

**THE ENVIRONMENTAL EFFECT ON THE COOLING RATE OF HOT MIX
ASPHALT PAVEMENT**

WARDATI BINTI HASHIM

**A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil-Transport & Highway)**

**Faculty of Civil Engineering
Universiti Teknologi Malaysia**

MAY 2008

**THE ENVIRONMENTAL EFFECT ON THE COOLING RATE OF HOT MIX
ASPHALT PAVEMENT**

WARDATI BINTI HASHIM

**A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil-Transport & Highway)**

**Faculty of Civil Engineering
Universiti Teknologi Malaysia**

MAY 2008

ABSTRAK

Permintaan tinggi terhadap jalan berturap asfalt yang baru menyebabkan kerja-kerja penurapan terpaksa dilaksanakan dalam keadaan yang tidak bersesuaian seperti suhu persekitaran yang rendah, tahap kelajuan angin yang tinggi atau kerja-kerja turapan pada waktu malam yang akan mempengaruhi kadar penyejukan campuran panas asfalt seterusnya memberi kesan terhadap tempoh pemadatan. Kadar penyejukan yang tinggi akan mengurangkan tempoh pemadatan. Di Malaysia, kawalan tempoh masa pemadatan yang digunakan hanyalah berdasarkan had suhu antara penghantaran dan penghamparan sesuatu campuran panas asfalt tersebut. Tiada sebarang penentuan terhadap kawalan masa pemadatan, khususnya yang berkaitan dengan kesan keadaan setempat. Oleh yang sedemikian, kajian ini dilaksanakan dengan objektif untuk menilai kesan persekitaran terhadap kadar penyejukan campuran panas asfalt serta dengan sasaran untuk menentukan tempoh pemadatan yang bersesuaian. Kajian dijalankan dengan melaksanakan ujian-ujian makmal dimana ia melibatkan parameter ujian seperti cahaya matahari, suhu sekitar dan tapak (perbandingan kesan pembinaan sewaktu malam dan siang) serta variasi kelajuan angin. Ujian akan dilaksanakan dengan memfokuskan kepada campuran jenis ACW 14 bagi lapisan haus dan jenis ACB 28 bagi lapisan pengikat. Sampel dibancuh dalam acuan berbentuk empat segi dan dipadatkan menggunakan penggelek besi. Bacaan suhu diambil pada bahagian tengah dan permukaan sampel. Suhu bancuhan adalah berdasarkan spesifikasi JKR. Sampel kawalan disediakan bagi setiap jenis campuran untuk tujuan perbandingan dengan sample ujian dan ia diuji di makmal tanpa sebarang kesan angin dan cahaya matahari. Daripada keputusan yang didapati, dapat dirumuskan bahawa kadar penyejukan campuran asfalt panas adalah sangat dipengaruhi oleh kesan persekitaran seterusnya memberi kesan kepada tempoh pemadatan. Apabila dibandingkan dengan sampel kawalan, tempoh pemadatan sampel ujian menurun antara 15-50% ketika keadaan berangin dan malam manakala meningkat sehingga 100% ketika keadaan siang.

ABSTRACT

High demand for new asphalt pavements often requires that paving be done in an unfavorable condition such as low air temperatures, high speed winds, and night construction that will influence the cooling rate thus affecting the Time Available for Compaction (TAC). Higher cooling rate will reduce the TAC. In local practice, the asphalt paving compaction control mechanisms quoted from the locally used specifications are normally based on the limits of the delivery and laying completion temperatures. There are no items to predict these control elements and to be specifically related to the local conditions. This study was carried out with objective to investigate the environmental effect on cooling rate, aiming to determine the appropriate Time Available for Compaction (TAC) using laboratory tests which include the study parameter; solar flux, base and ambient temperature (daytime and night paving) and wind velocity focusing at HMA ACW 14 of mix type for wearing course and ACB 28 of mix type for binder course. Samples were prepared in slab mold, compacted using manually operated steel roller. Temperature measurements were taken from slabs at middle and surface position. Temperature of mixing was based on JKR specification. A controlled sample was prepared for each mix type, tested in the laboratory without any wind velocity and solar flux effect. Based on the result obtained, it can be concluded that the cooling rate of HMA is significantly affected by the environmental factor thus influencing the TAC. The TAC tend to decrease by 15-50% during windy and night condition while increase up to 100% during daytime condition.

