

**LIFE CYCLE ENERGY AND ENVIRONMENTAL ASSESSMENT OF
WARM-MIXED ASPHALT (WMA)**

Suwimon Leedilok

A Thesis Submitted in Partial Fulfilment of the Requirements
for the Degree of Master of Science
The Petroleum and Petrochemical College, Chulalongkorn University
in Academic Partnership with
The University of Michigan, The University of Oklahoma,
Case Western Reserve University and Institut Français du Pétrole
2013

I2837177x


560979


Thesis Title: Life Cycle Energy and Environmental Assessment of Warm-mixed Asphalt (WMA)
By: Suwimon Leedilok
Program: Petrochemical Technology
Thesis Advisors: Asst. Prof. Pomthong Malakul
Dr. Thawach Chatchupong

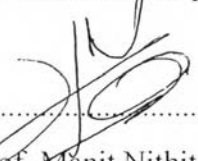
Accepted by the Petroleum and Petrochemical College, Chulalongkorn University, in partial fulfilment of the requirements for the Degree of Master of Science.

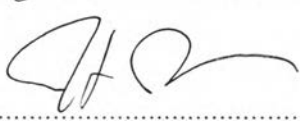

.....College Dean
(Asst. Prof. Pomthong Malakul)

Thesis Committee:


.....
(Asst. Prof. Pomthong Malakul)


.....
(Dr. Thawach Chatchupong)


.....
(Asst. Prof. Manit Nithitanakul)


.....
(Assoc. Prof. Thumrongrut Mungcharoen)

ABSTRACT

5471023063: Petrochemical Technology Program

Suwimon Leedilok: Life Cycle Environmental and Energy Assessment of Warm-mixed Asphalt (WMA)

Thesis Advisors: Asst. Prof. Pomthong Malakul and Dr. Thawach Chatchupong, 166 pp.

Keywords: Hot-mixed asphalt (HMA)/ Warm-mixed asphalt (WMA) / Life cycle assessment (LCA)

This study focused on evaluating the energy consumption and environmental performance of warm-mixed asphalt (WMA) technology as an alternative pavement to conventional hot-mixed asphalt (HMA) using life cycle assessment technique (LCA). The scope included data collection, analysis of energy and environmental impacts, and comparison between WMA and HMA. The system boundary covered provision of raw materials, asphalt production, transport, paving, maintenance, and disposal (demolition or recycling) based on a functional unit of 7 m x 1 km x 0.05 m road pavement. The data of asphalt production and pavement were collected from actual sites and compiled by using commercial LCA software, SimaPro 7.3. After that, a life cycle impact assessment (LCIA) was performed to evaluate the environmental impacts, focusing on global warming potential (GWP) and energy input. The results were compared with HMA based on the same functional units and also with results from other studies. The results of this study showed that GWP, represented by greenhouse gases (GHG) emissions, came mostly from raw materials and asphalt production with only a small contribution from the transportation and pavement process. When compared to HMA, the results showed that WMA had better performance in both GWP and energy aspects, but the benefits were not significant (<5%). It is expected that more environmental benefits can be achieved if the mixing temperature is further decreased. In comparison to other studies, the energy and environmental performance of HMA and WMA in Thailand is not as good as those observed in other countries. Finally, the end of life phase is obvious that recycling process helps reduce both energy input and GWP impact such that the more recycle leads to the better environment performance of asphalt.

บทคัดย่อ

สุวิมล หลีคิลิก : การประเมินผลกระทบต่อสิ่งแวดล้อมและพลังงานตลอดวัฏจักรชีวิตของแอสฟัลต์คอนกรีตแบบใช้ความร้อนต่ำ (Life Cycle Environmental and Energy Assessment of Warm-mixed Asphalt (WMA)) อ. ที่ปรึกษา: ผศ. ดร. ปมทอง มาลากุล ณ อยุธยา และ ดร. รัช นัตถบุหงส์ 166 หน้า

