The Third International Conference
on Innovation in Social Sciences Education and Engineering (ICoISSEE)-3
Bandung, Indonesia, July 08th, 2023

REPURPOSING MASK WASTE AS A SUSTAINABLE ADDITIVE FOR ENHANCING ASPHALT MIXTURES

*[1]**I Gusti Agung Ananda Putra**,[2]**I Nyoman Arya Thanaya**,[3]**I Made Agus Ariawan**
[4]**Yenni Ciawi**

[1]Civil Engineering, Universitas Pendidikan Nasional
[2,3]Civil Engineering, Universitas Udayana
[4]Environmental Engineering, Universitas Udayana

Author's email:
[1]anandaputra@undiknas.ac.id ;[2] aryathanaya@unud.ac.id [3]agusariawan17@unud.ac.id
[4]yenniciawi@unud.ac.id
*Corresponding author: [1]anandaputra@undiknas.ac.id

Abstract. *Masks play a critical role in protecting individuals from inhaling harmful substances and airborne contaminants. However, the improper disposal of masks poses a significant environmental challenge. Medical masks, primarily composed of polypropylene, consist of three layers: outer and inner waterproof non-woven fabric layers and a middle layer of melt-blown material. This review explores the potential of repurposing discarded polypropylene-based medical masks as an innovative additive in the formulation of asphalt mixtures. Through an extensive analysis of existing literature and the examination of the effects of mask waste on asphalt mixtures, this study sheds light on its potential applications. Notably, Research Gate, Science Direct, and Google Scholar serve as the primary sources of reference for this review. The results highlight the promising benefits of integrating medical mask waste into asphalt mixtures, including improved asphalt performance, recyclability for asphalt modification, and the promotion of environmentally-friendly practices in road construction.*

Keywords: *Discarded mask, polypropylene, asphalt additive, recycling, sustainable road construction.*

1. INTRODUCTION

The COVID-19 pandemic has created serious health, financial, and environmental problems around the world, and in the current pandemic period (Garel & Petit-Romec, 2021). During the current pandemic, the use of personal protective equipment (PPE) has increased sharply compared to the time before the pandemic (Maderuelo-Sanz et al., 2021). This is mainly due to the mandatory requirements for wearing PPE, especially medical masks (Rowan & Laffey, 2021). One effective way to fight the coronavirus is to use medical masks to avoid the spread of the virus (Royo-Bordonada et al., 2021). 20% annual growth in medical mask supply is estimated from 2020 to 2025 (Ilyas et al., 2020). At least 6.8 billion disposable masks are used worldwide every day (Novena, 2021). Masks can reportedly protect humans from the virus by up to 90% (Atmojo et al., 2020). Therefore, the use of medical masks is indispensable, but the disposal of medical masks threatens the environment (Boroujeni et al., 2021).

Masks are disposable personal protective equipment, if they are not recycled or reused in a sustainable way, discarded masks will seriously pollute the environment (Yang et al., 2022). This is because masks made of lightweight materials can be easily moved by wind and rain, even if they are thrown in the bin or dumped in a landfill. This is why face masks are everywhere in our cities, parks, car parks, and local areas. Ultimately, used face masks can easily find their way into rivers and oceans, threatening marine life (Kilmartin-Lynch et al., 2022). According to estimates, every year, nearly 0.15-0.39 million metric tons of waste masks enter the ocean, posing a potential threat to the survival of marine life (Chowdhury et al., 2021). According to Fauzi (2022), in Indonesia, from March 2020 to July 2021, there have been 18,460 metric tons of COVID-19 waste generation. This amount is very large and worrying. Therefore, with the increasing consumption of non-biodegradable materials, it is estimated that by 2050, the oceans will contain more plastic than fish (Morganti & Morganti, 2020). The method of disposing of masks by burning them at high temperatures will exacerbate not only global warming but also produce toxic gases that will aggravate environmental pollution (Xu et al., 2021). The use of landfills will cause pollution in the soil, and the decomposition of mask waste often takes a very long time, even up to hundreds of years (Patrício Silva et al., 2021).

