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Airport cargo loader rollers from aluminium to composite: Environmental, sustainability and social benefits

Peter Chiu[1] and Jackson Ho[2], and Yuhan Huang[3]

[1] *Management and Technology Consultants, Ltd., Hong Kong SAR, China*
[2] *Department of Mechanical Engineering, City University of Hong Kong, Hong Kong SAR, China*
[3] *School of Civil and Environmental Engineering, University of Technology Sydney, NSW 2007, Australia*

Abstract

The Hong Kong Airport Authority published the “Airport Authority Hong Kong Sustainability Report 2022/21” (HKIA, 2022) which set its environmental targets and a range of environmental footprint reduction measures in key environmental aspects such as carbon management and climate resilience. This paper is inspired by these targets and measures. The performance of two major types of rollers made of aluminium alloy and composite used in airport air cargo loaders is compared. It is noticed that the number of rollers used in the loaders is huge and they might be a hazard to the environment. Due to the developments in material technologies, the materials used in the making of the rollers may have impacts on the sustainability, environment and social responsibility. For the reduction of carbon footprint, one possible way is to reduce the weight of airport air cargo loaders. Thus, the energy for driving the loaders is reduced which results in the reduction of carbon footprint. The weights of an aluminium alloy roller and a composite roller are 275 and 130 g, respectively. With appropriate assumptions made, the total weight of rollers in loaders at the Hong Kong International Airport is reduced by 47.2 tonnes if all the aluminium alloy rollers are replaced by composite rollers. This results in significant reduction in the energy (~ 86.3 tonnes diesel per year) of moving such heavy load around the airport and hence carbon footprint reduction. The carbon footprint differs by 4.4 times for the refining the aluminium and nylon. The equivalent difference is 561.5 tonnes carbon footprint reduction which is even more significant. For the manufacture of rollers from the materials, preliminary finding is that as aluminium melts at 660 ºC and nylon melts at 264 ºC, so the energy needed is also significantly different. Last but not least, in terms of social responsibility, a detailed comparison on toxicity of the materials is presented in this paper. It is proposed to replace the aluminium alloy rollers by composite rollers for the sake of sustainability, environment and social responsibility.

Keywords: Air cargo loaders; Rollers; Aluminium alloy; Nylon composite; Environmental footprint

1. Introduction

Hong Kong International Airport (HKIA) has been one of the world’s busiest international airports since 1996, in terms of both total passengers and cargos (Lo et al., 2015; Tsui et al., 2014). In 2020, HKIA handled 4.5 million tonnes of total cargo throughput, which accounted for about 43% or HK$3,500 billion of the total value of Hong Kong's external trade. Currently, HKIA provides 43 parking stands for cargo aircraft and is recognized as a competitive advantageous air cargo hub in the world. Air cargo loaders are the key ground equipment for air cargo loading and are spread all around the ramp areas at HKIA. In recent years, operators are in great concern about the environmental impacts of ground equipment operating at the airport which include noise, dust, smell and toxic material.

Loaders engage quite a big number of ground equipment at the airport. It was noticed that the number of rollers used on the loaders was huge and it might be a hazard to the environment. In addition to the conventional aluminium alloy rollers, composite rollers had been used for about 10 years at airports and air cargo handling depots in the region for reasons of lighter, quieter and probably cheaper. While on the development of electric cargo loaders, weight is a big concern for cargo loader OEMs. As electrification is a must for airport operation in the coming decade, composite rollers are being seriously considered by loader manufacturers. This study compares these two categories of rollers on environmental, technical and operational aspects and analyzes the effectiveness of their utilization.

2. Methodology

The study focuses on two types of rollers, namely aluminium alloy and composite rollers. They are chosen because they are commonly used in the industry but are made of very different materials. Aluminium alloy rollers are usually made of aluminium alloys 6061-T6 (with >95% aluminium) and 7075-T6 (with >87% aluminium). Composite rollers are made of composite by a patented process (Hon, 2014) using nylon, glass beads, glass fiber powder, lubricating anti-wear agent; graft type toughening modifying agent; antioxidant; lubricating dispersant and nucleating agent. The highest percentage of material used in making the composite rollers is nylon-66 (also known as nylon 6-6, 6/6, 6,6 or 6:6).

This study is based on several types of information available. The first one is the theses, as well as information available from the Internet. The second type of information is results obtained from independent testing laboratories. In Internet, Wikipedia forms an important basis of this study. Although we are aware that Wikipedia cannot capture all the information needed, it does provide a consistent basis for comparison and it is updating regularly by an independent community in the field.

The remaining of this paper will be divided into the following three main parts:

Section 3 compares the environmental footprints of aluminium and composite rollers, including their weights and the energy consumption for moving and making them.

