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THE APPLICATION OF CLEANER TECHNOLOGY IN THE ACRYLIC CAST SHEET PRODUCTION: CASE STUDY OF ACRYLIC CAST SHEET COMPANY IN THAILAND

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ABSTRACT

Acrylic, Trade name of Poly(methyl methacrylate):PMMA, scrap generated during the casting process of acrylic sheet is an industrial waste, which has a high impact on the acrylic cast sheet production cost and environment. This research presents the application of cleaner technology in the acrylic cast sheet production of the Pan Asia Industrial Co., Ltd., Thailand, which demonstrates the alternative way to reduce the processing cost of acrylic cast sheet and decrease industrial waste by using acrylic scraps recycle within the acrylic cast sheet process. The influence factors such as the concentrations of acrylic scrap and initiators on the preparation of acrylic cast sheet mixed with acrylic scrap were investigated. The physical and mechanical properties of the final products were examined. The results show the possible mean to recycle acrylic scraps into the acrylic cast sheet process, which was not affected the properties of the final acrylic cast sheet products. Finally, the environment impact and economic evaluation by the recycling of acrylic scraps were investigated by using the life cycle inventory (LCI) data for material grouping according to environmental and material properties. The results of the application of cleaner technology in the acrylic cast sheet production by mean of recycle acrylic scrap show the decrease of environmental impact and processing cost.

Key words

Cleaner Technology, Acrylic, Cast Sheet, Scrap, Recycle, Life Cycle Inventory Data

1. INTRODUCTION

The new concept of industrial system is attempt to change from linear, where resources are consumed and damaging wastes are dissipated into the environment, to a more close system, where energy and wastes are constantly recycled and reused [1].Plastic are very functional materials used in everyday life. Waste plastics which are discarded in our daily life or manufacturing processes are the cause of the most troublesome waste issue. Industrial plastics such as those discarded through manufacturing loss or used in industry are discarded in relatively large amounts. In order to construct a society with circulating material, it is obvious that waste plastics discarded from industry must be appropriately recycled [2,3].

Acrylic, trade name of poly(methyl methacrylate):PMMA, is a clear, colorless transparent plastic with a higher softening point, better impact strength, and better weatherablility than polystyrene (PS). Acrylic is widely used in many application fields, such as transparency roof, automobile parts, and etc. The principal commercial processes for the production acrylic sheets are extrusion and casting [4]. The manufacturing of transparent acrylic sheet is normally produced by cell casting process, which utilizes two flat glass plates separated by an elastomeric gasket. The flexible gasket permits filling of the cell with monomer or syrup, prevents leakage, and controls thickness of the acrylic sheet. In general, gasket is used only once and must be removed from finished product by cutting in order to make a require sheet size. Most of acrylic scrap, residual acrylic material stick around unusable gasket, generated during cutting step comprises of approximately 10% of total final production, which becomes as an industrial waste plastic.

Cleaner technology (CT) is the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. CT for production process results from one or a combination of conserving raw materials, water and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process [5]. In order to conserve and reduce the quantity of acrylic waste from the production process, the concept of cleaner technology has been applied. This paper presents the application of cleaner technology in the acrylic cast sheet production of the Pan Asia Industrial Co., Ltd., Thailand, which demonstrates the alternative way to reduce the processing cost of acrylic cast sheet and decrease an industrial waste by using acrylic scrap recycle within the acrylic cast sheet process. The concentrations of acrylic scrap on the preparation of acrylic cast sheet mixed with acrylic scrap were investigated. The physical and mechanical properties of the final products were examined. Finally, the environment impact and economic evaluation by the recycling of acrylic scraps were investigated by using the life cycle inventory (LCI) data for material grouping according to environmental and material properties.

2. EXPERIMENTAL

2.1 Materials

Acrylic monomer (Methyl Methacrylate: MMA monomer), acrylic scrap, commercial peroxide and azo compound initiators were supplied by Pan Asia Industrial Co., Ltd. All chemicals were used as received.