CONTENTS

CHAPTER	TOPIC	PAGE
	DECLARATION OF THESIS	
	DECLARATION OF SUPERVISOR	
	TITLE	i
	DECLARATION OF STUDENT	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRAK	v
	ABSTRACT	vi
	CONTENTS	vii
	LIST OF TABLES	viii
	LIST OF FIGURES	ix
	LIST OF APPENDIXES	x
	LIST OF ABBREVIATIONS/SYMBOLS	xv
CHAPTER 1	INTRODUCTION	
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objective	3
	1.4 Aim	4
	1.5 Scope of Research	4
	1.6 Flow of Chapter	5

CHAPTER 2 LITERATURE REVIEW

2.1	Introduction	7
2.2	Hot Mix Asphalt (HMA)	8
2.2.1	Asphalt Cement	10
2.2.2	Aggregates and Fillers	11
2.3	Cooling Rate	12
2.3.1	Means of Heat Loss	14
2.3.2	Factor Affecting Cooling Rate	15
2.4	Environmental Factor	15
2.4.1	Wind Speed	16
2.4.2	Solar Flux	17
2.4.3	Ambient and Base Temperature	17
2.5	Compaction	18
2.5.1	Temperature Effect	20
2.5.2	Time Available for Compaction (TAC)	21
2.6	Conclusion	21

CHAPTER 3 METHODOLOGY

3.1	Introduction	23
3.2	Planning Stage	25
3.3.	Acquisition Stage	25
3.3.1	Laboratory Mix Property Test	28
3.3.1.1	Aggregates Gradation	29
3.3.1.2	Specific Gravity for Aggregates	29
3.3.1.3	Washed Sieve Analysis of Mineral Filler	30
3.3.1.4	Marshall Mix Design	30

3.3.1.5	Bituminous Binder	30
3.3.1.6	Theoretical Maximum Density (TMD)	31
3.3.1.7	Marshall Sample Preparation (Compacted Sample)	31
3.3.1.8	Bulk Specific Gravity	32
3.3.1.9	Voids Filled With Asphalt (VFA)	32
3.3.1.10	Voids in Total Mix (VTM)	33
3.3.1.11	Flow and Stability Test	33
3.3.1.12	Determination of Optimum Bitumen Content	34
3.3.2	Laboratory Test Procedure for Temperature Measurement	34
3.3.2.1	Test Apparatus	35
3.3.2.2	Determination of Sample Weight	35
3.3.2.3	Aggregates Gradation	36
3.3.2.4	Test Procedure	36
3.3.2.5	Test Parameter	37
3.4	Analysis Stage	38
3.5	Conclusion	39

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Introduction	40
4.2	Laboratory Marshall Mix Design	41
4.2.1	Aggregates Gradation	41
4.2.2	Washed Sieve Analysis	44
4.2.3	Specific Gravity	44
4.2.4	Asphalt	45
4.2.5	Marshall Sample	45

4.2.6	Determination of Optimum Bitumen Content (OBC)	46
4.2.7	Theoretical Maximum Density (TMD)	46
4.3	Cooling Time	47
4.3.1	Sample Weight Determination	47
4.3.2	Aggregates Gradation	48
4.3.3	Cooling Rate (°C/min)	49
4.3.4	Time Available for Compaction (TAC)	51
4.3.4.1	Wind Speed Effect	52
4.3.4.2	Paving Time (Daytime)	55
4.3.4.3	Paving Time (Night Time)	57
4.3.4.5	Difference in TAC	58
 CHAPTER 5 CONCLUSION AND RECOMMENDATION		
5.1	Introduction	61
5.2	Conclusion	62
5.3	Recommendation	64
 REFERENCES		66
 APPENDIX		69