Section 4 focuses on the toxicity properties of aluminium and composite materials. The toxicity of aluminium is raised in two theses of the Technological and Higher Education Institute of Hong Kong (THEi) under the theme of "*Investigation of Occupational Safety impacts of Operating Air Cargo Loaders at the Airport*". The research work was supported by the Hong Kong Airport Authority. The acute oral toxicity of the composite was inspired by the work of the discussion about toxicity of aluminium to humans. As there is not much similar information about harmful effects of the component materials making the composite rollers available from the Internet, an acute oral toxicity study of the composite was carried out by an independent testing laboratory.

Section 5 is about the comparison of other properties of these two types of rollers. Some of these are technical in nature such as the composition of material for making the rollers and adhesive wear. One interesting and useful comparison is on the trend of the material cost. Engineers are very mindful on the production cost. When the economy comes back, it might be difficult to get the necessary material in a reasonable cost.

3. Environmental footprints of Aluminium and Composite Rollers

As we have found a main deck loader with approximately 1464 rollers and a lower deck loader with approximately 960 rollers. It is estimated to have around 300 loaders in the HKIA, among which 25% are main deck loaders and 75% are lower deck loaders. Therefore, the total number of rollers is:

$$1464 \times 75 + 960 \times 225 = 325{,}800$$

3.1 Carbon footprint comparison in moving aluminium and nylon rollers

With the above assumptions made, the total weight of rollers in loaders at the HKIA is reduced by 89.6 - 42.4 = 47.2 tonnes if all the aluminium alloy rollers are replaced by composite rollers (see Table 1). This will result in significant reduction in the energy consumption of moving such heavy load around the airport. Such benefit could be estimated based on assuming a kinetic friction coefficient of 0.9 between the tractor and the ground. Assuming the rollers were moved 10 km per day in the airport, the saved energy due to weight reduction from aluminium to composite rollers can be calculation as:

$$47.2 \text{ tonnes} \times 9.8 \text{ N/kg} \times 0.9 \times 10 \text{ km/day} \times 365 \text{ day/year} = 1.52 \times 10^{12} \text{ J/year}$$

The heat value of diesel is typically around 44 MJ/kg. Assuming a thermal efficiency of 40% for the diesel engine of the tractor, the above energy reduction is equivalent to saving the following amount of diesel fuel:

$$1.52 \times 10^{12} \text{ J/year} \div 44 \text{ MJ/(kg diesel)} \div 40\% = 8.63 \times 10^{4} \text{ (kg diesel)/year}$$

Table 1: Weight and carbon footprint data.

	Aluminium alloy roller	Composite roller
Weight of a roller (w)	0.275 kg	0.130 kg
Total weight of rollers (w×325,800)	89.6 tonnes	42.4 tonnes
Emission factor (f) of refining aluminium/nylon*	8.14** kg CO_2 per kg	7.9 kg CO_2 per kg
Carbon Footprint (w×1250×300×f)	729 tonnes CO_2	335 tonnes CO_2

Notes: * https://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf

** It is between 11.89 and 8.14 kg CO_2 per kg

3.2 Carbon footprint comparison in refining aluminium and nylon

The carbon footprint for refining the aluminium and nylon for making the rollers can be found quite easily. The result is also shown in Table 1. For all the rollers at the airport, such carbon footprint for refining the major material aluminium and nylon are 729 and 335 tonnes CO_2, respectively. The ratio of carbon footprint is 2.2 (=729/335) and the difference is 394 tonnes (=729 – 335) CO_2 which is very significant. In the letter from GSEL, it states that "the operating life of a smart composite roller is close to double that of an equivalent aluminium roller. Thus the ratio of carbon footprint is 4.4 (=2*2.2). The equivalent difference is 561.5 (=729 – 335/2) tonnes CO_2 which is even more significant.

For the manufacture of rollers from the materials, as data are not readily available, this study will continue upon such availability. Preliminary finding is that as aluminium melts at 660 ºC and nylon melts at 264 ºC, the energy needed is significantly different.

4. Toxicity of Aluminium and Composite

4.1 Toxicity of Aluminium to Humans

Aluminium alloy is a neurotoxic rich material which gives side effects on the function of the brain (associated with Alzheimer's disease) such as loss of balance, memory issues, lack of coordination, loss of bodily control, mental decline (Cheng, 2021). Long-term inhalation of aluminium dust will accumulate in the lungs and will not be discharged (Mak, 2021). It has been suggested that the inhaled aluminium accumulates in the brain through absorption via the olfactory system (Roberts, 1986; Exley et al., 1996) or systemized (a) through the lung epithelial (Gitelman et al., 1995) and (b) via the gastrointestinal tract as particulates are swallowed.

