INNOVATIVE USE OF MEDICAL COVID WASTE

Term Project in CE20201 Introduction to Civil Engineering and Materials Course

Report Prepared by

Team 5

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ABSTRACT

This report is made with the objective of researching about the various avenues for utilising the non-biodegradable medical wastes such as masks, PPE kits etc generated in huge amount via exploring different methodologies that exist for converting or recycling similar materials as used in masks and PPE kits into some utilisable commodity and trying to apply them to assess the feasibility and impact of those methods in solving the issue of increasing Covid generated waste.

This report also further entails the solution of Covid-related medical waste management and includes details such as logistics for facilitating the transport, disinfection, storage and preparation of the medical waste to be ready for the recycling processes along with focusing on the infrastructure setup necessary to carry the above procedure.

There will be three broad avenues to utilise and recycle the medical waste that will be covered upon in this report. Those methods include recycling the medical waste, primarily masks and PPE kits, into woven bags, adhesive polypropylene tapes and construction bricks and reinforcing it.

PROBLEM STATEMENT

Since the Coronavirus outbreak in early 2020, the virus has reached a global level and caused multitudes of negative impact over people’s lives. The current most efficient ways of restricting the spread of the virus involve some form of shielding. Hence the most widely used protective equipment for this are masks and PPE kits.

However even before the world has reached a stage where the outbreak has been brought under control, there has been another negative externality of the crisis, which is a surge in plastic and otherwise waste due to excessive demand and usage for masks and PPE kits. However till the time the virus passes and becomes dormant, the usage of masks and PPE kits is extremely important and cannot be compromised upon, as they are the only cost-effective way which can assure public safety at a global level.

Hence the problem statement which this report will try to address is to find out innovative ways to use masks and PPE kits to ensure the waste generated doesn’t end up supplementing the huge problem of plastic waste.

INTRODUCTION

Coronavirus has claimed over 4 and half million lives and the virus is not showing any indications of stopping or disappearing anytime soon. Hence the best and most feasible way for the general public to protect themselves from the virus is to use protective equipment such as masks and PPE kits.

After the viral outbreak, many countries had ramped up the production of masks and PPE kits and had issued to the public to use them in all open and public spaces. As a result of this, the daily medical waste generated due to Covid-19 is estimated to be 129 billion pieces of single use disposable masks, which, assuming one mask to weigh 3.5 grams, puts the daily waste at over 15000 tonnes.

The 15000 tonne figure is extremely huge and a major portion of it being highly non-biodegradable means that it will likely stay in the environment for a rather long time. Due to this accumulation there are a wide plethora of issues that can rise and cause problems in the future. Also it will be extremely difficult to remove such a large quantity of waste from the environment.

The optimal approach to this problem requires limiting the amount of masks that go into the waste disposal channels that have already been overburdened with increasing medical waste. For this there needs to be a system that can handle the logistics as well as can recycle the waste coming in.

Fortunately, masks and PPE kits are made of polypropylene. Polypropylene is one of the more versatile plastics and hence has a broad application spectrum. However there is a lack of a system that can ensure this process goes on without much overhead costs or inefficiency caused problems

Such huge quantities of waste pose a serious problem, which needs to be dealt with in the real time, as the pandemic may go on for a long time and by then the plastic waste would have already become too huge to deal with. Hence this report will attempt to use technology to solve this problem.

WHY IS IT IMPORTANT

This section will deal with the most pressing concerns of increasing plastic waste and will emphasise on the importance of searching for alternate channels to reuse the medical waste generated due to covid.

Non-biodegradable nature of medical waste

Generally, single use or disposable masks contain 3 layers (commonly referred as 3-ply masks). The top and bottom layers contain non-woven fabric (spunbond), which is generally some form of cotton blended with synthetic material. The middle layer is made up of meltblown polypropylene, which is a synthetic polymer[1].