Masks have several types and classifications that the general public needs to know about, such as medical masks, cloth masks, and N95 masks. Medical masks consist of three layers that prevent transmission: spun-bond, melt-blown filter, and spun-bond again. Fabric masks need to have three layers: an innermost layer made of hydrophilic material (such as cotton), a middle layer of hydrophobic material (such as polypropylene), and an outer layer of hydrophobic material (such as polypropylene). The N95 mask uses a material consisting of 4-5 layers (an outer layer of polypropylene, a middle layer of polypropylene electret, and an inner layer of cotton). In every research study on the manufacture of asphalt using a type of medical mask, all the constituent layers of the medical mask are made of polypropylene. The characteristics of this material are a soft and thin surface, good durability, absorbency, and strength. It has a high melting point of 165°C and can be used at a temperature of 100°C in a short time (Ririn et al., 2021). Generally, masks are semi-liquid between 115.5 and 160°C, which is in the hot mix asphalt and paving temperature range, and can act as a bonding agent to bond aggregates together (Wang et al., 2022). Medical masks are made of polypropylene plastic material that is difficult to decompose, but the material can be an alternative mixture material in asphalt by utilizing its elastic properties, which are good for use as an adhesive (Setyaningrum et al., 2022). According to Budiman et al. (2022), medical masks are made of materials mostly made of polypropylene with thermoplastic properties. This makes polypropylene material similar to the properties of the main material in road pavements, namely asphalt. Asphalt material is a non-renewable resource because it comes from nature, whose formation takes millions of years (Putri et al., 2017). Therefore, a possible solution to this problem is to recycle used medical mask waste and reuse it as reinforcement for construction materials (Selvaranjan et al., 2021).

The collection of mask fiber from domestic activities is an option considering that mask waste from health department activities is not allowed because it has special handling procedures (Wiryadi et al., 2021). Due to the fact that the coronavirus does not last more than 5 minutes at 70°C (Eslami & Jalili, 2020), Asphalt mixing usually takes place at 150–180°C; the time required for asphalt production, transport, and implementation lasts at least 30 minutes, and the asphalt temperature remains in the range of 120–150°C during this time. The coronavirus is predicted to be completely eliminated in the asphalt production and implementation process.

Researchers have also explored the utilization of medical mask waste on road pavements (Saberian et al., 2021). This article summarizes some of the utilization analyses in developing recycled medical mask waste from polypropylene in the manufacture of asphalt mixtures from previous researchers.

2. RESEARCH METHODS

Method used through an extensive analysis of existing literature. The topic was chosen based on the fact that the accumulation of mask waste has increased due to the coronavirus that has occurred around the world. The result of the increasing amount of mask waste accumulation is that it can pollute the environment. Therefore, an innovative and effective solution to reduce the amount of mask waste accumulation is to recycle the mask waste, which can be used as an additional material in asphalt mixtures. Notably, Research Gate, Science Direct, and Google Scholar serve as the primary sources of reference for this review. The number of references found in this study was 47.

3. RESULTS AND DISCUSSION

3.1 Aggregate

Aggregate or rock is generally defined as the hard, solid formations of the earth's crust. Aggregate is the main component of the pavement layer, containing 90%–95% aggregate by weight or 75%–85% aggregate by volume (Saodang, 2005). Thus, the quality of the pavement is also determined by the nature of the aggregate and the resultant mixture of the aggregate with other materials. The selection of the appropriate type of aggregate for use in pavement construction is influenced by several factors: gradation, strength, grain shape, surface texture, adhesion to asphalt, and chemical cleanliness and properties. The type and mix of aggregate greatly affect the durability or stability of a pavement (Sumiati & Sukarman, 2014).

3.2 Asphalt

Asphalt is a natural material with hydrocarbon chemical components, the result of exploration with a black color is plastic to liquid, insoluble in dilute acid and alkali solutions or water, but soluble mostly in ether, CS2, benzene, and chloroform (Saodang, 2005). The function of asphalt in asphalt pavement is as a binder so that the aggregate is not easily separated due to traffic and the environment. In addition, asphalt also functions as an impermeable layer that protects the aggregate and other materials underneath from the influence of water (Al-Amri, 2013).

