the easiest and simplest way. The grinded particles are reused as fillers but form inferior products. According to Chiemela V Amaechi, et. al mechanical processing is the cheapest of all the processes. Due to nonuse of any toxic chemicals or burning of any fuels, these naturally become the most environment friendly among the alternatives present. But the major disadvantage is that there is no retrieval of Fibers for reuse. On the other hand, the thermal recycling has the advantage of retrieving far more number of recyclates when compared to mechanical recycling. As the energy demands of pyrolysis is very high, microwave assisted pyrolysis is implemented where the microwaves are used to heat. This helped in reducing the energy demands. The main drawback however, is the high complexity of retrieving monomers and polyepoxy resins. Adding to this, due to char contamination there is a deterioration in mechanical properties of approximately 60% in the retrieved fiber. The cleaner Fluidized bed can be used to reduce the char contamination however the quality of the fiber is poor. The investments needed to build a pyrolysis based plant are also very high as compared to mechanical recycling. Lastly the chemical recycling of the FRPs is the best method as the retrieved FRP has almost 99% of the original or virgin fiber mechanical properties. Moreover, it can be stated that with proper safety measures, chemical recycling of the FRPs can be made environment friendly.

C. Now there remain two processes that have the least environmental impact at the same time be useful. The first among them is the Co-processing process that is considered the best possible way of recycling the FRP. This has a very low carbon footprint and the waste generated can be used as filler in cement. On the other hand, nearly 99% of the mechanical properties are recovered from the recycled FRPs by chemical process. The chemical recycling of FRP takes place at a very high temperature and thus energy demands for this type of recycling is high.

D. The chemical recycling requires an average energy of 56 MJ/kg where as the mechanical processing requires only 5 MJ/kg. Along with the cost of manufacturing of new fibers is relatively low. When comparing this to the cement kiln process, the thermal energy is produced from the waste FRPs. The left overs are also consumed as fillers in cement.

V. CONCLUSION

Upon the review of the process for recycling of FRPs on economic and environmental scale we can infer that pyrolysis and chemical treatment consume a lot of energy.

On the other hand, the coprocessing of FRPs and its use in cement kiln shows a positive impact as the energy is liberated and has the potential to replace coal. Moreover, the heavy investment needed for pyrolysis and solvolysis is also avoided.

A further research is needed in solvolysis method of recycling as this method retrieves fibers of almost 99% mechanical strength of the original fibers.

An analysis consisting of installation and operational costs and can be performed so as to find the net weight of material that is required to be recycled so that the chemical recycling becomes economical. For the time being, co-processing of FRPs is the best option to recycle them.

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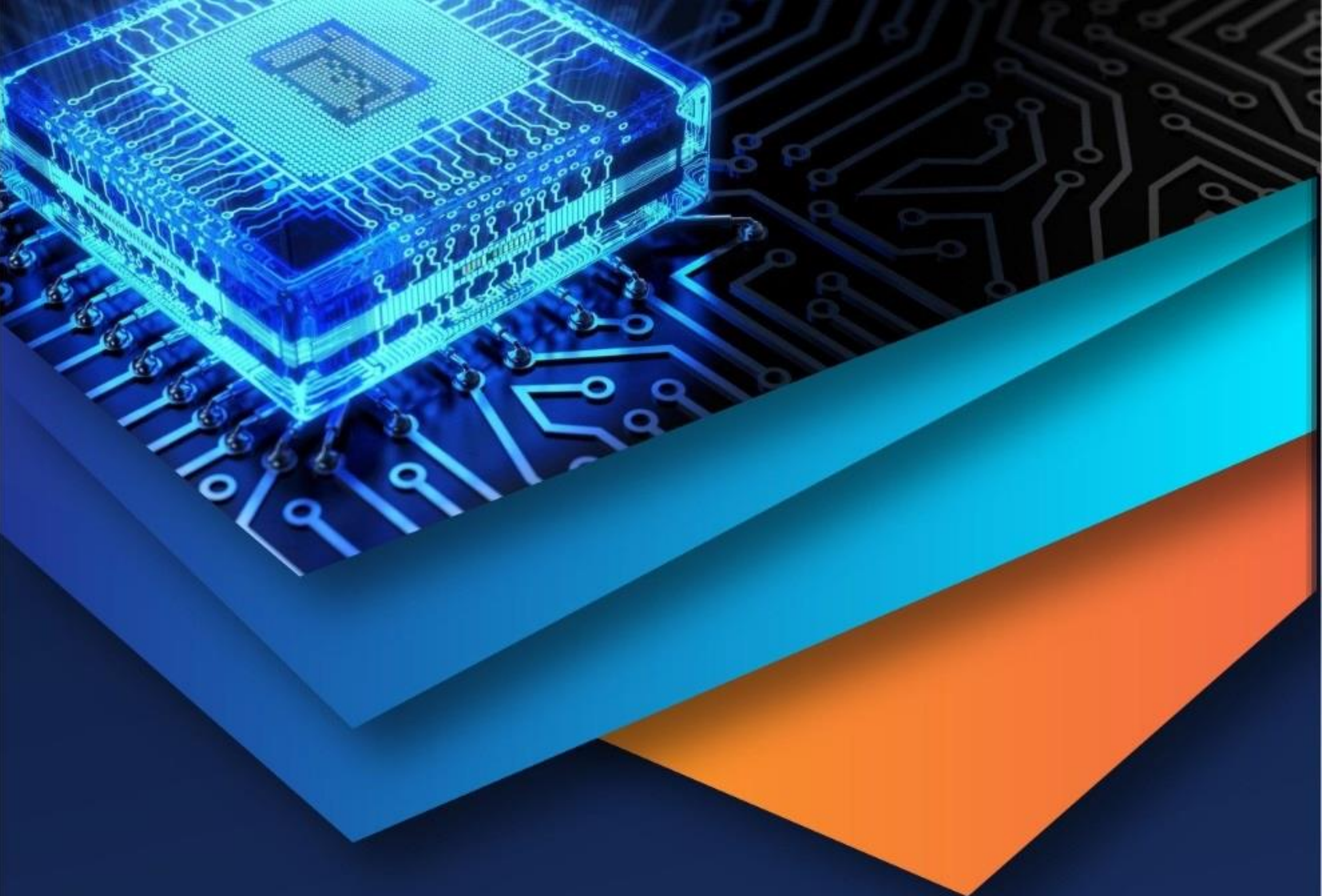

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