Estimated put the average time it takes for polypropylene to decompose to be around 20-30 years[2]. However similar statistics regarding the lifespan for meltblown propylene aren't available. However, considering that melt blowing isn't a chemical process, the lifespan of surgical and disposable masks will also be around 20-30 years since the chemical and molecular structure does not undergo any drastic changes.
20-30 years is still a long time for a plastic article to decompose because the plastic fibres can seep through to the environment and surrounding water bodies. Hence polypropylene and the synthetic fibers present in a surgical mask pose threat to the environment as the any combination of the following problems may arise[3]:

- Eutrophication
- Acidification
- Abiotic depletion
- Carcinogenic impacts

Apart from the aforementioned impacts, improper disposal and management of medical waste can lead to their direct and indirect ingestion by the wildlife which can cause respiratory and gastrointestinal obstructions or death by starvation, and the fundamental problem of entanglement of animals in plastics which leads to them being unable to escape or free themselves

There are also issues regarding these waste materials reaching the oceans and becoming marine debris. It is estimated that 1.56 billion masks ended up entering the oceans during the pandemic[4]. The plastics can lead to accumulation in the gastrointestinal tracts of marine animals and result in death for the organism.

These plastics can also further be fragmented into smaller pieces while they are in the oceans. The impacts of this are two-fold:

- Firstly, it may become extremely difficult to restore the damage as recollecting the fragmented mask debris will become appreciably more difficult.
- Secondly, it can lead to worse biological magnification as with smaller fragments, the chances of the mask fragments being ingested by smaller organisms increases, which can lead to this plastic, polypropylene, further being accumulated in the organisms at the top of the food chain.

Stress on Waste Disposal Systems

The current waste disposal systems that exist in many countries were unable to cope up with the tremendous amounts even during pre-pandemic times. The reasons for which are many ranging from funding issues to huge amounts of waste generated.

This paper will focus on the data available regarding the increase in use of masks in Taiwan and will try to extrapolate from that the estimated values for masks discarded in India and the stress it potentially created on the waste disposal system.

In a span of 105 days from February to mid-May, when the number of Covid cases in Taiwan peaked, Taiwan used 1.3 billion masks[5]. The figure of 1.3 billion masks signifies that Taiwan, a nation of 26 million people, has an average consumption of 50 masks per person during that period. Considering this to be a mixture of N-95 and disposable masks in a reasonable 30:70 ratio, an average Taiwanese used 15 N-95 masks in 105 days, one mask every week. Normally the recommended usage time of an N-95 mask is 3-4 weeks during a non-peak time frame. Hence during the peak of Covid, the consumption and usage of masks in Taiwan skyrocketed.

From the data available on Taiwan, the estimated number of masks used in India can be extrapolated.

India also had a peak during April to mid June, which is roughly 75 days. With a population of 139 billion, keeping all others factors constant and multiplying with a factor of 0.70 to accommodate for the less usage of marks in India in rural areas and to accommodate for a higher reuse and usage time of masks, the estimated usage of masks in India during the 75-day period comes out to be 29.2 billion.

29.2 billion masks used in just a 75-day period creates tremendous pressure on the waste management system of the country. To quantify the impact in terms of additional mass load that the system will have to deal with, the average mass of one mask will be used.

Assuming a 25:75 ratio for N-95 mask to disposable mask, and knowing the weight of them being 12g and 3.5g respectively, the average weight of a mask can be assumed to be 5.625g. The daily extra load that the country would have to deal with just because of masks is approximately 220 metric tonnes.

A point to note here is that this external load is just due to masks, other protective equipment such as PPE kits, gloves, face shields etc will inflate this number. Even in the absence of them, the weight is still tremendous for an already overloaded system to try to dispose or recycle.

Certain estimations about the increase in mask consumption over the years bring up tremendously huge figures. One estimate made in 2020 stated that "*Hypothetically assuming the pandemic that was declared March 2020 will end 18 months later, the world will have used an estimated 2,322,000,000,000 (that's 2.32 trillion) masks—and with our current directives in place, less than 1% will have been recycled*." Clearly the pandemic has lasted longer than 18 months and will keep on raging for some more time, hence this number will inflate a lot over time.