LIST OF TABLES

TABLE NUM.	TITLE	PAGE
3.1	Design bitumen content	30
3.2	Matrix for laboratory test	38
4.1	Gradation limit for ACW 14	42
4.2	Gradation limit for ACB 28	43
4.3	Washed sieve analysis	44
4.4	Specific gravity of materials used	44
4.5	Volumetric properties for ACW 14 and ACB 28	45
4.6	TMD for ACW 14 and ACB 28	46
4.7	Sample weight	48
4.8	Cooling rate at 10 minutes interval in 30 minutes time	50
4.9	Sample distance for wind speed variables	52
4.10	TAC for each test	60

LIST OF FIGURES

FIGURE NUM.	TITLE	PAGE
1.1	Flow of chapter in the research	5
2.1	HMA pavement	9
2.2	Graph of viscosity versus temperature	10
2.3	Coarse aggregates	12
2.4	Fine aggregates	12
2.5	Graph of slab (HMA) temperature versus cooling time	13
2.6	How heat is lost from hot bituminous material as it is laid	14
2.7	Compaction at field using mechanical roller	19
2.8	Compaction process	20
3.1	Framework of study	24
3.2	Operational framework of laboratory work	27
3.3	Sample size	36
4.1	Gradation limit for ACW 14	42
4.2	Gradation limit for ACB 28	43
4.3	Example of scattered graph plotted for the determination of cooling rate ($^{\circ}\text{C}/\text{min}$)	49

4.4	Comparison of ACW 14 cooling time at various wind speed	53
4.5	Comparison of ACB 28 cooling time at various wind speed	54
4.6	Comparison of ACW 14 cooling time at various time of paving (daytime)	55
4.7	Comparison of ACB 28 cooling time at various time of paving (daytime)	56
4.8	Comparison of ACW 14 cooling time at various time of paving (night time)	57
4.9	Comparison of ACB 28 cooling time at various time of paving (night time)	58

LIST OF APPENDIXES

APPENDIX NUM.	TITLE	PAGE
A	Aggregate Size Distribution And Determination Of Filler	69
B	Wash Sieve Analysis And Specific Gravity For Aggregates	71
C	Marshall Test Result	73
D	Determination of OBC at 4% Air Void (NAPA) for ACW 14 and ACB 28	75
E	Theoretical Maximum Density	76
F	Aggregates Gradation for Cooling Rate Test	78
G	Temperature Recorded For ACW 14 Cooling Time at Affecting Test Parameter	80
H	Temperature Recorded For ACB 28 Cooling Time at Affecting Test Parameter	106
I	Process and Apparatus for Marshall Test	132
J	Process and Apparatus for Cooling Rate Test	135

LIST OF ABBREVIATIONS/SYMBOLS

ACW 14	- Asphaltic Concrete Wearing with Nominal Maximum Aggregate Size 14mm
ACB 28	- Asphaltic Concrete Binder with Nominal Maximum Aggregate Size 28mm
ASTM	- American Society for Testing and Materials
AASHTO	- American Association of State Highway and Transportation Officials
G_{mb}	- Bulk specific gravity of compacted mix
G_{sb}	- Combined bulk specific gravity of total aggregate
G_{mm}	- Theoretical maximum density
HMA	- Hot Mix Asphalt
NMAS	- Nominal Maximum Aggregate Size
NAPA	- National Asphalt Pavement Association
JKR	- Jabatan Kerja Raya
OBC	- Optimum Bitumen Content
SSD	- Saturated Surface Dry
TAC	- Time Available for Compaction
TMD	- Theoretical Maximum Density
VTM	- Voids in Total Mix
VMA	- Voids in Mineral Aggregate
VFB	- Voids Filled with Bitumen

CHAPTER 1

INTRODUCTION

1.1 Background

Hot Mix Asphalt (HMA) is one of the most often used material for road pavement. Usually being produced at the premix plant, HMA after spread onto the pavement surface, needed to be compacted to a specific range of density in order ensure that a stable and durable pavement is built (Brown, et.al. 2004).