งานวิจัยนี้ทำการประเมินผลกระทบต่อสิ่งแวดล้อมและพลังงานของแอสฟัลต์คอนกรีตแบบใช้ความร้อนต่ำซึ่งพัฒนามาจากการใช้แอสฟัลต์คอนกรีตแบบใช้ความร้อนปกติแบบเดิม โดยใช้กระบวนการประเมินผลกระทบต่อสิ่งแวดล้อมในการวิเคราะห์ การศึกษานี้จะทำการเก็บข้อมูลจากโรงงานจริง วิเคราะห์ผลกระทบ นำแอสฟัลต์ทั้ง 2 อย่างมาเปรียบเทียบกันและเปรียบเทียบกับการศึกษาของต่างประเทศ ขอบเขตของการศึกษารอบคลุมตลอดวัฏจักรตั้งแต่วัตถุดิบ การผลิตแอสฟัลต์ การขนส่ง การปูถนน จนถึงการจัดและการนำกลับมาใช้ใหม่ของแอสฟัลต์คอนกรีต โดยการศึกษาครั้งนี้ มีหน่วยของการศึกษา คือถนนขนาดความกว้าง 7 เมตร ความยาว 1 กิโลเมตรและความหนา 5 เซนติเมตร ข้อมูลต่างๆ ที่เก็บรวบรวมจะถูกนำมาวิเคราะห์โดยใช้โปรแกรม SimaPro 7.3 ด้วยวิธี Eco-Indicator 95 และ CML baseline 2000 เพื่อประเมินภาระด้านสิ่งแวดล้อมด้านต่างๆ โดยเน้นที่ผลกระทบด้านภาวะโลกร้อนและพลังงานที่ใช้ จากผลการศึกษาในแบบ cradle-to-gate แสดงให้เห็นว่า ผลกระทบด้านภาวะโลกร้อนและพลังงานที่ใช้เกิดมาจากขั้นตอนการผลิตมากที่สุด ตามด้วยการขนส่งและการปูถนนที่มีเพียงเล็กน้อยเท่านั้น นอกจากนี้แอสฟัลต์คอนกรีตแบบใช้ความร้อนต่ำมีผลกระทบด้านภาวะโลกร้อนและพลังงานที่ใช้ในกระบวนการต่ำกว่าแอสฟัลต์คอนกรีตแบบใช้ความร้อนปกติแต่ต่ำกว่าไม่มาก ซึ่งคาดว่า การลดอุณหภูมิในการผลิตมากขึ้นจะช่วยลดผลกระทบต่อสิ่งแวดล้อมมากขึ้นด้วย นอกจากนี้เมื่อนำข้อมูลที่เก็บรวบรวมมาเปรียบเทียบกับการศึกษาของต่างประเทศพบว่าผลกระทบด้านภาวะโลกร้อนและพลังงานที่ใช้ของข้อมูลที่เก็บในประเทศไทยมีปริมาณมากกว่ามาก และเมื่อพิจารณาตลอดวัฏจักรชีวิต (cradle-to-grave) พบว่า การนำกลับมาใช้ใหม่ของแอสฟัลต์ส่งผลดีทางด้านภาวะโลกร้อนและพลังงานที่ใช้มากกว่าการฝังกลบ

ACKNOWLEDGEMENTS

This work would not have been possible without the assistance of the following individuals:

First and foremost, I sincerely appreciate Asst. Prof. Pomthong Malakul, my advisor, and Dr. Thawach Chatchupong, my co-advisor, for providing invaluable knowledge, creative comments, untouchable experience in classroom, and kind support throughout this research work.

I would like to thank Asst. Prof. Manit Nithitanakul and Assoc. Prof. Thumrongrut Mungcharoen for being my thesis committee. Their suggestions and comments are very beneficial for me and this work.

I also thank Mr. Sompit Petchprayul and Pharawee Wibul for your kind suggestion and kind support throughout this research work.

This thesis work is funded by the Petroleum and Petrochemical College and PTT Public Company Limited, Thailand

I greatly appreciate all PPC staffs and my friends who gave me support and encouragement.

Finally, I am deeply indebted to my family for their love, understanding, encouragement, and support for me at all time.