2.2 Acrylic Cast Sheet Process

The radical bulk polymerization of acrylic monomer with acrylic scrap was prepared by glass cell casting process. 1%-6% of acrylic scrap was dissolved in MMA monomer under viscous agitation. The viscosity of the solution was examined by using Brookfield viscometer. After viscosity checking, initiators, 0.05% of peroxide initiator and 0.03% of azo compound initiator, were introduced into solution and agitated for 10 minutes. The solution was degassed by using a vacuum pump. The solution was then poured into polymerization casting cells and left into water bath at 60°C to form a rigid object. Finally, the polymerization casting ce1ls were placed in the oven at 100°C for 2 hours in order to complete polymerization**.**

2.3 Mechanical Tests

The Notched Izod impact strength was determined according to ASTM D256. The specimens were cut from the mid section of the copolymer casted sheets. The Izod samples were notched by using V-Notch sampling machine (GOTECH: GT-7045-I). The impact speed was 3.46 m/sec, and the energy of the hammer was 150 kg-cm. The Izod impact tests were carried out in an air-conditioned room at 25°C. Prepared samples were tested by using Izod impact testing machine (GOTECH: GT-7045-I). The shores D hardness was determined according to ASTM D2240 and was tested by using shore D durometer (TECLOCK GS-7206). The tensile properties were determined according to ASTM D 638 using universal testing machine CHUNYEN: CY-6040A8, the type of test specimen was type I and the speed of testing was 1.0 mm.min^{-1}.

2.4 Physical Properties

The ultraviolet (UV) and heat resistances of the acrylic cast sheets were investigated according to the Pan Asia Industrial Co., Ltd, Thailand standard. The UV resistance and heat resistance specimens (5cm x 20cm x 3mm) were placed in the UV box with the UV wavelength at 320 nm for 24 hours and in the oven for 25 minutes at 165°C, respectively. The yellowness changing of the specimens after the UV and heat resistance tests were examined by using an X-Rite machine (TOPWAY: SP 62).

3. ENVIRONMENTAL IMPACT EVOLUTION OF THE ACRYLIC SCRAP RECYCLE

The environmental impact of the acrylic waste scrap recycle was calculated based on the material balance [3, 6] of the acrylic cast sheet production process. The environmental impact data was achieved from the life cycle inventory data for materials grouped according to environmental and material properties, which published by C. J. Rydh, M. Sun, and H. Kaebernick [7, 8].

4. RESULTS AND DISCUSSIONS

4.1 Generating CT Option for Acrylic Cast Sheet Production Process

Since the Pan Asia Industrial Co., Ltd., Thailand, which produces acrylic cast sheet, becomes interested in CT, the CT project of acrylic sheet has been started and committed by the managing director of the company. During the assessment phase of the CT project, the material balance was used as a tool to identify and generate CT option for the acrylic cast sheet production process. The overall material balance of the Pan Asia Industrial Co., Ltd. acrylic cast sheet production process is shown in Fig. 1. It can be seen that approximate 10% of acrylic scrap is generated during cutting step. In order to control the cause of acrylic waste scrap generation, recycling of acrylic waste scrap within the production process is a technical option that can be reduces the generation of acrylic waste scrap.

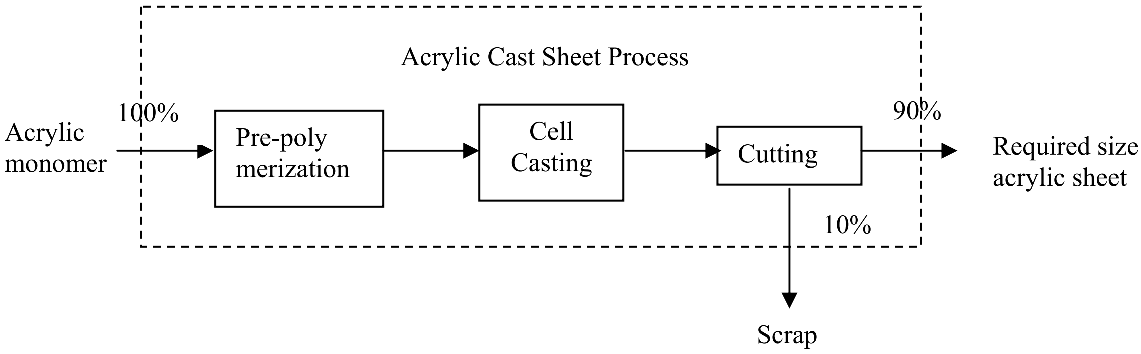


Fig. 1. Material Balance of the Pan Asia Industrial Co., Ltd. Acrylic Cast Sheet Process