3.3 Asphalt Pavement Mix

Asphalt pavement mix is a combination of aggregate and asphalt. Asphalt acts as a binder or glue between aggregate particles and the aggregate itself acts as reinforcement. The mechanical properties of the asphalt in the mix are obtained from the friction and cohesion of the ingredients. Aggregate friction is obtained from interlocking; the strength of the aggregate depends on the gradation, surface texture, grain shape, and maximum aggregate size used. While its cohesion properties are obtained from the properties of the asphalt used. Therefore, the performance of a paved mixture is strongly influenced by the properties of the aggregate and asphalt, as well as the properties of the solid mixture that has been formed from these two materials (Departemen Kimpraswil, 2002).

3.4 Mask

Masks play a critical role in protecting individuals from inhaling harmful substances and airborne contaminants. Respiratory protection, or masks, are not intended to replace the preferred method of eliminating disease but are used to adequately protect the wearer (Cohen & Birdner, 2012). The type of mask used in this article is a medical mask, which is generally made of a type of non-woven or non-woven fabric. The characteristics of this material are a soft and thin surface, durability, good absorption, and strength. It also has a high melting point of 165°C and can be used at a temperature of 100°C in a short time (Ririn et al., 2021). The mask consists of three layers: the outer layer and the inner layer are waterproof non-woven fabric, and the middle layer is melt-blown material (Fadare & Okoffo, 2020). The three main functions of the medical mask (Figure 1) are that the outer layer is waterproof, the middle layer serves as a filter, and the inner layer is useful for absorbing fluids that come out of the mouth (Sunda, 2020).

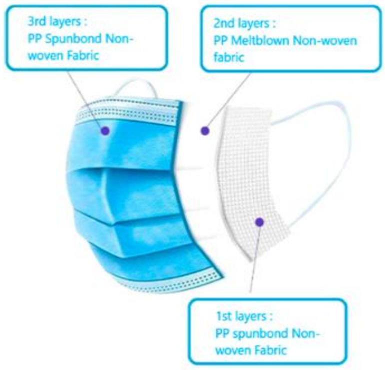

Figure 1. Three-layer medical mask
Source: Goli and Sadeghi (2022)

Generally, masks are semi-liquid at temperatures between 115.5 and 160°C, within the hot mix asphalt and paving temperature ranges, and can act as a bonding agent to bond aggregates together (Wang et al., 2022). The mask starts to melt at 115°C after 10 minutes in the oven, which can be seen in Figure 2. N95 masks and medical masks contain approximately 11 and 4.5 g of polypropylene and/or other plastic derivatives (e.g., polyethylene, polyurethane, polystyrene, polycarbonate, and poly acrylonitrile) (Abbasi et al., 2020). Mostly, the chemical composition of the mask is polypropylene (Chalermsinsuwan et al., 2022) (Table 1). Polypropylene is a downstream petrochemical product derived from the olefin monomer propylene through addition polymerization to form polymers with long molecules, or polymer chains (Maddah, 2016). Polypropylene is one of the polymers of the thermoplastic type that can be recycled. It is the lightest among other polymeric materials, has a high melting point, is corrosion-resistant, is easy to process, has low processing costs, is easily available in the market, and can be recycled, so it is widely applied to household furniture (Amalia et al., 2014). Polypropylene has a strength that is still considered normal at the sixth recycling process, although its tensile strength will be reduced due to pressure and heat during extrusion (Vidakis et al., 2021). The fibers used in masks known as melt-blown and spun-bond are non-woven fibers. Due to their physical structure, these fibers are produced without the use of weaving operations. These fibers have very small pores to perform the filtration operation well. This type of fiber is most widely used in the medical industry due to its filtration properties (Goli & Sadeghi, 2022). The main difference between melt-blown and spun-bond fibers lies in the manufacturing process and the resulting fiber structure (Affifah & Zulfa, 2021), not on the elemental composition of the chemical compounds present in the material.