TABLE OF CONTENTS

	PAGE
Title Page	i
Abstract (in English)	iii
Abstract (in Thai)	iv
Acknowledgements	v
Table of Contents	vi
List of Tables	ix
List of Figures	x
CHAPTER	
I INTRODUCTION	1
II THEORETICAL BACKGROUND AND LITELATURE	
REVIEW	3
2.1 Asphalt	3
2.1.1 Definition	3
2.1.2 General Information	3
2.1.3 Application of asphalt	4
2.2 Hot-mixed asphalt	7
2.3 Warm-mixed asphalt	8
2.3.1 History of Warm-Mixed Asphalt	8
2.3.2 Benefits of Warm-Mixed Asphalt	9
2.3.3 Drawbacks of Warm-Mixed Asphalt	15
2.3.4 Warm-Mixed Asphalt Technologies	17
2.4 Life Cycle Assessment (LCA)	27
2.4.1 History of LCA	27
2.4.2 Definition of LCA	28
2.4.3 LCA Methodology	29
2.4.4 Application of LCA	37

CHAPTER	PAGE
2.5 LCA Studies of Warm-Mixed Asphalt	38
III METHODOLOGY	40
3.1 Materials and Equipment	40
3.1.1 Equipment	40
3.1.2 Software	40
3.2 Methodology	40
3.2.1 Preparation	40
3.2.2 Goal, Scope, Functional Unit, and System Boundary	41
3.2.3 Inventory Analysis	42
3.2.4 Impact Assessment	43
3.2.5 Interpretation	45
3.2.6 Assumptions and limitations	45
IV RESULTS AND DISCUSSION	47
4.1 Hot-Mixed Asphalt	47
4.1.1 Description Sites of Data Collection	47
4.2 Warm-Mixed Asphalt	88
4.2.1 Description Sites of Data Collection	88
4.3 Comparison Between of Hot-Mixed Asphalt and Warm-Mixed Asphalt	109
4.4 Energy and Environmental Benefits of Warm-Mixed Asphalt	112
V CONCLUSIONS AND RECOMMENDATIONS	
5.1 Conclusions	113
5.2 Recommendation	114
REFERENCES	116

APPENDICES	120
Appendix A Calculation	120
Appendix B Life Cycle Impact Assessment (LCIA)	125
CURRICULUMVITAE	167

LIST OF TABLES

TABLE	PAGE
2.1 Summary of WMA products description (Zaumanis, 2010)	25
3.1 Template of data collection for production of mixed asphalt	41
3.2 Source of data	43
3.3 Sources of data for calculation	44
4.1 Results of the inventory analysis of electricity for office	63
4.2 Results of the inventory analysis of electricity	64
4.3 Results of the inventory analysis of one ton asphalt concrete production	66
4.4 Emissions from transportation for asphalt binder	67
4.5 Emissions from transportation for aggregate	68
4.6 Emissions from transportation for fuel-oil	69
4.7 Emissions from transportation for hot-oil	70
4.8 Emissions from transportation for grease	71
4.9 Emissions from transportation for asphalt concrete	72
4.10 Emissions from transportation for water	73
4.11 Results of the inventory analysis of paving per one ton asphalt concrete production	74
4.12 Results of the inventory analysis of one ton asphalt concrete Production	75
4.13 Results of the inventory analysis of landfill based on one ton of asphalt waste	76
4.14 Results of the inventory analysis of recycling scenario based on one ton of asphalt waste	76
4.15 Representative specific heats of asphalt component	99
4.16 Emission Reduction	101
4.17 Results of the inventory analysis of one ton WMA production	101

LIST OF FIGURES

FIGURE	PAGE
2.1 The cross section of the road	5
2.2 Prime coat	6
2.3 Tack coat	6
2.4 Laying and Steel wheeled Tandem roller compaction	7
2.5 Typical temperature ranges for mixes, from cold mixes to conventional HMA	18
2.6 SETAC triangle (Klöpffer, 1997)	30
2.7 General methodological framework of LCA	31
3.1 System boundary of the LCA warm mix asphalt study	42
4.1 The team visited Thaiwat Engineering Co.,Ltd (Bangbuatong)	47
4.2 The hot-mixed asphalt production of Thaiwat Engineering Co.,Ltd (Bangbuatong)	48
4.3 Asphalt binders in storage tank	49
4.4 Asphalt binders bucket	49
4.5 Hot oil storage tank	49
4.6 Pouring aggregate and transporting inside	50
4.7 Cold aggregate tank and transporting to rotary dryer	50
4.8 Rotary dryer system and fuel oil storage	51
4.9 Trapping the dust and piling up of sediment	51
4.10 Pond of plant	52
4.11 Ridge of plant	52
4.12 Hot-mixed asphalt plant	53
4.13 Controlled room	54
4.14 Interview Supervisor	55
4.15 Interview Foreman	55
4.16 Truck for carrying asphalt concrete	56
4.17 Thermometer to measure temperature	56