Another overlooked factor that is increasing the usage of masks, PPE kits and other protective equipment is the unavailability of proper ventilation systems in the hospitals and other makeshift medical facilities. PPE kits generally are made of non-breathable synthetic fabrics such as polypropylene and as a result of that the wearer such as doctors, nurses and sanitation staff have to endure more heat and sweat. In this situation, many prefer to keep on changing the PPE kits more often, sometimes 2-3 times in a day. A direct impact of this is an exponential increase in the usage of PPE kits from the healthcare sector which is already a major consumer of PPE kits. The large base effects compounds the problem that already exists regarding the increase in use of masks and PPE kits, thereby increasing the excessive load on the environment.

Problems with recycling plastic aren't new—between 2015 and 2018, the U.S. only managed to recycle 8.7% of it. Echoing that, annual global production of plastics measures 380 million pounds (excluding the uptick in masks and PPE), and 91% is never recycled[7].

All this factored in, an additional concern with PPE, equipment designed to filter viral particles, is that the stream coming from hospitals and long-term care facilities is deemed Category B waste. It cannot even be sent through the existing inefficient MRFs, complicating the growing predicament.

Increased risk of more air pollutants in future

As such since there is already huge stress on the waste management system and there is a lack of proper recycling avenues for solid medical waste such as masks and PPE kits, the only other alternative to landfills that exists today are incinerators.

Incinerators are large furnaces used to combust the waste material and hence reduce it to ashes. The advantage of incinerators is that ashes take significantly less space than solid waste and hence can easily be disposed of in landfills without surpassing the maximum limiting capacity of the landfill.

However, since the main material used in masks and PPE kits is polypropylene which is a hydrocarbon, combustion of it leads to release of several harmful gases such as Carbon Dioxide, Carbon Monoxide along with trace quantities of oxides of sulphur and nitrogen due to other materials used in making them. The following is the chemical equation of combustion of polypropylene:

$$\left(CH_2\text{-}\underset{\displaystyle CH_3}{\underset{|}{CH}} \right)_n + n\frac{9}{2}O_2 \longrightarrow 3nCO_2 + 3nH_2O$$

Equation 1: Combustion of Polypropylene

From the above equation it can be concluded that 42g of polypropylene results in a total carbon dioxide release of 132g. However masks contain other sulphur and phosphorus based compounds as well in the form of the fabric, hence there will also be release of oxides of these elements which have severe impacts.

These pollutants are directly released into the air, even though there are some measures deployed in incinerators to reduce the release of harmful oxides, the efficiency of those is still unproven or not remarkably well to limit the huge flux of gases.

The impact of this is that huge amounts of such gases are released into the atmosphere and many of them are greenhouse gases. These gases have been documented to cause a variety of complications in humans especially in the respiratory systems. The air pollutants also cause cardiovascular diseases and may also cause nervous tissue damage in children and adolescents[18]

PROPERTIES OF MASKS

Masks contain non-woven polypropylene fabric (spunbond) in the top and bottom layers while the middle layer of the masks are made out of meltdown polypropylene.

The physical properties of single use face mask are given below:

Specific Gravity	0.91
Melting Point (Degree celsius)	160
Water absorption 24h (%)	8.9
Tensile strength (MPa)	4.25
Tensile strength at break (MPa)	3.97
Elongation at break (%)	118.9
Rupture force (N)	19.46

Table 1: Physical Properties of Single-use Face Masks

SOLUTION

The solution to mitigate the impacts of the rising use of masks and the resultant polypropylene accumulation in the environment would involve some mechanism that tries to channel back as many used masks into recycling systems and develop different avenues for it to be utilised.

This report will showcase the solution divided into two components, namely logistics and transformation. Logistics will involve tackling problems such as collection, segregation and storage while transformation will elaborate upon different methods to recycle the waste mask material.

Logistics

Collection

The collection of the masks are one of major challenges in the entire process due to the mask usage being highly ubiquitous amongst many households, though hospitals also use masks and PPE kits in a large amount. Collection will thus need to directly collect the mask and PPE from hospitals in the form of medical waste, which almost all hospitals themselves segregate at the internal level. For households, even though it is possible to try to segregate the masks from other waste at household level, it isn't very reliable since such mechanisms exist for other plastic waste as well and are not working up to the expectations. Hence what can be done is that collection happens normally for the household waste and then it is segregated at later levels.