4.2 Recycling of Acrylic Waste Scrap in the Acrylic Cast Sheet Process

The recycling of acrylic waste scrap by return to the original process as a substitute for an input material is an appropriate option, which was implemented in this research. The raw material, MMA monomer, mixed with acrylic scrap generated during the acrylic cast sheet production process was produced via bulk polymerization using free radical initiators. The acrylic cast sheets were obtained from different proportional concentration of acrylic scrap. Therefore, the effects of acrylic waste scrap concentrations on the physical and mechanical properties were investigated. Finally, the evaluation of environmental impact according to the recycling of acrylic scrap was examined.

4.3 The Effect of Acrylic Scrap Concentrations on the Viscosity of Acrylic Monomers Solutions

The Brookfield viscometer was used to measure the appropriate concentration of the acrylic waste scrap that can cause a change in the acrylic monomer solution viscosity. Fig. 2 shows the effect of acrylic scrap concentrations on the acrylic monomer solution viscosity. It can be seen that the acrylic monomer solution viscosity increases with increasing the concentration of acrylic waste scrap. According to the industrial preparation of acrylic cast sheet, the appropriate viscosity of acrylic syrup before pouring into a casting cell is in the range of 500-3000 cp, therefore the appropriate concentration of acrylic monomer solution mixed with acrylic waste scrap should almost reach that of industrial standard viscosity value. From the results above, it can be concluded that the appropriate concentrations of acrylic waste scrap mixed within the acrylic monomer solution are in the range of 4% and 5%, which give the viscosity values in the range of 500-1611 cp.

4.4 Mechanical Properties of the Acrylic Cast Sheet Mixed with the Acrylic Scrap

The mechanical properties of the acrylic cast sheet mixed with the acrylic waste scrap were examined. The effects of acrylic waste scrap on the impact strength property, tensile strength property, and hardness property are shown in Fig. 3, 4, and 5, respectively. It can be conclude that the acrylic waste scrap did not affect the impact strength and hardness properties of the acrylic cast sheet product. Only tensile strength property of the acrylic cast sheet product increases with increasing the amount of acrylic waste scrap. It can be explained that the acrylic waste scrap is a polymer form. When it dissolves within the acrylic monomer and passes through the casting process, the chemical blending of the two components was produced. The final product consists of the previously polymer from acrylic waste scrap distributed in the acrylic matrix. The compatibility of the two components usually affects to the tensile strength property of the final product.

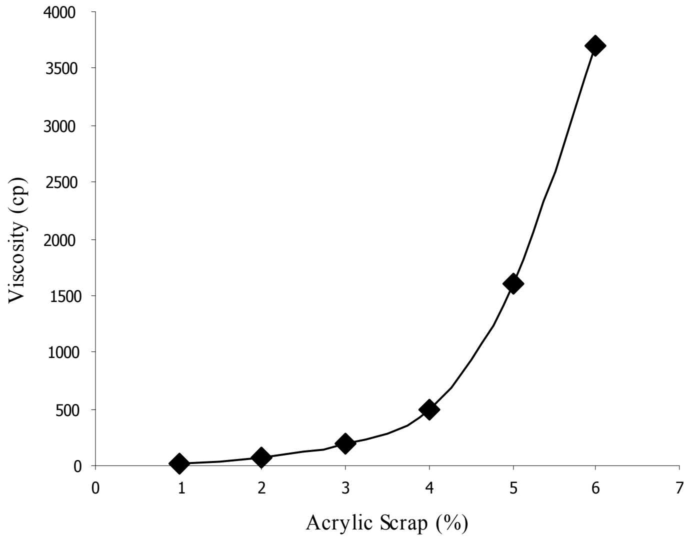


Fig. 2. The effect of acrylic scrap concentrations on the acrylic monomer solution viscosity.

