学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Advanced jig separation for resources recycling: effects of particle geometry on separation efficiency and development of continuous-type jig using restraining wall
(リサイクリングのためのアドバンスドジグ選別:選別に及ぼす粒子形状の影響と Restraining wall を用いた連続式ジグの開発)

There are two common types of plastic recycling: (1) material recycling wherein plastics are recovered and reused, and (2) thermal recycling whereby plastics are used as fuel for power generation. Among the two, material recycling is a more sustainable and profitable approach, but different types of plastics must be separated to obtain very high purities. Most separation techniques for recycling were modified from techniques developed for mineral processing. Among of these techniques, jig separation, one of the oldest techniques that separates particles based on density differences, that is widely used in mineral processing especially in coal cleaning because of its simplicity, low cost, and high efficiency, was also applied for resources recycling. However, there is a critical challenge in the use of jig separation for secondary resources because of the wide variety of shapes formed after crushing, which is very different from the more uniform and sphere-like particles traditionally treated in mineral processing. In jig separation, the separation efficiency is dependent on particle motion, which is also a function of geometrical properties like size and shape. This means that understanding the effects of particle shape is important in the design of suitable jig separation process. This study investigated the effects of particle shape (disk-like plastics and rod-like metals wires) on the jig separation and identified the reasons why the particles shape affects to their behaviors and jig separation efficiency. Moreover, novel methods to estimate the jig separation efficiency using shape factors were proposed and modified waveform and shape separation methods to improve jig separation efficiency were developed. Finally, a discharge system for continuous jig separation of plastics using a restraining wall was developed.

Chapter 1 describes the background and objectives of the study.

In Chapter 2, previous studies on “the effects of particle geometry on physical separation” and “the application of gravity separation for coal cleaning and resources recycling” are reviewed.

In Chapter 3, effects of particle geometry (size and shape) on jig separation efficiency of crushed plastics are investigated. The shape factors (flatness ratio etc.) and settling velocity of crushed plastics containing various size and shape were measured and the results showed that particles are more disk-like at coarser size fraction while the fine fraction is dominated by sphere-like particles. The results of jig separation of mixed plastics showed that separation efficiency was higher for the mixture of light, disk-like particles and heavy, sphere-like particles that was in line with the results of settling velocity experiments. These results indicate that settling velocity and jig separation are affected by both size and shape.

In Chapter 4, empirical equation to calculate settling velocity of non-spherical particles using flatness ratio and projection area was developed, and a modified concentration criterion (CC_s) is proposed to estimate jig separation efficiency of non-spherical particles. The experimental results showed that sharpness index decreased with increasing CC_s calculated from the velocity of non-spherical particles. This result indicates that CC_s can be used to estimate jig separation efficiency of non-spherical particles. Based on the CC_s proposed here it was hypothesized that separation efficiency of the mixture of light, sphere-like particles and heavy, disk-like particles will be improved when the water rising velocity increase. This hypothesis was confirmed by the jig separation of the mixed plastic samples.

In Chapter 5, separation of rod-like and sphere-like particles are discussed. Jig separation was applied to separate plastics and metals including copper (Cu) wires obtained from a recycling plant. The results showed that separation efficiency was low because of Cu wire entanglement that prevents particle motion in the separation chamber. The results of model experiments showed that the separation efficiency decreased with increasing the amount and length of Cu wires. To limit the effects of wire entanglement, two methods of shape separation were investigated. In addition, estimation of jig separation efficiency using the entanglement factor of rod-like particles is proposed.

In Chapter 6, discharge systems for continuous jig separation of plastics are discussed. The purity of bottom layer products becomes lower when the heavy particles ratio in feed is low, because entrainment of light particles by a screw-extractor occurs. To suppress the entrainment, a new discharge system using a vertical restraining wall was developed. The restraining wall was installed to separate a chamber into two and particles can transfer from one to another through the channel under the wall. The results showed that purity of bottom layer products was improved with a restraining wall.

Finally, Chapter 7 gives the general conclusions of this study.