Unit Placement

The recycling and segregation unit needs to be placed optimally to ensure minimum wastage of resources as well as minimize the threat to human beings. This implies that the optimal location for setting up a unit that can perform the functions is to place it nearby an already existing dumping ground or landfills or a waste disposal centre. The benefits of this will be 2-fold: 1) the new facilities can be integrated into the already existing waste management system due to close proximity and 2) landfills are placed such that they have minimal impact on the human settlements in the region and also require less cost for transportation.

Segregation

Next important step is segregation. Segregation can be done using manual labour, however manual labour is slow and it puts the lives of the workers at huge risk since they have to deal with potentially infected materials at close distance. Using the Grey Level Co-occurrence Matrix (GLCM) is a method to segregate masks from waste. GLCM is a texture identification algorithm that uses reinforced machine learning algorithms to identify different textures in the image given to it.

Implementing GLCM in the segregation process will require the waste to be spread out on a moving conveyor belt and will require a camera which can take the live pictures of the waste. It can then pass on these images to a processing unit that using GLCM will convert the pixels in the image into grey-scale and allocate an intensity to that pixel. Based on this the texture of different objects can be identified, and hence masks and PPE wastes can be identified as well. The next step will involve a robotic pitchfork to collect the identified pieces of articles.

Sterilisation

After segregation, the masks and PPE kits will be sterilized to ensure they are safe to further work with. For sterilisation, machines that rely on UV rays will be utilized to sterilise the masks. UVC radiation of optimal wavelength 222 nm has proven to destroy the proteins that form the outer coating of the coronavirus[9]. Though the radiation hasn't been proven to destroy Sars-Cov-2 virus it has proven to destroy other coronaviruses and hence with fair conviction can be expected to destroy Sars-Cov-2 virus as well.

Shredding

This method will be followed by passing the masks through shredders to shred the masks into shredded waste masks of dimensions 0.5x2cm. These shredded waste masks will act as the raw material for the transformation processes where these polypropylene based materials will be transformed into other commodities. For this purpose a double shaft hydraulic shredder with a shredding capacity of 1500-2000kg/hour will be sufficient.

Shredding is an important step here since shredding reduces the size of the masks to tiny bits. These tiny bits are more convenient for the processes such as compression that need to be done on them compared to large pieces of unshredded masks. Shredding improves the efficiency as well as the quality of the final product

PROPERTIES OF POLYPROPYLENE

Before describing various processes of recycling it is imperative to see the properties of polypropylene and to realise the strengths of the material which can be further implemented in the channels for recycling into other items.

Polypropylene, abbreviated as PP, is a recyclable thermoplastic polymer widely used in many different products. PP is rugged and resistant to different chemical solvents, acids, and bases. PP's resin identification code is 5, and it is recyclable. It is an important thermoplastic material, which only consists of carbon and hydrogen.The basic material for the manufacturing of adhesive tapes is currently polypropylene (PP). Polypropylene used for manufacturing adhesive tapes is machine-drawn in advance, so as not to stretch any further during use.

Polypropylene is a monomeric polymer of propylene (C_3H_6). It is a thermoplastic polymer which is manufactured using the chain-growth process. Polypropylene is a polyolefin which is partially crystalline and non-polar solid. Polypropylene is similar in a lot of properties to polyethylene (which is another non-biodegradable plastic), except being a bit harder and more heat resistant.

Mechanical Properties

The relative density of PP is between 0.89 and 0.92. It is one of least dense plastics. It has a Young's modulus of elasticity in the range of 1.3GPa to 1.8Gpa which makes it a durable and flexible plastic and which is complemented by its good resistance to fatigue

Thermal Properties

Due to being a crystalline-amorphous mixed polymer, PP has a melting and boiling range instead of a point. It has a melting range of 160℃-175℃. PP becomes brittle in sub-zero (less than 0℃) temperature. It also has a high coefficient of expansion.