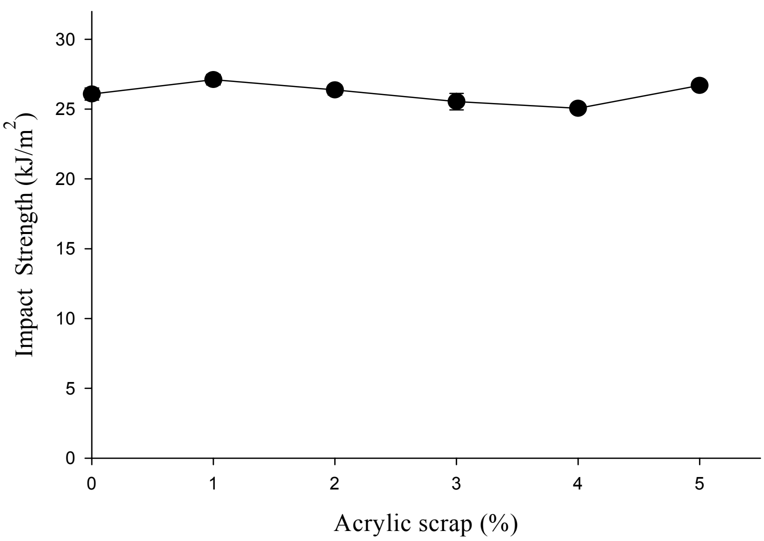


Fig. 3. The effect of acrylic scrap on the impact strength of the acrylic cast sheet products.

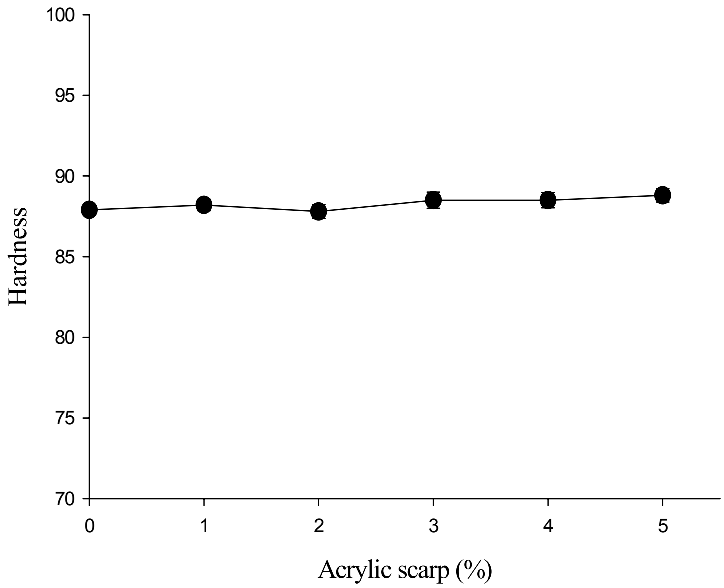


Fig. 4. The effect of acrylic scrap on the hardness of the acrylic cast sheet products.

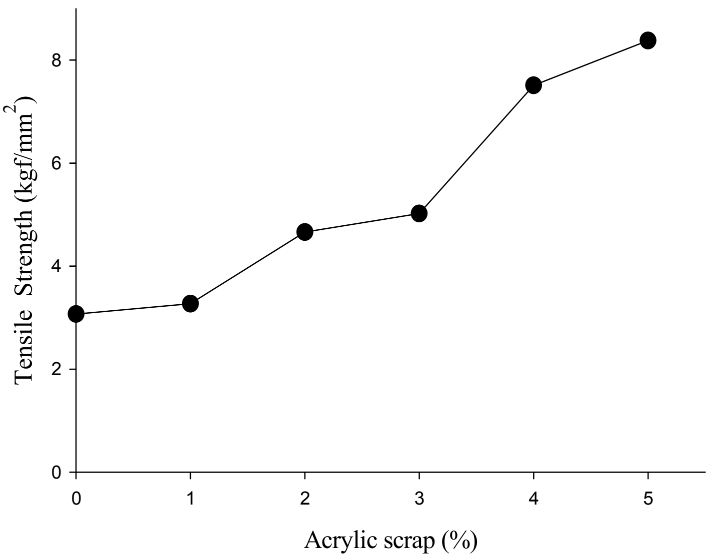


Fig. 5. The effect of acrylic scrap on the tensile strength of the acrylic cast sheet products.

