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Research Article

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Environmental Performance Assessment of Batch Type Hot Mix Plant Using LCA

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Abstract

The environmental impacts from production of Hot Mix Asphalt (HMA) in batch Hot Mix Plant (HMP) has been evaluated using Life Cycle Assessment (LCA) methodology. The hot mix technology has been in use since long time for production of HMA used in construction of road pavements. The functional unit adopted is 100 tonnes of HMA production and CML 2001 method is used for assessment using GaBi 10.5. The study found that the production of HMA in batch HMP had very high environmental impacts on marine aquatic ecotoxicity potential (MAETP) impact category (8,25,573 kg DCB eq.), abiotic depletion fossil (ADP fossil) (2,87,295 MJ) impact category and global warming potential (GWP) impact category (2,770 kg CO_2 eq.). The raw material phase had higher environmental impacts compared to production process phase on all the impact categories. It was also concluded that the use of renewable energy and fuel and adoption of cold mix technology will reduce the environmental impacts.

Keywords: Life Cycle Assessment, Hot Mix Asphalt, Hot Mix Plant

Introduction

Road pavement consumes significant amount of resources and energy and have significant environmental impacts throughout its life cycle. India has about 6.386 million km of road network, the second largest in the world [1]. Out of the total road network, National Highways/Expressway are 1,32,500 km; State Highways are 1,86,528 km; District Roads are 6,32,154 km; Rural Roads are 45,35,511 km; Urban Roads are 5,44,683 km and Project Roads are 3,54,921 km [1]. Around the world, most of the roads and highways have flexible pavement while around 90% of roads are built as flexible pavement using asphalt mix technology in India [2,3]. In this technology, is used for mixing aggregates and bitumen are mixed together in Hot Mix Plant (HMP) to prepare the hot mix paving material mainly used for flexible road construction [4]. The bitumen is heated up to 150–160 °C to make it workable. There are two types of HMP (i) batch type and (ii) drum type. In batch type plant, HMA is produced in fixed batches and one after another batches are continuously made to make HMA while drum type plant prepares the HMA through a continuous process. Batch type HMP is mostly used for HMA production as this type of plant offers highest level of flexibility in production and produces better quality of HMA compared to drum type plant.

HMP consumes huge amount of energy to heat bitumen and aggregates and emits emissions containing particulate as well as gaseous air pollutants. Primary sources of pollutants in HMP are dryers and mixers which emit particulate matters and other gaseous pollutants such as carbon monoxide, sulphur dioxide etc. It is important to evaluate the environmental impacts due to the production of HMA in HMP using LCA approach. LCA is widely used methodology to evaluate potential environmental impacts of products, services, or systems during its life cycle [5].

Many pavement LCA studies have been performed by several authors all over the world evaluating environmental impacts due to construction of flexible pavement (using hot mix technology) along with other life cycle stages but these LCA studies did not consider impacts due to production of asphalt concrete in HMP in detail [6-10]. Kar conducted LCA study to evaluate carbon footprint of road construction using hot-mix and warm-mix technology in India [11]. The study concluded that warm-mix technology saved nearly 590 tonne equivalent CO2 for 1,798,000 m^2 paving area. Ma et al. performed LCA study to evaluate greenhouse gas emissions from construction of flexible pavement in China. The study found that the total greenhouse gas emissions from HMA mixing phase was the highest (4,927,045.97 kg CO2 eq.) among other process during construction of asphalt course [12]. Mazumder et al. (2016) evaluated the environmental impacts of hot mix asphalt and production of warm mix asphalt. The study found that the HMA production contributed more than 50% in five impact categories which are global warming, acidification, depletion of fossil fuel, photo oxidant formation and eutrophication [13]. The Energy and Resources Institute (TERI) performed a LCA study and compared cold mix and hot mix technologies for construction of rural roads in India. The study concluded that hot mix construction technology had higher energy consumption and CO_2 emissions compared to cold mix construction technology [14]. Ma et al. (2019) conducted LCA study to compare warm mix asphalt (WMA) and HMA pavement in China. The study also showed the environmental impacts due to asphalt mixture production and considered global warming potential (GWP), particulate matter formation (PMF) and abiotic depletion potential-fossil fuel (CADP) as impact indicators. The study found that HMA mixture production had higher environmental impacts on all the considered impact categories compared to WMA mixture production [15].

There are a few studies such as Santos et al [16]. which adopted HMA production data from US EPA report. Peng et al. performed LCA study to assess CO_2 emissions from HMA. The study found that carbon emissions from heating aggregates, asphalt heating, and mixing process accounted for 67%, 14%, and 12% of total carbon emissions respectively [17].