Chemical Properties

PP has all the characteristic properties of any other plastic i.e. it is resistant to oils, fats and is non-biodegradable. PP is also insoluble in water due to its polar nature and can only be dissolved in nonpolar solvents such as xylene, tetralin etc. PP burns at the flash combustion point of 260℃.

Usage

The current global PP market was valued at more than $80 billion in 2014, according to Transparency Market research, and is anticipated to reach $133.3 billion by 2023.

PROCESSES

There will be 3 different processes aimed at producing 3 different items that will be expanded upon in this section.

Polypropylene Tapes Manufacturing

Motivation: By Keeping in mind The large scale of the polypropylene recycling Industry and further increasing interest and scope we as a team want to Innovate something for using it in the manufacturing of polypropylene tape. Also in this Covid pandemic, the time use of polypropylene increased manifolds. Waste Polypropylene is also widely present. There could be a boost to manufacturing plants and cost for raw materials also decreases which also reduces the price people will buy more and easier to establish a name in the market. The PP tape guarantees the highest extensibility of all types of tapes, and has a high resistance to deformation. It is appreciated not only in the packaging industry, but PP tape is also often used in the furniture, paper and many other industries that need to pack and transport goods.

Process:
The total process can be summarised as:
1. Preparation of adhesive.
2. Coating of adhesive in P.P. Film rolls
3. Drying rolls.
4. Slitting of rolls and packaging.

(1) Preparation of adhesive:As part of the adhesive preparation process, a calculated amount of natural rubber and antioxidants are charged into a reactor. Zinc oxide and magnesium oxide are then added into the reactor. Finally, phenolic resin and solvent are added and heated with steam to polymerize the adhesive and this is cooled to set the adhesive in liquid state.
(2) Coating of adhesive: By using an automated machine, the liquid adhesive is sprayed on polypropylene film from a hopper.
(3) Drying of rolls:In the next step, the rolls are dried to an optimum temperature of not less than 40°C
(4) Slitting of rolls & packaging: the tapes are slit and cut into smaller sizes, and they're wound onto thick craft paper rolls. and packed in cartoons.

Polypropylene Woven Bags

This process involves transforming the shredded mask polypropylene mask material into a yarn after which it can be made to undergo the same processes as in the manufacturing of any other cloth item from yarn,

The shredded mask material is sent to an extruder which compresses and extrudes the mask shreds into small plastic pellets. This process is vital as pellets are easier to convert into yarns compared to shreds.

These pellets are then converted into yarn while simultaneously mixing it with these PP pellets with HDPE (High Density Polyethene) pellets. Once converted into yarns, PP resin is heated with a $CaCO_3$ feeler and colour, then melted and extruded as a flat sheet. These sheets are passed through a splitter. The splitter splits the sheets into long fibres of the form of tape yarns that are stretched and annealed. This is followed by passing the tape yarns into a take-up winder that winds the heat-oriented tape yarns into bobbins.

Weaving yarn into fabric follows a process similar to weaving textiles at an industrial scale. These flat tapes are woven into circular fabric by a circular weaving machine. The woven circular fabric is cut into the required dimensions. Thread from the bobbin in the circular loom's creel stand is woven into tubular cloth. In the process of weaving, circular looms are installed according to the production capacity of the plant. The cloth produced by each Loom is continuously wound on rotating pipes.

Hence it will be more feasible if the transformation of these masks and PPE kits into these pellets are done at the unit where the processes of segregation and shredding are done and then these pellets are further shipped off to the looms and mills that convert these into fabric.

The last step in the production chain is stitching and finishing. In the stitching and finishing section of the Unit, the woven cloth is cut into desired sizes and then printed. After the prints are completed, the cut pieces are sent to stitch. The following step will be quality assessment, as is integral in any other manufacturing process.

Following the Quality Control test, the woven bags will be bundled in quantities of 500 or 1000 and pressed using a Baling Press. Once pressed, the bags will be wrapped, bundled, packed and dispatched. Quality control will be maintained at all points to prevent rejections using the same processes that the loom uses to ensure security.