4.5 Physical Properties of the Acrylic Cast Sheet Mixed with the Acrylic Scrap

Transparency is an important property for acrylic cast sheet product. 15% of the opacity value is expected for the acrylic cast sheet of the Pan Asia Industrial Co., Ltd. The influence of the acrylic waste scrap on the opacity value of acrylic cast sheet is shown in Fig. 6. At 1-5% of the acrylic waste scrap, the opacity values were observed in the range of 15.27-15.85%. The results can be summarized that the acrylic waste scrap did not affect to the transparent property of the acrylic cast sheet.

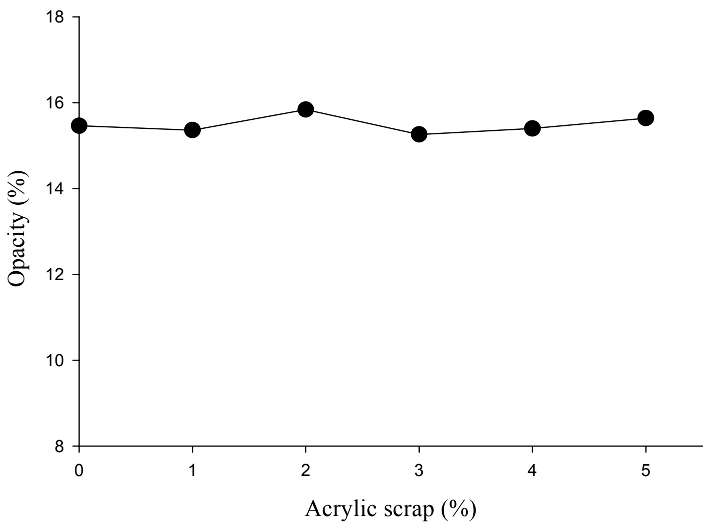


Fig. 6. The effect of acrylic scrap on the opacity value of the acrylic cast sheet products.

The UV and heat resistance methods were applied to investigate the weathering property of the acrylic cast sheet mixed with the acrylic waste scrap. The UV and heat resistances were examined by monitoring the yellowness shifts of the test specimens, which are reported in the terms of color difference (ΔE). The effects of acrylic waste scrap concentration on the UV and heat resistances are shown in Fig. 7 and 8. From Fig. 7, it can be seen that the ΔE of the acrylic cast sheets increased as the acrylic waste scrap concentration increased. On the other hand, Fig. 8 shows that the ΔE of the acrylic cast sheets remain constant over the range of the acrylic waste scrap concentration. It can be concluded that the acrylic waste scrap affects to the UV resistance property but did not affect to the heat resistance property. However, the UV resistance property of the acrylic cast sheet product mixed with the acrylic waste scrap can be improved by the addition of UV stabilizer additive, which is usually added to the final product of acrylic cast sheet before sale to customer.

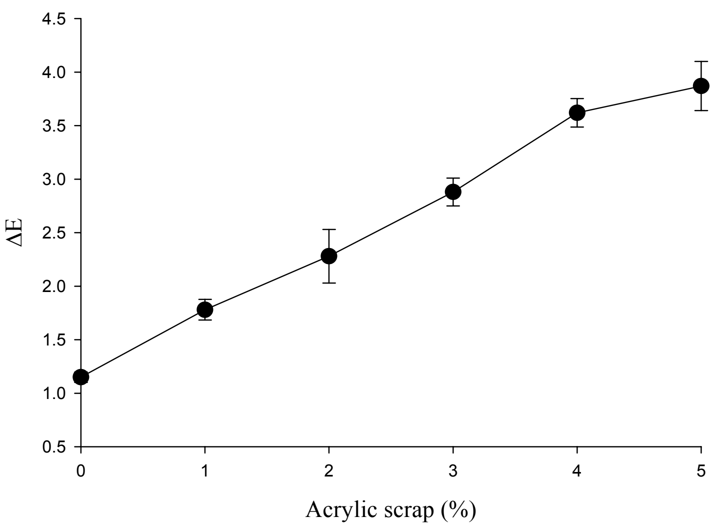


Fig. 7. The effect of acrylic scrap on the UV resistance property of the acrylic cast sheet products.