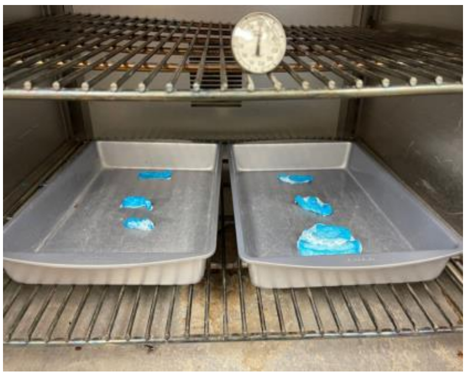

Figure 2. The mask starts to melt
Source: Wang et al. (2022)

Table 1. Chemical composition of the mask

Elemen	Berat (%)
Mg	2.94
Al	9.99
Ca	25.85
Si	59.11
K	2.11

Source: Ali et al. (2022)

3.5 Types of Masks

The following are the types and classifications of masks that the general public needs to know:

1. Cloth Mask
   According to Hapsari and Munawi (2021), cloth masks can be used to prevent transmission while anticipating the scarcity of masks that occurs. The filtering effectiveness of cloth masks increases with the number of layers and the density of the woven fabric used. The cloth mask needs to have three layers: an innermost layer made of hydrophilic material (such as cotton), a middle layer made of hydrophobic material (such as polypropylene), and an outer layer made of hydrophobic material (such as polypropylene). Cloth masks need to be washed and can be worn many times. The materials used for cloth masks include cotton cloth, scarves, and so on.
2. Medical Mask or Surgical Mask
   The medical mask consists of three layers that prevent transmission: spun bond, melt blown filter, and spun bond again. The outer layer of non-woven fabric is impermeable to water, the inner layer is a high-density filter layer, and the inner layer is directly attached to the skin, which functions as a large liquid absorber that comes out of the wearer when coughing or sneezing. Because they have this filter layer, medical masks are effective in filtering droplets that come out of the wearer when coughing or sneezing (Badan Nasional Penanggulangan Bencana, 2023).
3. N95 Mask
   N95 masks use materials consisting of 4-5 layers (an outer layer of polypropylene, a middle layer of polypropylene electrete, and an inner layer of cotton) and have better filtration capabilities compared to surgical masks. This type of mask has the advantage of not only protecting the wearer from exposure to droplet-sized liquids but also liquids up to aerosol size. This group of masks is recommended especially for health workers who must be in close contact, directly handling cases with high infectious levels, such as patients positively infected with the COVID-19 virus (Farmalkes, 2021).

3.6 Products produced from polypropylene

According to Winata (2007), polypropylene products can be used in various applications. Applications of the various product specifications can be used for various purposes, among them:

a. BOPP (Biaxial Oriented Polypropylene) Film
   This type of resin has the highest molecular weight. Its uses include food packaging materials, cigarettes, plastic lamination, and plastic decoration.

b. Yarn
   Widely used as a raw material for making chemical sacks, the bottom of carpets, and raffia. It is strong, slippery, and does not absorb water.

c. IPP (Inflation Polypropylene) Film
   These resins are most widely produced and used for food packaging, inner plastic bags, and textile wrapping.

d. Injection Molding
This resin is widely used for household appliances such as bottles, chairs, and kitchen utensils, as well as for automotive purposes.

e. Fiber
This type is used for carpets, yarns, and upholstery carpets.

f. Thermoforming
This resin is widely used for glass and plastic containers. It is clear, strong, and does not cause odor or taste.

g. Cast film
Used for coating materials on metal. The sheet is drawn only in one direction but is softer because it is flexible.

3.7 Mask Waste Management

Based on guidelines from Kementerian Kesehatan Republik Indonesia (2020), the steps for managing used masks in the community are:

1. Collecting used disposable masks
2. Disinfect the used masks. Mask disinfection can be done by soaking the mask in a disinfectant, chlorine, or bleach solution.
3. Change the shape of the mask. After disinfection, the mask must be cut or damaged so that it cannot be reused.
4. Dispose of it in domestic waste after wrapping it in tight plastic. In accordance with the Minister of Environment and Forestry's circular, if the government has provided special mask bins or drop boxes in public spaces, the public can dispose of the disposable masks in the special mask bins provided.
5. Wash hands with soap and running water after handling masks.

3.8 Previous Research Results

Based on the results of the analysis of the addition of medical mask waste to asphalt mixtures derived from several previous studies, they can be seen in Table 2.