Methodology

Batch Type HMA Plant

The batch HMA plant produces HMA mixture in fixed batches one by one continuously. The aggregates are fed in cold feed hopper and taken to the drum dryer through conveyor. The drum dryer heats the aggregates and the heated aggregates are then conveyed to the top of the mixing tower with the help of bucket elevator. The heated aggregates are dropped into the weigh hopper of mixing tower. The heated aggregates from the weigh hopper are fed into the pug mill where it is coated with hot bitumen pumped from a heated storage tank. The specified amount of filler is added during coating. The finished hot asphalt mix is then transported directly to the required site through a truck or by a conveyer to heated asphalt storage silos. The process flow chart for the batch HMP is shown in Fig. 1.

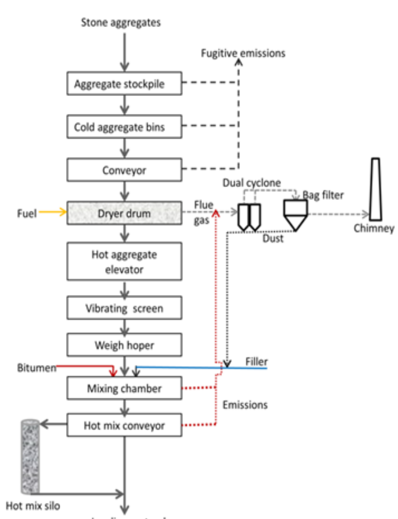

Figure 1: Process flow diagram of batch HMP [18]

Goal and Scope

The present study aims to evaluate the environmental impacts of the batch type HMP. The study considered the raw material phase and the product processes performed in the batch type HMP. The present study is cradle-to-gate LCA and accounted for raw material extraction phase; energy, fuel and water consumed in the HMP for production of HMA mixture along with gaseous emissions from the HMP. The functional unit selected for the present study is 100 tonnes of HMA production. The system boundary defines the input and output processes, which are considered in LCA study. The system boundary for present study is given in Fig. 2.

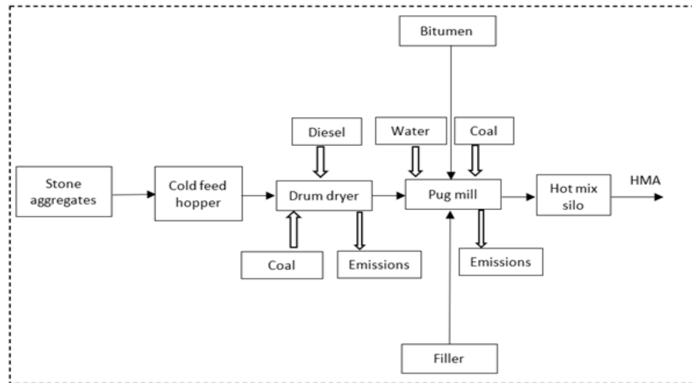

Figure 2: System boundary of the present study

Life Cycle Inventory

Life cycle inventory (LCI) is an important and crucial phase of LCA study dealing with the collection and quantification of the processes input and output data [19]. The present study considered data from the CPCB (Central Pollution Control board) report on hot mix plants to develop LCI. According to CPCB report, the batch type HMP plant considered for this study is located in Madhya Pradesh, India. The manufacturer is Linnhoff and was installed in year 2015. The present study also used background data present in GaBi database for impact assessment. The average production of HMP is 100 tonnes per hour. The present study assumed water consumption for sprinkling inside plant from the reference of other HMP as the data for water consumption for the HMP was not available. Data related to inputs and outputs of the batch HMP per functional unit (100 tonnes) is shown in Table 1.

Table 1: Data for production of 100 tonnes of HMA in the batch type HMP

Linnhoff Batch HMP	
Inputs	
Coal consumption for drum burner	1500 kg
Coal consumption for bitumen heating	100 kg
Diesel consumption for DG set	40 litres
Water consumption for sprinkling inside plant	3125 litres
Emissions	
Carbon monoxide	10.99 kg
Particulate matter	5.71 kg
Sulphur dioxide	5.55 kg
Nitrogen oxides	3.53 kg

Life Cycle Assessment

Life cycle impact assessment phase quantifies the potential environmental impacts based on LCI data [20]. In this phase, the environmental loads are translated into environmental impacts. Here, GaBi 10.5 software is used to perform LCIA for assessing the environmental impacts. The study adopted CML 2001 method (University of Leiden, 2001) for impact assessment as the impact categories included in this method found to be the most relevant. CML 2001 method includes 11 impact categories [i.e., abiotic depletion, ADP fossil, GWP, ozone layer depletion (ODP), human toxicity potentials (HTP), fresh water aquatic ecotoxicity potential (FAETP), marine aquatic ecotoxicity potential (MAETP), terrestrial ecotoxicity potential (TETP), photochemical ozone creation potential (POCP), acidification potential (AP), and eutrophication potential (EP)] and all of them were considered in this study. The HMA production process model has been developed in GaBi 10.5 and is shown in Fig. 3.