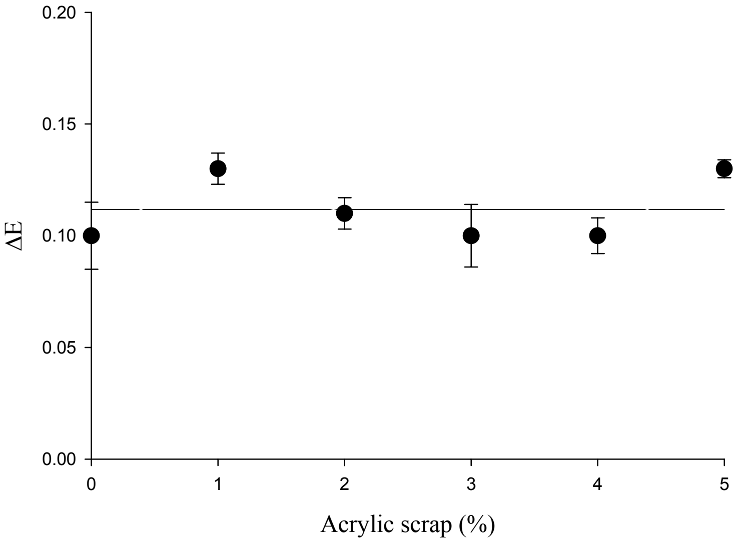
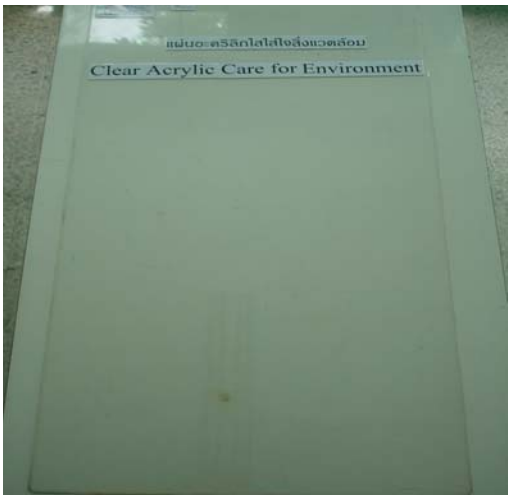


Fig. 8. The effect of acrylic scrap on the heat resistance property of the acrylic cast sheet products.

4.6 Implementation to Pilot Scale

The results from preliminary study can be concluded that the acrylic waste scrap does not affect much to the physical and mechanical properties of the acrylic cast sheet product. Next, the acrylic monomer mixed with the appropriate amounts of acrylic waste scrap, 4% and 5% were implemented to the pilot scale. 3 kg of the total solutions, acrylic monomer mixed with the 4% and 5% of the acrylic waste scrap, were introduced in the 5 liters stainless steel reactor, respectively. 2x4 ft of acrylic cast sheet products were obtained from the pilot scale study. The final products produced in pilot scale are shown in Fig. 9 a and b, which show a transparent cast sheet without any deformation.

a)



b)

Fig. 9 The pilot scale of acrylic cast sheet mixed with acrylic waste scrap products; a) 5% acrylic waste scrap; b) 6% acrylic waste scrap.

4.7 Environmental Impact Evolution of the Acrylic Scrap Recycle

It can be said that the specific environmental data of PMMA in Thailand are not available yet. In this research, we can be estimated the environmental impact of acrylic waste scrap recycle by using the material grouping for simplified product life cycle assessment [7, 8]. The material grouping for simplified product life cycle assessment provides the average data of 17 material groups for mechanical properties and environmental impact, which can be used as estimates when LCI data for specific materials are missing.