Table 2. The analysis results of the addition of medical mask waste to the asphalt mixture

No.	Authors/ Year	Asphalt Mixture Types	Results
1	Goli and Sadeghi (2022)	Asphalt Concrete	The masks were added to the asphalt concrete mix in 4 different weight percentages (0% (control), 0.07%, 0.1%, 0.12%, and 0.15%) to the aggregate weight and in two different sizes (12 mm and 8 mm), and tests were conducted. The results showed that the addition of these materials to the asphalt mix improved the performance of the asphalt.
2	Wang et al. (2022)	Rapid Setting Asphalt Emulsion (RS)	The Rapid Setting (RS) emulsified asphalt mixtures modified with fiber masks exhibited excellent resistance to permanent deformation. The rutting depth value was reduced from 3.0 mm to 0.93 mm by increasing the fiber mask content from 0% to 1.5% by weight.
3	Zhao et al.(2022)	*Stone Mastic Asphalt* (SMA)	Adding medical mask waste fiber as an additive into SMA mixtures in 4 different weight percentages (1%, 2%, 3%, and 4%) can improve strength and stiffness, as well as deformation resistance. Overall, medical mask waste can be recycled to modify asphalt in road construction.
4	Saberian et al.(2021)	Asphalt Concrete	The asphalt concrete mixtures adding mask fiber at three different percentages (1%, 2%, and 3%) to the aggregate

			can increase the strength and stiffness but also increase the elasticity and flexibility of the asphalt mixtures.
5	Permata et al. (2023)	Asphalt Concrete	The percentage addition of mask waste mixture is sensitive to the stability and flow values. The optimum percentage addition was obtained at a percentage of 1.50% with stability and flow values of 1020.36 kg and 4 mm, respectively.
6	Dadwal et al. (2022)	Asphalt Concrete	The addition of COVID-19 plastic waste to the asphalt concrete mixture at a percentage of 10%, 12.5%, 15%, 17.5%, and 20% by weight of asphalt can increase the stability and flow values of the asphalt mixture. The addition of COVID-19 plastic waste to asphalt concrete is safe and sustainable for road construction.

CONCLUSION

The results highlight the promising benefits of integrating medical mask waste into asphalt mixtures, including:

1. Improved asphalt performance.
2. Recyclability for asphalt modification.
3. The promotion of environmentally-friendly practices in road construction.

Based on the results of the analysis and conclusions above, the suggestions that can be given are:

1. Using medical mask waste as an additive in asphalt mixtures can serve as an environmentally friendly method to reduce environmental pollution while producing high-quality asphalt.
2. Further analysis is needed regarding the effect of the addition of medical mask waste on asphalt properties.

REFERENCES

Abbasi, S. A., Khalil, A. B., & Arslan, M. (2020). Extensive use of face masks during COVID-19 pandemic: (micro-)plastic pollution and potential health concerns in the Arabian Peninsula. *Saudi Journal of Biological Sciences*, *27*(12), 3181–3186. https://doi.org/10.1016/J.SJBS.2020.09.054

Affifah, H. N., & Zulfa, A. L. (2021). *Pra Rancangan Pabrik Masker Bedah (3 Ply) Spunbond Pp Kapasitas 950 Ton/Tahun*. Universitas Islam Indonesia.

Al-Amri, F. (2013). Studi Perbandingan Penggunaan Aspal Minyak Dengan Aspal Buton Lawele Pada Campuran Aspal Concrete Base Course (Ac-Bc) Menggunakan Metode Marshall Test. *Radial*, *4*(2), 181–190.

Ali, M., Opulencia, M. J. C., Chandra, T., Chandra, S., Muda, I., Dias, R., Chetthamrongchai, P., & Jalil, A. T. (2022). An Environmentally Friendly Solution for Waste Facial Masks Recycled in Construction Materials. *Sustainability (Switzerland)*, *14*(14). https://doi.org/10.3390/su14148739

Amalia, S. R., Kartika Fajarwati, Margi Fitriawan, Mahardika Prasetya Aji, & Agus Yulianto. (2014). Kuat Tarik Komposit Polipropilena (PP) dengan Penguji Silika (SiO2). *Seminar Nasional Mahasiwa Fisika*, *April 2015*, 107–110. https://doi.org/10.13140/RG.2.1.3253.2002