FIGURE	PAGE
4.18 Asphalt concrete truck pour hot-mixed asphalt into paver	57
4.19 Equalize at edge joints	57
4.20 Steel drum rollers (DYNAPAC CS142)	58
4.21 Static pneumatic tired roller (SAKAI TS200)	59
4.22 Truck for carrying the water	59
4.23 Electricity bill	62
4.24 Analysis emission report	65
4.25 A Simple process diagram of asphalt production and usage	77
4.26 GHG emission of hot-mixed asphalt production for each unit process by CML 2 baseline 2000	78
4.27 Comparison of GWP of production process between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using CML 2 baseline 2000	79
4.28 Comparison of GWP of transportation between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using CML 2 baseline 2000	80
4.29 Comparison of GWP of paving process between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using CML 2 baseline 2000	81
4.30 GWP of 100%Recycle and 100%Landfill technologies based on 1 ton asphalt treated	82
4.31 Energy resources of hot-mixed asphalt production for each unit process by using Eco-Indicator 95 method	83
4.32 Comparison of energy resources of production process between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using Eco-Indicator 95 method	84
4.33 Comparison of energy resources of transportation between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using Eco-Indicator 95 method	85

FIGURE	PAGE
4.34 Comparison of energy resources of paving process between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using Eco-Indicator 95 method	86
4.35 Energy input per 1 ton asphalt concrete treated by 100%recycle and 100%landfill after service period.	87
4.36 The hot-mixed asphalt production of Thaiwat Engineering Co .,Ltd (Sriracha)	88
4.37 Asphalt binders in storage tank	89
4.38 Asphalt binders bucket	90
4.39 Hot oil storage tank	90
4.40 Cold aggregate tank and transporting to rotary dryer	91
4.41 Rotary dryer system and fuel oil storage	91
4.42 Trapping the dust and piling up of sediment	92
4.43 Hot-mixed asphalt plant	93
4.44 Controlled room	94
4.45 Asphalt concrete in paver	95
4.46 Equalize at edge joints	95
4.47 Steel drum rollers (DYNAPAC CC211)	96
4.48 Static pneumatic tried roller (SAKAI TS200)	96
4.49 GHG emission of warm-mixed asphalt production for each unit process by CML 2 baseline 2000	102
4.50 Comparison of GWP of production process between WMA from calculation and WMA_Butt (2012) by using CML 2 baseline 2000	103
4.51 Comparison of GWP of transportation between WMA from calculation and WMA_Butt (2012) by using CML 2 baseline 2000	104
4.52 Comparison of GWP of paving process between WMA from calculation and WMA_Butt (2012) by using CML 2 baseline 2000	105

FIGURE	PAGE
4.53 Comparison of energy resources of production process between WMA from calculation and WMA_Butt (2012) by using Eco-Indicator 95 method	106
4.54 Comparison of energy resources of transportation between WMA from calculation and WMA_Butt (2012) by using Eco-Indicator 95 method	107
4.55 Comparison of energy resources of paving process between WMA from calculation and WMA_Butt (2012) by using Eco-Indicator 95 method	108
4.56 Comparison of GWP between HMA from Bangbuatong plant and WMA from calculation by CML 2 baseline 2000	109
4.57 Comparison of energy resource between HMA from bangbuatong plant and WMA from calculation by using Eco-Indicator 95 method	110
4.58 Comparison of GWP between HMA from Bangbuatong plant, WMA from calculation and other studies by CML 2 baseline 2000	111
4.59 Comparison of energy resource between HMA from bangbuatong plant ,WMA from calculation and other studies by using Eco-Indicator 95 method	111