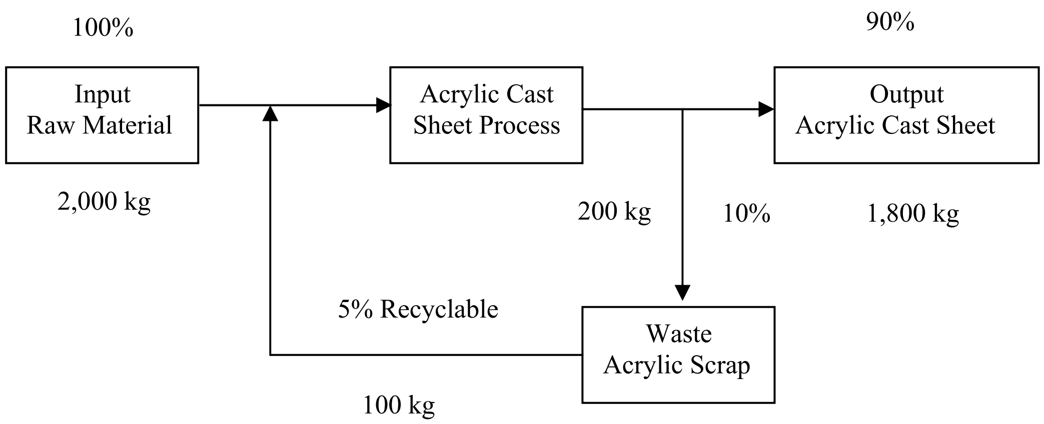


Fig. 10. Material balance of the recyclable acrylic waste scrap.

According to the Pan Asia Industrial Co., Ltd production process, 16,000 kg of acrylic monomer is fed into a batch reactor and approximate 1,600 kg of acrylic waste scrap is generated during the production process per day. From our research above, 5% (800kg/day) of acrylic waste scrap was the maximum concentration that can be recycled as a part of raw material for produces acrylic cast sheet. By using the material balance analysis (Fig. 10) and the material grouping for simplified product life cycle assessment, the environmental impact evaluation of the 5% of acrylic scrap recycle was calculated. The decrease of natural resources consumption and pollutions with respect to the recycling of acrylic waste scrap in the acrylic cast sheet production process are shown in Table 1. Moreover, 5% of acrylic waste scrap recyclable can reduce the costs of raw material (acrylic monomer), waste disposal, processing, and transportation, which are approximate 6-7% saving of the total cost. It can be concluded that the recycling of acrylic waste scrap within the acrylic production process generates a double outcomes to industry both in environmental and economical aspects. In environmental aspect, company can minimize the waste and pollutions by enhancing recyclability, which is striving for zero-waste or 100% product targets. Economical aspect, company can optimize resource use while increasing resource productivity. This ensures that more product/or services are obtained from less energy and raw material input. It can be said that zero-waste targets and by-product synergies lead to more effective use of resource in a process and create an additional cash benefit.

Table 1. The decrease of natural resource consumption and pollutions with respect to the recycling of acrylic waste scrap in the acrylic cast sheet production process.

Environmental Aspects	Unit
Raw material (Acrylic monomer)	800 kg/day
Coal	208 kg/day
Oil	472 kg/day
Natural gas	576 kg/day
CO_2	2,640 kg/day
NO_x	12.8 kg/day
SO_x	14.4 kg/day
CH_4	10.4 kg/day
Dust	2.5 kg/day
BOD	281,600 mg/day
Land conversion	32 m^2/800 kg of scrap

5. CONCLUSIONS

The concept of cleaner technology was applied in the acrylic cast sheet production process of the Pan Asia Industrial Co., Ltd., Thailand. The recycling of acrylic waste scrap generated during the production process was carried out as a CT option. The acrylic monomer mixed with various concentrations of acrylic waste scrap was produced. The appropriate concentrations of acrylic waste scrap, which can be used to generate the appropriate syrup solution, are 4% and 5%. The final products show the alternative using of acrylic waste scrap that were not affect to the physical and mechanical properties of the final products. The recycling of acrylic waste scrap demonstrates outcomes to company both in economic and environment, which can decrease natural resource consumption and pollutions.

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