Atmojo, J. T., Iswahyuni, S., Rejo, R., Setyorini, C., Puspitasary, K., Ernawati, H., Syujak, A. R., Nugroho, P., Putra, N. S., Nurrochim, N., Wahyudi, W., Setyawan, N., Susanti, R. F., Suwarto, S., Haidar, M., Wahyudi, W., Iswahyudi, A., Tofan, M., Bintoro, W. A., … Mubarok, A. S. (2020). Penggunaan Masker Dalam Pencegahan Dan Penanganan Covid-19: Rasionalitas, Efektivitas, Dan Isu Terkini. *Avicenna : Journal of Health Research*, *3*(2), 84–95. https://doi.org/10.36419/avicenna.v3i2.420

Badan Nasional Penanggulangan Bencana. (2023). *Mengenal Jenis-jenis Masker Berdasarkan Kebutuhannya*. https://she-kalimantan.co.id/mengenal-jenis-jenis-masker-berdasarkan-kebutuhannya/

Boroujeni, M., Saberian, M., & Li, J. (2021). Environmental impacts of COVID-19 on Victoria, Australia, witnessed two waves of Coronavirus. *Environmental Science and Pollution Research International*, *28*(11), 14182. https://doi.org/10.1007/S11356-021-12556-Y

Budiman, A. S., Rebia, R. A., Hidayah, F. N., Septyani, D. W., Isla, S. A., Studi, P., Tekstil, R., Industri, F. T., & Indonesia, U. I. (2022). Masker Medis Tiga Lapis Dengan Variasi Berat. *Jurnal Ilmiah Cendekia Eksakta*, 73–78.

Chalermsinsuwan, B., Li, Y. H., & Manatura, K. (2022). Optimization of gasification process parameters for COVID-19 medical masks using response surface methodology. *Alexandria Engineering Journal*, *62*, 335–347. https://doi.org/10.1016/J.AEJ.2022.07.037

Chowdhury, H., Chowdhury, T., & Sait, S. (2021). Estimating marine plastic pollution from COVID-19 face masks in coastal regions. *Marine Pollution Bulletin*, *168*. https://doi.org/10.1016/j.marpolbul.2021.112419

Cohen, H. J., & Birdner, J. S. (2012). Department of Occupational And Environmental Medicine. *Respiratory Protection*, 783–793.

Dadwal, T., Kumar, V., & Bhatia, U. K. (2022). Experimental investigation on the use of COVID-19 waste in bituminous concrete. *Materials Today: Proceedings*, *xxxx*. https://doi.org/10.1016/j.matpr.2022.08.055

Departemen Kimpraswil. (2002). *Manual Pekerjaan Campuran Beraspal Panas*. Departemen Pemukiman dan Prasarana Wilayah. Direktorat Jenderal Prasarana Wilayah. Jakarta.

Eslami, H., & Jalili, M. (2020). The role of environmental factors to transmission of SARS-CoV-2 (COVID-19). *AMB Express*, *10*(1). https://doi.org/10.1186/s13568-020-01028-0

Fadare, O. O., & Okoffo, E. D. (2020). Covid-19 face masks: A potential source of microplastic fibers in the environment. *Science of The Total Environment*, *737*, 140279. https://doi.org/10.1016/J.SCITOTENV.2020.140279

Farmalkes. (2021). *Gunakan Masker Medis Yang Telah Memiliki Izin Edar | Direktorat Jenderal Kefarmasian dan Alat Kesehatan*. https://farmalkes.kemkes.go.id/2021/04/gunakan-masker-medis-yang-telah-memiliki-izin-edar/

Fauzi, G. (2022). *Sampah Medis Pascapandemi, Siapa Berani Tanggung Jawab*. https://www.kompas.id/baca/opini/2022/07/31/sampah-medis-pascapandemi-siapa-berani-tanggung-jawab

Garel, A., & Petit-Romec, A. (2021). Investor rewards to environmental responsibility: Evidence from the COVID-19 crisis. *Journal of Corporate Finance*, *68*, 101948. https://doi.org/10.1016/J.JCORPFIN.2021.101948

Goli, A., & Sadeghi, P. (2022). Evaluation on the use of COVID-19 single-use face masks to improve the properties of hot mix asphalt. *Road Materials and Pavement Design*, *May*. https://doi.org/10.1080/14680629.2022.2072376