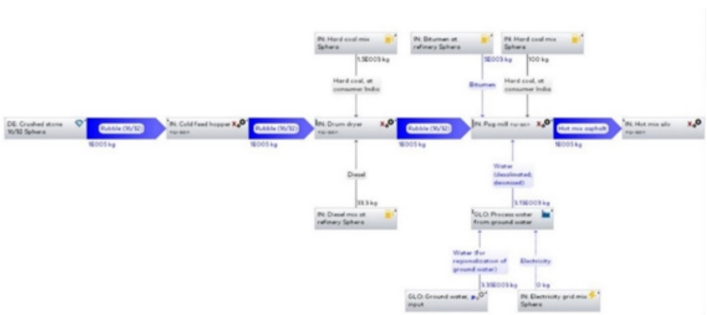

Figure 3: HMA production process model

Results and Discussions

The results of the life cycle assessment of production of 100 tonnes of HMA are presented in Figs. 4 to 14. It is observed that the raw material phase has much higher environmental impacts compared to HMA production process phase on all the impact categories (Figs. 4-14). The HMA production has the highest environmental impacts on MAETP impact category (8,25,573 kg DCB eq.) due to extraction of huge amount of stone aggregates and bitumen for production of HMA and due to coal consumption during production process of HMA in batch HMP (Fig. 4). The second highest environmental impact is on ADP fossil (2,87,295 MJ) due to significant amount of bitumen and coal consumed in the production of HMA (Fig. 5.). The third highest environmental impact is on GWP impact category (2,770 kg CO_2 eq.) due to consumption of significant amount of bitumen and coal during production of HMA (Fig. 6).

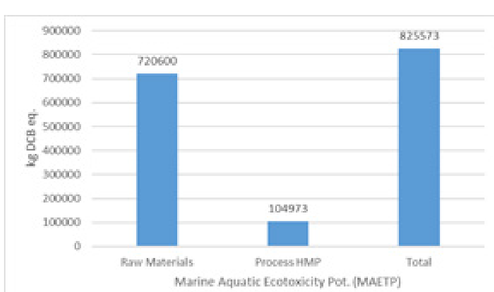

Figure 4: HMA production impacts on MAETP impact category

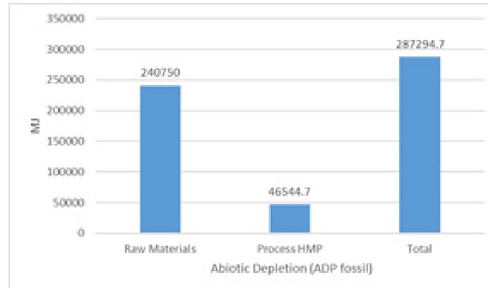

Figure 5: HMA production impacts on ADP fossil impact category

The HMA production had significant environmental impacts on HTP impact category (337 kg DCB eq.) mostly due to use of bitumen as raw material during production of HMA (Fig. 7).

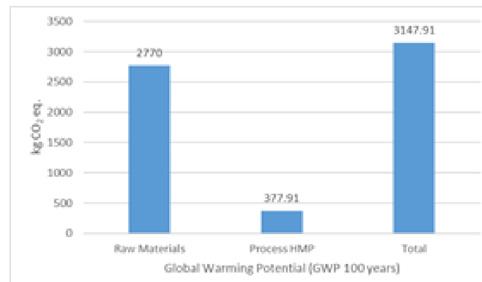

Figure 6: HMA production impacts on GWP impact category

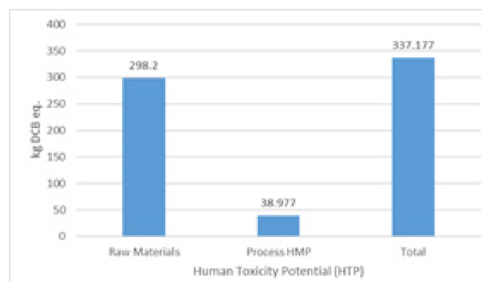

Figure 7: HMA production impacts on HTP impact category

The HMA production had very less environmental impacts on FAETP, AP, TETP and POCP impact categories shown in Figs. 8-11.