4.2 Acute Oral Toxicity of the Composite Rollers

There are two main ways to study the toxicity of the composite rollers. One way is to get the composition of the roller and see if any of the component is toxic in nature. The results will be presented in Section 5. A testing laboratory has advised and adopted the National Standard "GB/T 21603-2008 Chemicals-Test Method of Acute Oral Toxicity" for such purpose (Nanjing Medical University, 2021). 20 clean-grade Institute of Cancer Research (ICR) mice were specially prepared for this purpose, fed with the stipulated quantity in a controlled environment for 14 days following GB/T 21603-2008. The key findings of the tests are presented as follows.

Animals showed a trend towards increased body weight after dosing, and animals showed no abnormal signs. None of the animals died during the course of the experiment. All animals had been subjected to gross necropsy at the end of test. No obvious abnormality was found.

Acute oral toxicity test LD_{50} of both female and male mice of smart composite roller are more than 20000 mg/kg-bw. According to the acute toxicity (hazard) classification, smart composite roller acute toxicity (hazard) toxicity category is IV. Toxicity category IV is practically non-toxic and not an irritant. That is to say, the composite is rather safe as substantiated by the Conclusion of the Test.

4.3 Comparison on the compositions of rollers

Compositions of the rollers are obtained from two reports done by an independent testing laboratory. The results on the compositions of a typical aluminium alloy roller (STS Testing Services, 2021a) and a typical composite roller (STS Testing Services, 2021b) are presented in **Tables 2** and **3**, respectively. Wikipedia is used to extract the relevant information. Two key terms, "toxicity" and "poisoning" were used in searching. Such findings are also presented in Tables 2 and 3. Relevant pages of the component/element were reviewed as well.

For the elements found in the aluminium alloy roller, 99.9% (except from Silicon and Titanium) have been classified as toxic and/or poisoning in nature. Toxicity of aluminium to human is of serious concern because aluminium contributes for around 95% of the composition of the aluminium alloy roller. There is a potential hazard caused by the aluminium powders generated during the operation which might be inhaled by workers nearby. The seriousness of the hazard depends on a number of factors such as quantity and size of aluminium powder inhaled. This hazard results in the safety and health concerns that is major accountability of the employer to address.

Table 2: Compositions of aluminium alloy rollers.

Element	Mass content (%)
Silicon (Si)	0.077
Iron (Fe)	0.20
Copper (Cu)	4.02
Manganese (Mn)	1.01
Magnesium (Mg)	1.48
Zinc (Zn)	0.015
Titanium (Ti)	0.023
Beryllium (Be)	0.023
Aluminium (Al)	Remainder

Table 3: Compositions of composite rollers.

Component	Mass content (%)
Polyamide 6 (PA6)	82
Polytetrafluoroethylene (PTFE)	3
Silicate	14
Ethylene bis stearamide and Pigment	1

For the composite, according to the manufacturer, both PA66 and PA6 are used for the manufacturing of rollers. However, because of very similar molecular structure, the equipment used for testing could not explicitly tell the difference between them. This explains why PA66 is not mentioned in the report.

There may be an issue of Safety of Polytetrafluoroethylene (PTFE) that needs further discussion. Pyrolysis of PTFE is detectable at 200 °C. The degradation by-products can be lethal to birds, and cause flu-like symptoms in humans. The load sticks tightly with the roller. Thus, the chance of generating frictional heat is low. The operating environment also cannot provide the high temperature 200 °C.

It is quite clear that information presented in Table 3 shows that the Composite is not toxic in nature. This is further reconfirmed with the "Acute Oral Toxicity Study".

5. Other Properties of the Rollers

5.1 Noise pollution

Aluminium is much harder than the nylon and thus the aluminium alloy rollers produce much higher noise than that of composite rollers. The effect of absorption of noise by composite roller is an interesting topic. Unfortunately, data is not available and this may be an area of exploration subject to funding available.

5.2 Adhesive wear

According to Ludema (1996), severe adhesion is at least as an initiator of damage. This is explained further in (Theo et al., 2010) that many polymers (e.g., PTFE, Telfon) possess excellent adhesion resistance. As polymers are more adhesion resistance, the composite roller has an interesting and useful high frictional characteristics.

Fugro Technical Services Limited (2022) provides the comparison of the frictional characteristics for the two types of rollers. The results are presented in Table 4. The composite roller has a much higher coefficient of dynamic friction (as reflected by higher pull-out force). That is to say, the chance of skidding is much lower. It is also interesting to note that this coefficient increases under a wet condition. This results in further reduction in the chance of skidding. Such characteristic is a very desirable feature to avoid accident due to the skidding of the load.