Hapsari, K. R., & Munawi, H. A. (2021). Pemilihan Masker Kain dalam Mencegah Penularan Virus Covid-19. *Nusantara of Engineering (NOE)*, *4*(1), 45. https://doi.org/10.29407/noe.v4i1.15910

Ilyas, S., Srivastava, R., & Kim, H. (2020). Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *The Science of the Total Environment*, *749*, 141652. https://doi.org/10.1016/J.SCITOTENV.2020.141652

Kementerian Kesehatan Republik Indonesia. (2020). *Pedoman Pengelolaan Limbah Masker dari Masyarakat*.

Kilmartin-Lynch, S., Roychand, R., Saberian, M., Li, J., & Zhang, G. (2022). Application of COVID-19 single-use shredded nitrile gloves in structural concrete: Case study from Australia. *Science of The Total Environment*, *812*, 151423. https://doi.org/10.1016/J.SCITOTENV.2021.151423

Maddah, H. A. (2016). Polypropylene as a Promising Plastic: A Review. *American Journal of Polymer Science*, *6*(1), 1–11. https://doi.org/10.5923/J.AJPS.20160601.01

Maderuelo-Sanz, R., Acedo-Fuentes, P., García-Cobos, F. J., Sánchez-Delgado, F. J., Mota-López, M. I., & Meneses-Rodríguez, J. M. (2021). The recycling of surgical face masks as sound porous absorbers: Preliminary evaluation. *The Science of the Total Environment*, *786*, 147461–147461. https://doi.org/10.1016/J.SCITOTENV.2021.147461

Morganti, P., & Morganti, G. (2020). Surgical & Beauty Facial Masks: The New Waste Problem of Post Covid-19. *Biomedical Journal of Scientific & Technical Research*, *29*(5). https://doi.org/10.26717/BJSTR.2020.29.004878

Novena, M. (2021). *Jadi Limbah Selama Pandemi, Ahli Bakal Bikin Jalan Pakai Masker Halaman all - Kompas.com*. https://www.kompas.com/sains/read/2021/02/09/080500023/jadi-limbah-selama-pandemi-ahli-bakal-bikin-jalan-pakai-masker-?page=all

Patrício Silva, A. L., Prata, J. C., Walker, T. R., Duarte, A. C., Ouyang, W., Barcelò, D., & Rocha-Santos, T. (2021). Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations. *Chemical Engineering Journal*, *405*. https://doi.org/10.1016/J.CEJ.2020.126683

Permata, M., Dewi, P., Andaresta, W., Putri, E., & Kurniawan, P. (2023). *PEMANFAATAN LIMBAH MASKER SEKALI PAKAI SEBAGAI BAHAN PENGGANTI BITUMEN TERHADAP*. *17*(April), 112–123. https://doi.org/10.24002/jts.v17i2.6913

Putri, E. E., Andilla, M. A. T., Sipil, M. T., Teknik, F., & Andalas, U. (2017). *PEMANFAATAN MATERIAL RECLAIMEND ASPHALT PAVEMENT (RAP) SEBAGAI BAHAN CAMPURAN UNTUK LAPISAN ASPHALT PAVEMENT CONCRETE WEARING COURSE (AC-WC)*. *November*, 483–492.

Ririn, Sulaiman, L., & Ardiansyah, M. R. (2021). Studi Penambahan Serat Polypropylene Yang Terkandung Pada Masker Medis Terhadap Kuat Tekan Mortar. *jurnal, Teknik Sipil Universitas Andi Djemma*, *2006*, 137–142.

Rowan, N. J., & Laffey, J. G. (2021). Unlocking the surge in demand for personal and protective equipment (PPE) and improvised face coverings arising from coronavirus disease (COVID-19) pandemic – Implications for efficacy, re-use and sustainable waste management. *Science of the Total Environment*, *752*. https://doi.org/10.1016/J.SCITOTENV.2020.142259

Royo-Bordonada, M. A., García-López, F. J., Cortés, F., & Zaragoza, G. A. (2021). Face masks in the general healthy population. Scientific and ethical issues. *Gaceta Sanitaria*, *35*(6), 580. https://doi.org/10.1016/J.GACETA.2020.08.003

Saberian, M., Li, J., Kilmartin-Lynch, S., & Boroujeni, M. (2021). Repurposing of COVID-19 single-use face masks for pavements base/subbase. *Science of the Total Environment*, *769*, 145527. https://doi.org/10.1016/j.scitotenv.2021.145527

Saodang, H. (2005). *Konstruksi Jalan Raya*. Nova.