HMA spread onto the road surface is most often freshly hot from the premix plant with the temperature around 140⁰C to 160⁰C (Roberts, et.al.1996) thus making the bitumen under liquid condition easily getting attached to those aggregates. Through the process of cooling in which the mix tends to lose heat, the previous temperature of HMA shall decrease within certain period of time until it becomes stable. This process will usually relate to the time available for compaction thus the compaction job should be done within the particular HMA cooling time to achieve desired density.

Rate of cooling is usually affected by various factors which include grading, lift thickness as well as environmental factor such as wind, sunlight thus making compaction process usually having inadequate time which results to less durable pavement.

1.2 Problem Statement

High demand for new asphalt pavements often requires that paving be done in unfavorable construction conditions. Low air temperatures, high winds, and night construction create adverse conditions for hot-mix asphalt paving. These conditions may occur at any time. This presents a risk for owners and contractors. According to Collins,et.al (2006), to achieve optimum load-bearing and weathering characteristics, an asphalt mix must be compacted to a specific range of density, and the time required for HMA to reach the proper compaction temperature to achieve this density decreases with an increased rate of cooling.

Hot-mix asphalt compaction is generally begun as soon as the mix can support the roller weight. The roller operator determines the best time to begin compaction by means such as judging the depth of a heel imprint. This method works well when the ambient temperature is high enough. However, low ambient temperatures, high wind speeds, and night construction increase the rate of heat loss from the mix (Newcomb, 1998). During these conditions, the ability to predict mix temperature is more critical because the Time Available Compaction (TAC) is decreased.

In local practice, the control mechanisms quoted from the locally used specifications are normally the acceptable limits of delivery and laying completion temperature. There are no items to predict these control elements and to be specifically related to the local conditions. Therefore, research is needed to validate these limits in order to be specifically related to the local conditions, i.e. material characteristics, environmental conditions and compaction mechanisms to suite locally environmental conditions.

Less research had been done on this topic as it includes lots of parameters to be tested. However, Jendia and Jerada (2005) research focusing on TAC and time opening traffic (TOT) and a research focusing on HMA thermal properties during construction (Chadbourn, et.al. 1996) can be referred to.

1.3 Objective

The objective of this research is to investigate the cooling rate of HMA affected by the environmental factor by conducting laboratory tests which will then indicate the TAC.

1.4 Aim

The research was carried out with the aim to determine the Time Available for the Compaction (TAC). This is supposed to lead to a better control during compaction process thus making a proposal of specifications to be used in the local industry related directly to the asphalt compaction procedures.

1.5 Scope of Research

The research focused on parameters tested to see the effect on the cooling rate of HMA. Those parameters included solar flux, base and ambient temperature (tested according to time of paving - daytime and night time) and wind velocity effect

Tests were conducted on two types of mix which were ACW 14 for wearing course of and ACB 28 for binder course. As the tests focused on the effect of environmental, the sample thickness was made constant which was 50mm for both types of mix.

