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学位論文題目	Development of the low-cost and high-value recycling method of fiber reinforced plastic
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## 論文内容の要旨

From published recycling technologies (mechanical recycling, thermal processing and chemical recycling), fibers could be recycled by all these method. However, they are not fully satisfactory: Mechanical recycling leads to fillers/short fibers mixtures, with poor reinforcing properties. Thermal processing is conducted under high temperature, so clean fibers are produced with a lost in the mechanical properties of the fibers. Chemical recycling is a new and promising route for converting plastic wastes by returning them back to their original constituents, that is, monomers or petrochemical feedstock, and has received a great deal of attention in recent years. But chemical processing is very costly, for both expensive equipment and chemical agent. One other problem is recycling of chemical agent.

It is should be concerned that the recycled fibers are usually fragmented into short lengths, as a result of (i) size-reduction of FRP waste before reclamation, (ii) fiber breakage during reclamation, and (iii) chopping of the fibers after reclamation. In addition, all fiber reclamation processes remove the sizing from the fibers, so the recyclate is in a filamented, random, and low-density-packing (fluffy).

Higher fiber lengths have greater intrinsic value further down the fiber lifecycle due to their ability to achieve higher mechanical properties in molded parts. The longer the recycled fibers are, the more orderly the recycled fibers are, and the more valuable the recycled fibers are. Kemmochi et al. reported that reinforced fibers do not deteriorate under accelerated aging experiment, which corresponds to 10 years. It could be considered that fibers which inside FRP is the same as virgin fiber. So we put our eye on the value fiber. Fiber is very expensive, carbon fiber is about 10 thousand yen/kg and glass fiber is about 750 yen/Kg. In this research, we are interested in these expensive fibers. In other words, we investigated recycled fiber reused in low cost and high value with low damage even if no damage. If we can recycle fiber without a lost in the mechanical properties, the value of recycled fiber will greater than cost of recycling. It will realize sustainable recycling without support of government. Besides, we can reduce the environment impact in the future.

**Recycling of fiber** In order to reduce the fiber breakage during reclamation and enhance the value of recycled fiber, a new recycling technology using a steam system, which is a kind of pyrolysis belong to thermal processing, has been developed. As mentioned above, in a pyrolysis process, the first step is to reduce the size of the waste so that it will pyrolyze more easily and fit into the autoclave. Polymeric materials are then heated in in the absence of oxygen. Thermal processing is conducted under high temperature, so clean fibers are produced with a lost in the mechanical properties of the fibers. In this research, size of waste FRP needn't to reduce, so long fiber can be collected after decomposition process. The size of waste FRP is only enslaved to size of heating chamber of equipment. Besides, we investigated the effect of pyrolysis time and temperature on the mechanical properties of recycled fiber, based on tensile strength measurements, determining the optimum decomposition conditions for FRP by

superheated steam. So the polymeric matrix is volatilized into lower-weight molecules organic substances under a lowest limit of temperature, the fiber recycled without a lost in the mechanical properties. In short, we develop a recycling method to recycle long fiber with low damage even if no damage. The value of fiber was recycled furthest.

**Recycling and reusing plastic** Although resin is recoverable, since it deteriorated in years of use, the polymeric matrix is volatilized into lower-weight molecules organic substances in a pyrolysis process. It is difficult to reuse as resin by re-polymerization. So we propose that it can be reused as fuel. The bomb calorimeter was the most common device for measuring the heat of combustion or calorific value of a material. The calorific value of recycled pyrolysis oil was measured by bomb calorimeter. Calorific value of recycled pyrolysis oil was a little lower than that of diesel, petrol and kerosene, higher than wood (15% water), the same as steam coal (1% water). It was possible to use recycled pyrolysis oil as a fuel in the further.

**Reusing fiber** Because FRPs were pyrolyzed under a lowest limit of temperature, fibers with clean surface can't be produced. Recycled fibers were surface treated for reuse as FRP composites. A low cost and simple surface cleaning method was developed for surface treatment. Recycled glass fibers and carbon fibers were treated using acetone and N-Methyl-2-pyrrolidinone (NMP) respectively. Most residual resin impurities were removed by surface treatment. Analysis indicated no adverse effect of surface treatment on bending strength. The mechanical properties of the treated recycled glass fiber reinforced plastic (TR-GFRP) and treated recycled carbon fiber reinforced plastic (TR-CFRP) composites were determined and compared with those of recycled glass fiber reinforced plastic (R-GFRP) and recycled carbon fiber reinforced plastic (R-CFRP). The bending strengths of R-GFRP and R-CFRP were very low, compared to that of virgin glass fiber-reinforced plastic (V-GFRP) and that of virgin carbon fiber-reinforced plastic (V-CFRP). The bending strength of TR-GFRP composites was improved to about 90% of that of V-GFRP, and the bending strength of TR-CFRP composites was improved to about 80% of that of V-CFRP.

Since dynamic power may be received in further application of recycled FRP, the influence of recycling on the impact damage resistance of recycled FRP composites was investigated using low-velocity impact and compression after impact (CAI) tests. The relationships among load, force, and time were analyzed to gain insight into the damage characteristics of three types of composite laminate: virgin FRP, recycled FRP, and treated recycled FRP. Special emphasis was placed on evaluating the extent of damage and the residual mechanical properties as affected by three different fiber surface states. Substantial differences were noted in the shape, area, and damage mode of impact using ultrasonic c-scanning, photography, and scanning electron microscopy (SEM). Virgin FRP indicated significant improvement in impact damage resistance in the form of less damage, higher residual strength, and greater shear failure angle. Damage resistance was improved up to 80% of V-CFRP by surface cleaning while R-CFRP is 50% of V-CFRP. Shear failure angle of  $16^\circ$  was attained from R-CFRP and it was increased to  $24^\circ$  when the recycled fibers were cleaned. The result of SEM showed that there was less delamination of TR-CFRP compared with R-CFRP. This work proves that the low-velocity impact response of recycled composites can rival that of virgin composites, while providing a basis for future applications of recycled carbon in many fields.