Polypropylene in Bricks

There are two major approaches to use masks and PPE kits waste in the process of manufacture of bricks. One approach is to make the bricks with the shredded mask material as the major component. The other approach is to use shredded mask material as a reinforcing material and mix it in small quantities in the recycled concrete aggregate to make bricks.

Masks as Major Component

In this process masks will be shredded and will be soaked in order to make a pulp. The pulp will be mixed by adding river sand to it in 1:1 proportion. Mixing is an important step in the manufacture to ensure uniform and strong bricks which reduces the risk of future cracks or buckling under compression. The mixture will be then put into moulds of standard Indian brick size (190mm x 90mm x 90mm) and the excess water will be drained by applying compressive pressure. After this, the bricks will be left to dry in the sun or baked at a temperature below the polypropylene's combustion temperature. The temperature at which the bricks will be baked will be in the range of 90℃-110℃.

Masks as a Reinforcement Material

There is scientific evidence to back up the claim that adding shredded masks and PPE kits in small amounts (1%, 2% and 3%) in the Recycled Concrete Aggregate (RCA) can increase the strength of the RCA[10]. The process is fairly simple. Procedure to infuse single use face masks into bricks

- Shredding the masks into thin strips of 0.5x2 cm
- RCA class II has to be oven dried for one day at temperature above 100 degrees celsius
- The shredded masks are mixed with the RCA in 1%, 2% and 3% quantities by weight to depending on strength requirement
- The mixture is made into a blend with particle sizes ranging from 75 µm to 26 mm
- The mixture is sieved to ensure a consistent mixture and then compacted to form bricks weighing 2kg

The resultant brick becomes stronger after the addition of shredded mask material. The below table shows the resilient modulus of the bricks based on different proportions of added shredded face masks in the RCA. A higher resilient modulus indicates a stronger and stiffer material.

RCA Content	Shredded face mask content	Resilient Modulus
100%	0%	302.17 MPa
99%	1%	314.35 MPa
98%	2%	304.78 MPa
97%	3%	296.58 MPa

Table 2: Resilient Modulus of RCA-Shredded Face Mask Bricks

CONCLUSION

From the above data the conclusion drawn is that during this pandemic the amount of plastic waste produced all over the world is very much high as discussed above. The presence of these plastics has affected the environment in a deadly manner since plastics such as polypropylene take a long time to decompose and if they enter the food chain of living organisms they are likely to cause deaths of the organisms including the endangered oneeResearching about the properties of the plastic produced as waste ,there are a lot of characteristic properties which can actually be utilised for the progress of certain alternate avenues given that polypropylene is already a very widely preferred plastic.

So, the reality is those plastic-woven blue face masks and those PPE kits will likely still be around—in the oceans, landfills, and hazmat repositories—through the next four "once-in-a-generation" pandemics unless a way to break them down or a way to sustainably recycle them is figured out. Therefore it is really important to explore different avenues to dispose of them in the right way by using innovative methods.

The methods will need to be logistically well supported with the channels for collection and separation clearly mapped out. The placement of the units is also important as that will decide the cost and efficiency factors and also the threat to public health to a huge extent. It is also important to have systems that break down the waste into the smallest unit such as shredded pieces in this case so they can be further utilised at multiple places

The three methods elaborated in this report involve conversion of polypropylene into tapes, woven bags and bricks. The results are motivating even though the initial set-up will be high. We can conclude via the results that adding 1% shredded face mask into RCA increases its resilient modulus by 3.82%. This is particularly environmentally friendly because RCA itself is a recycled aggregate and hence with improved strength can be a better alternative in pavement bricks.

References

[1] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7848518/

[2] Thomas, G.P.. 2020. *Recycling of Polypropylene (PP)*. AZoCleantech, viewed 09 October 2021, https://www.azocleantech.com/article.aspx?ArticleID=240

[3] https://link.springer.com/article/10.1007/s10924-007-0064-5

[4] [5]
https://www.greenpeace.org/international/story/44629/where-did-5500-tonnes-of-discarded-face-masks-end-up/

[6]https://www.roadrunnerwm.com/blog/impact-of-ppe-waste

[7] https://www.medicalnewstoday.com/articles/327447