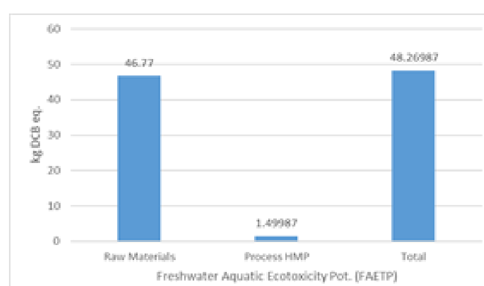

Figure 8: HMA production impacts on FAETP impact category

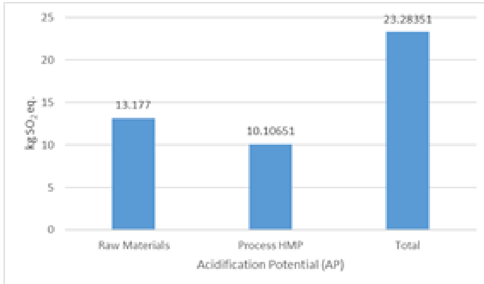

Figure 9: HMA production impacts on AP impact category

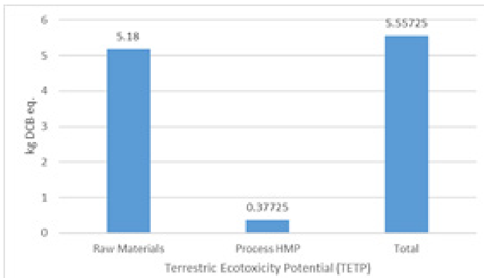

Figure 10: HMA production impacts on TETP impact category

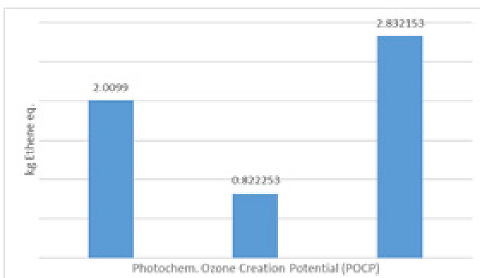

Figure 11: HMA production impacts on POCP impact category

The results showed that the HMA production phase has negligible environmental impacts on EP, ADP elements and ODP impact category and is shown in Figs. 12-14.

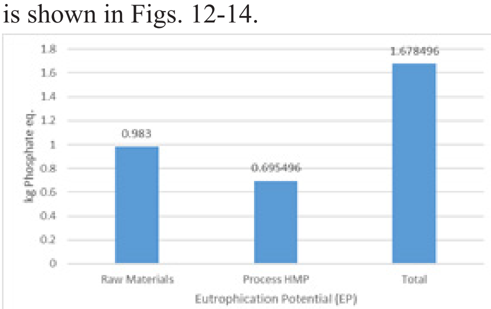

Figure 12: HMA production impacts on EP impact category

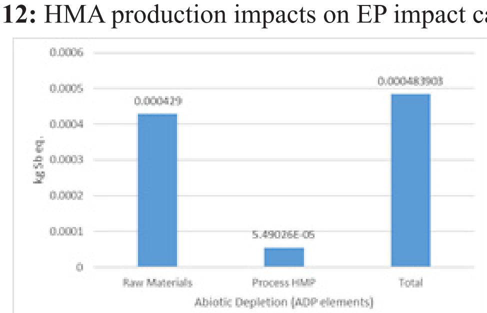

Figure 13: HMA production impacts on ADP elements impact category

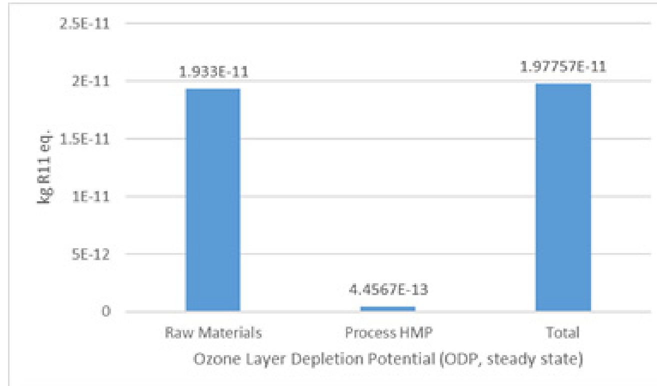

Figure 14: HMA production impacts on ODP impact category

Conclusions

From the present study, it can be concluded that the HMA production in batch type HMP has very high environmental impacts on the 3 impact categories (ADP fossil, MAETP and GWP) out of 11 impact categories. These high environmental impacts could be mainly attributed to the raw material phase of HMA production. The processes performed in the batch HMP for production of HMA has significant but less compared to raw material phase on ADP fossil, MAETP and GWP impact categories. The use of renewable source of energy or fuel will reduce the environmental impacts and adoption of cold mix technology will also reduce the environmental impacts compared to hot mix technology.

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