1.6 Flow of Chapter

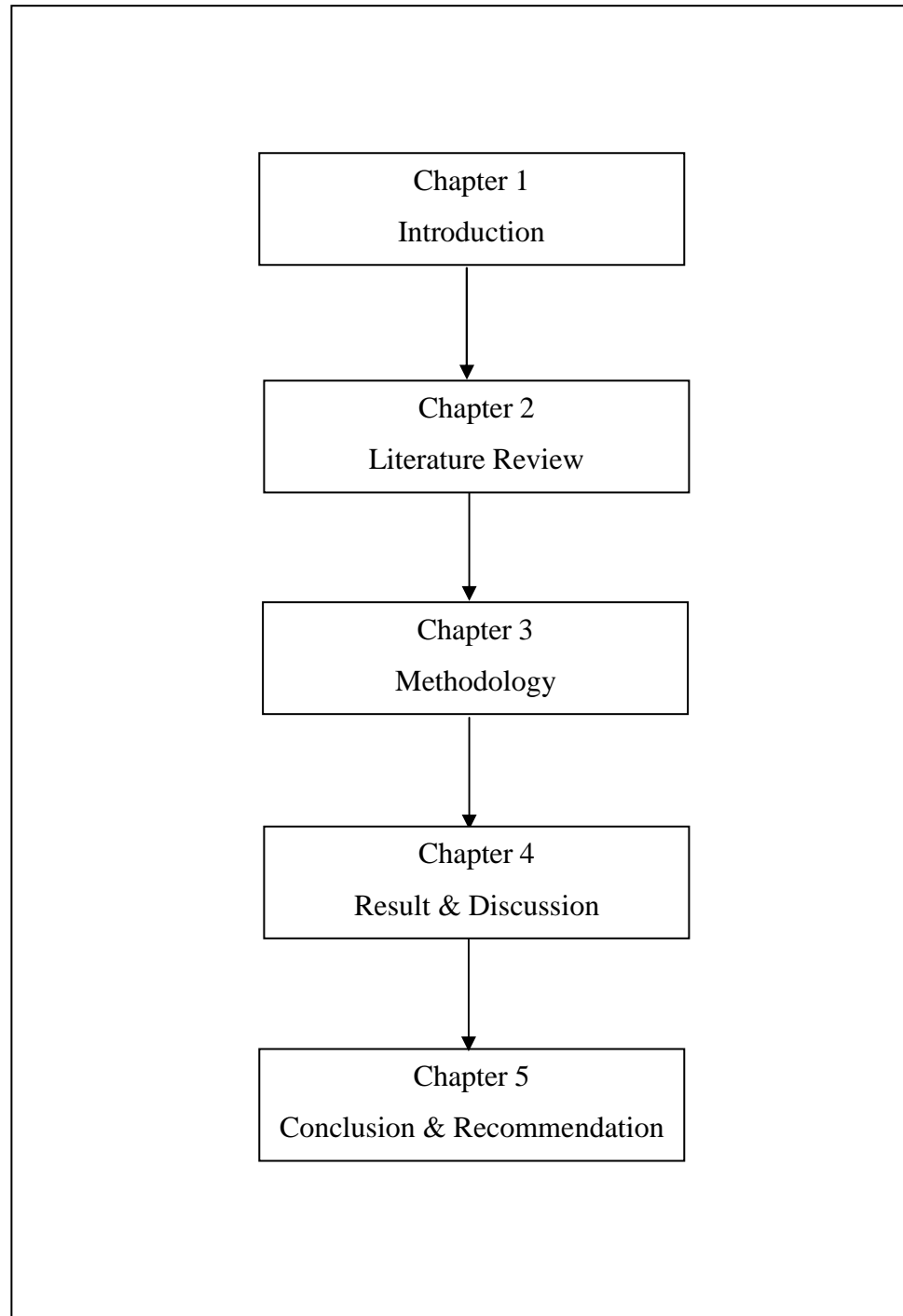


Figure 1.1: Flow of chapter in the research

Figure 1.1 shows the flow chapter involved in the research. Chapter 1 tells about the introduction to the research by discussing on some background related to the topic and explaining the problem statement which lead to the selection of research title, objective, aim and scope.

While in Chapter 2, literature review is done to give a preliminary view on the research being done as well as to create strategies for the research to be carried out. The literature review will refer to previous researches that were presented in a form of dissertation, working paper or journal. .

When it is done with the literature review, methodology is selected and explained in Chapter 3. Methodology functions as a necessity in acquiring data of research. As for this research, data are acquired from the laboratory test and the result will then be explained and discussed in Chapter 4. Result will base on analysis being carried out, referring to the theories which have been set up.

Finally, conclusion and recommendation is discussed in Chapter 5. In this chapter, explanation is done on whether the research complies to the objectives and theories. It may conclude on how the result of the research might affect the way paving process being carried out in the industry. Furthermore, recommendations are given out for any upcoming reserach related to the topic.