Selvaranjan, K., Navaratnam, S., Rajeev, P., & Ravintherakumaran, N. (2021). Environmental challenges induced by extensive use of face masks during COVID-19: A review and potential solutions. *Environmental Challenges*, *3*, 100039. https://doi.org/10.1016/J.ENVC.2021.100039

Setyaningrum, S., Salsabila, Z. N., Rahmawati, A. A., Putri, A. I., Amalia, D. N., & Tsany, S. A. (2022). Coaxyl-mask: Masker Ramah Lingkungan dari Sabut Kelapa (Cocos nucifera) dan Acetobacter xylinum. *Fluida*, *15*(1), 43–50. https://doi.org/10.35313/FLUIDA.V15I1.3481

Sumiati, & Sukarman. (2014). Influence of Aggregate Gradation on Asphalt Concrete Characteristic Value (AC-BC). *Journal of Civil Engineering*, *10*(1), 85–91.

Sunda, U. (2020). *Dijelaskan Kemenkes, Ini Beda Spesifikasi Masker Bedah dan N95*. https://rm.id/baca-berita/nasional/32932/dijelaskan-kemenkes-ini-beda-spesifikasi-masker-bedah-dan-n95

Vidakis, N., Petousis, M., Tzounis, L., Maniadi, A., Velidakis, E., Mountakis, N., Papageorgiou, D., Liebscher, M., & Mechtcherine, V. (2021). Sustainable additive manufacturing: Mechanical response of polypropylene over multiple recycling processes. *Sustainability (Switzerland)*, *13*(1), 1–16. https://doi.org/10.3390/SU13010159

Wang, G., Li, J., Saberian, M., Rahat, M. H. H., Massarra, C., Buckhalter, C., Farrington, J., Collins, T., & Johnson, J. (2022). Use of COVID-19 single-use face masks to improve the rutting resistance of asphalt pavement. *Science of the Total Environment*, *826*, 154118. https://doi.org/10.1016/j.scitotenv.2022.154118

Winata, R. W. (2007). *Prarancangan Pabrik Polypropylene dari Propylene Kapasitas 150.000 Ton/Tahun*. Universitas Muhammadiyah Surakarta.

Wiryadi, I. G. G., Wirawan, I. P. A. P., Wijaya, I. M. W., Putra, I. K. A., & Sutrisno, W. T. (2021). The Compressive Strength of Concrete with Addition of Single-Use Mask Waste Fiber. *International Conference on Sustainable Development*, *5*, 131–139.

Xu, G., Jiang, H., Stapelberg, M., Zhou, J., Liu, M., Li, Q. J., Cao, Y., Gao, R., Cai, M., Qiao, J., Galanek, M. S., Fan, W., Xue, W., Marelli, B., Zhu, M., & Li, J. (2021). Self-Perpetuating Carbon Foam Microwave Plasma Conversion of Hydrocarbon Wastes into Useful Fuels and Chemicals. *Environmental Science and Technology*, *55*(9), 6239–6247. https://doi.org/10.1021/ACS.EST.0C06977/SUPPL_FILE/ES0C06977_SI_009.PDF

Yang, M., Chen, L., Msigwa, G., Ho, K., Tang, D., & Yap, P.-S. (2022). Implications of COVID-19 on global environmental pollution and carbon emissions with strategies for sustainability in the COVID-19 era. *Science of the Total Environment*, *809*, 151657. https://doi.org/10.1016/j.scitotenv.2021.151657

Zhao, Z., Wu, S., Liu, Q., Xie, J., Yang, C., Wang, F., & Wan, P. (2022). Recycling waste disposable medical masks in improving the performance of asphalt and asphalt mixtures. *Construction and Building Materials*, *337*(May), 127621. https://doi.org/10.1016/j.conbuildmat.2022.127621