Table 4: Comparison of pull out forces.

	Dry condition	Wet condition
Aluminium roller	10.33 N	8 N
Composite roller	16.66 N	The 18.33 N

5.3 Comparison of material cost trends

The two types of rollers are made from very different materials. Therefore, it is not that useful to compare the cost of the material directly. Instead, the comparison of the trend of material cost is more important. Figures 1 and 2 show the trend in the material cost in terms of US$/t for aluminium and RMB thousands/t for nylon 66. It is quite obvious that the cost of aluminium goes up rapidly in the recent months while the cost of nylon 66 is quite steady in China where the material is sourced to support the manufacturing of composite rollers.

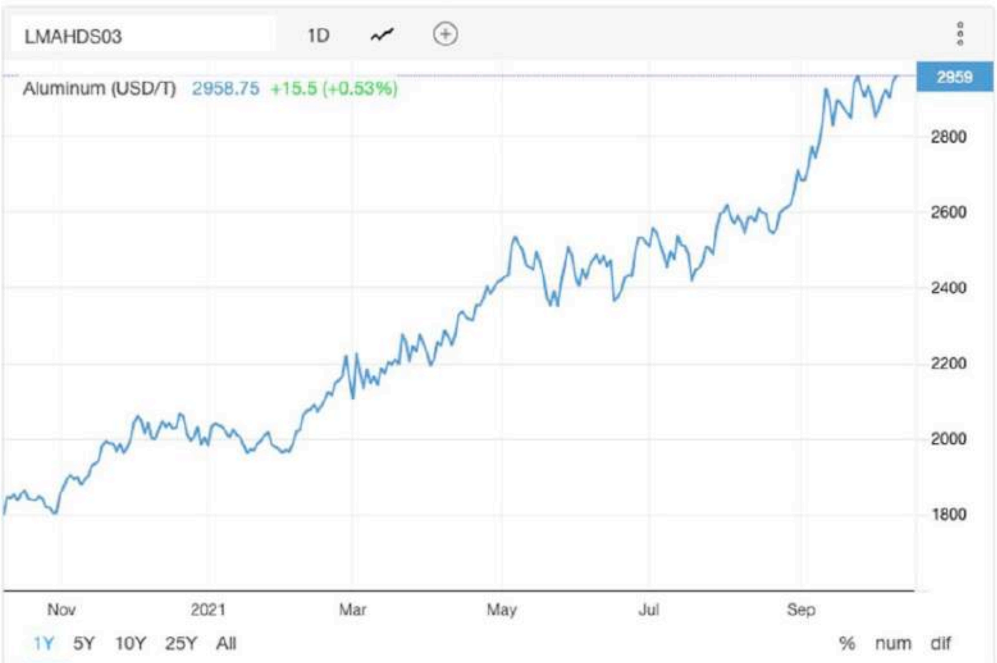

Figure 1. Material cost of aluminium (in US$/t).
Source: https://tradingeconomics.com/commodity/aluminum

Figure 2. Material cost of nylon 66 (in RMB thousand/t).
Source: https://www.fibre2fashion.com/news/textile-news/nylon-66-chips-price-in-china-may-recover-by-end-of-q3-2021-texpro-275026-newsdetails.htm

6. Conclusion

Two types of rollers commonly used in air cargo loader applications were studied. The methodology is based on information from theses and Internet plus results from independent testing laboratories. The conclusions of this study are summarized as follows:

1) The two types of rollers differ in environmentally friendliness. The composite roller weights lighter and thus a lot of energy is saved in moving it. Assuming moving the loaders 10 km per day, a total of 86.3 tonnes of diesel fuel could be saved from the tractors every year. The carbon footprint differs by 4.4 times for the refining the aluminium and nylon.

2) Toxicity of aluminium to humans was a major concern. The comparison on roller composition demonstrates that aluminium alloy roller has 99% of its material being toxic in nature in different degrees, while the composite is not toxic at all. An independent test laboratory found that the toxicity of the composite was in Category IV which is practically non-toxic and not an irritant.

3) The composite roller is adhesion resistant. Thus it has the preferred characteristics of non-skidding and in particular when the roller is operating under rainy condition.

4) The cost of aluminium has gone up very rapidly in the recent months but the cost of nylon in making the composite is quite steady.

5) Composite rollers, due to its various positive characteristics, might be one of the alternate choices to replace aluminium rollers in future environmentally friendly, sustainable, and economic operation. This further addresses the social responsibility of achieving a safety and health environment for people working at the airport where air cargo loaders are in operation.

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