REFERENCES

- American Society for Testing and Materials. (1992). *Standard Method for Sieve Analysis for Fine and Coarse Aggregate*. Philadelphia, ASTM C 136.
- American Society for Testing and Materials. (1992). *Standard Test Method for Materials Finer than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing*. Philadelphia, ASTM C 117.
- American Society for Testing and Materials. (1992). *Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate*. Philadelphia, ASTM C 127.
- American Society for Testing and Materials. (1992). *Standard Test Method for Specific Gravity and Absorption of Fine Aggregate*. Philadelphia, ASTM C 128.
- American Society for Testing and Materials. (1992). *Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens*. Philadelphia, ASTM D 2726.
- American Society for Testing and Materials. (1992). *Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures*. Philadelphia, ASTM D 2041.
- American Society for Testing and Materials. (1992). *Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus*. Philadelphia, ASTM D 1559.

- American Society for Testing and Materials. (1992). *Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures*. Philadelphia, ASTM D 3203.
- Baeur, E.E. (1932). *Highway Materials*. Illinois, USA
- Brown, R.E., Hainin, M.R., Cooley, A., Hurley, G. (2004). *Relationship of Air Voids, Lift Thickness, and Permeability in Hot Mix Asphalt Pavement*. National Cooperative Highway Research Program. Report 531.
- Bouldin, M.G. (2002). *Gilsonite Modified Hard Pen Binder Study*. American Gilsonite Company
- Chadbourn, B.A., Desombre, R.A., Newcomb, D.E., Luoma, J.A, Voller, V.R. and Timm, D.H. (1998). *An Asphalt Paving Tool for Adverse Condition*. Minnesota Department of Transportation. Final Report 1998-18.
- Collins, P., Masson, J.F., Al-Qadi, I.L. (2006). *Cooling Rates In Hot-Poured Bituminous Sealants*. 85th Annual Meeting of the Transportation Research Board, Washington, D.C., Paper #06-0757.
- Deddens, T.K., Hinrichsen, J., and McDaniel, R. (1999). *Hot Mix Asphalt (HMA) Technician Training Manual*. FHWA Multi-Regional Asphalt Training and Certification Group
- Fwa, T F. Low, B H. Tan, S A. (1995). *Laboratory Determination of Thermal Properties of Asphalt Mixtures by Transient Heat Conduction Metho*. Transportation Research Record, No. 1492, Jul 1995, pp. 118-128.
- Hunter, R.N. (2000). *Asphalt in Road Construction*. London.

- Hunter, R.N. (1986). *Cooling of Bituminous Material During Laying*. Journal of The Institute of Asphalt Technology. 38. 19-26
- Jabatan Kerja Raya (JKR) (2005). *Standard Specifications for Road Works*. Kuala Lumpur, Malaysia, JKR/SPJ/rev2005.
- Jendia, S. and Jarada, A. (2005). *Traffic Opening Time And Time Available For Compaction For Fresh Asphalt Layer Using Slab Specimens Model*. The Islamic University Journal (Series of Natural Studies and Engineering). Vol.14, No.1, P.11-35, 2006, ISSN 1726-6807.
- Kari, W.J. (1967). *Mix Properties as They Affect Compaction*. Asphalt Paving Technology Proceedings: Association of Asphalt Paving Technologists Technical Sessions, Vol. 36, pp. 295-309.
- Lavin, P. (2003). *Asphalt Pavement: A Practical Guide To Design, Production, and Maintenance For Engineers and Architects*. London. New York.
- McGuire, G.R. and Hunter, R.N. (1988). Are Texture and Density in Hot Rolled asphalt Wearing Course Compatible? Journal of The Institute of Asphalt Technology, 40, 29-31.
- Newcomb, D.E., Chadbourn, B.A., Luoma, J.A. and Voller, V.R. (1996). *Consideration of Hot-Mix Asphalt Thermal Properties During Compaction*. .
- O'Flaherty C., Highway Engineering Volume 2 (1988), London: Edvard Arnold
- Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y. and Kennedy, T.W. (1996). *Hot Mix Asphalt Materials, Mixture, Design and Construction*. NAPA Research and Education Foundation. Maryland, USA.