

**STANDARDIZATION OF FRICTION CORDS AND ITS  
APPLICATION IN RUBBER FORMULATION  
TECHNOLOGY**

Kuda Thantrige Pubuduni Madurika Ahugammana

(138251K)

Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree  
Master of Science

Department of Chemical Engineering

University of Moratuwa

Sri Lanka

July 2017

## DECLARATION

“I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Masters dissertation under my supervision.

Signature of the supervisor:

Date:

## **ACKNOWLEDGEMENTS**

It is with a great pleasure and gratitude that I acknowledge my supervisor, Dr. Olga Gunapala for giving me the correct guidance in spite of her busy schedule and tasks.

My special thanks goes to Dr. Shantha Egodage, course coordinator for her great encouragement by giving us a good guidelines on this dissertation.

My sincere thanks to the staff of the polymer processing laboratory and the physical testing laboratory of the chemical and process engineering department in University of Moratuwa.

Board of directors of US Lanka Rubber Solutions Private Limited, Seeduwa in Sri Lanka for their permission to carry out this reaserch.

The staff of the Research and Development Department at US Lanka Rubber Solutions Private Limited for their support in conducting this research.

Mr. Kishan Jayawardena from Samjay and Sons, LLC, Ohio in USA for proving me the required information for this research.

My special gratitude and thanks to my parents and all those who helped and encouraged me in numerous ways.

## Abstract

Dramatic growth in both the use and manufacturing of pneumatic tires including car, bus, truck and airplane tires have led to the accumulation of calendering scraps referred to as unvulcanized rubber friction in junkyards where they pose a fire threat and breeding sites for animals including rodents and insects spreading various diseases. These scraps appeared in bulky nature were subjected to a size reduction process in order to produce friction cords. Since calender scraps cannot undergo natural degradation, piling up of them causes definitely a huge environmental problem. Environment is benefited greatly by reusing these materials as friction cords. Additionally, rubber products manufacturers use friction cords in blends by incorporating them into their rubber compounds. Friction cords are manufactured from leftover materials and as a result they are definitely a cheap product at the market. This results in lowering the final cost of products manufactured by blending friction cords. Six samples of friction cords collected from each bulky material were tested for basic physical properties including specific gravity, hardness, tensile strength, elongation at break, moisture content and rheological properties such as  $t_{s2}$ ,  $t_{c90}$ ,  $M_L$  and  $M_H$ . Results obtained showed that each and every property of each bulky material varied and that variation occurred from one material to the other. Therefore the main objective of this study was to standardize friction cords by physically mixing one material with the other in different weight proportions. Results obtained for each blend/mixer showed that all tested properties including specific gravity, hardness, tensile strength, elongation at break and moisture content could be controlled within the required range and it was concluded that friction cords can be standardized by mixing them at different weight ratios. In addition, variation in rheological, physical and mechanical properties of fiber filled rubber compounds were studied by replacing nylon flocks partially and completely with friction cords. Results obtained showed that minimum torque, scorch time ( $t_{10}$ ), optimum cure time ( $t_{c90}$ ) decreased with the addition of increased quantity of friction cords. However, maximum torque increased with increased loading of friction cords. There was no significant change in specific gravity and elongation at break. But hardness modulus at 100 % elongation, tensile strength gradually increased with the addition of friction cords.

Keywords:

Friction cords, short fibers, standardization, rheological, physical and mechanical properties

## TABLE OF CONTENTS

Declaration of the candidate & supervisor	i
Acknowledgements	ii
Abstract	iii
Table of contents	iv
List of Figures	v
List of Tables	vii
1. Introduction	1
2. Objective	3
3. Literature Review	4
4. Experimental	35
5. Results and Discussion	49
6. Conclusion	93
References List	95

## LIST OF FIGURES

	Page	
Figure 1.0	Defects on calendar sheets	6
Figure 1.1	Calendered scraps	9
Figure 1.2	Impurities on bulky raw materials	11
Figure 1.3	Cutting raw materials into large pieces	12
Figure 1.4	Cutting large pieces of raw materials into small pieces	13
Figure 1.5	Cutting small pieces of raw materials into FRC granules	13
Figure 1.6	Granulator screen	14
Figure 1.7	Packing of FRC	15
Figure 1.8	Process flow chart	16
Figure 1.9	Rubberized nylon friction	17
Figure 2.0	Rubberized Kevlar friction	18
Figure 2.1	Rubberized steel friction	19
Figure 2.2	Chemical structure of rayon	23
Figure 2.3	Chemical structures of nylons	24
Figure 2.4	Chemical structure of polyester	25
Figure 2.5	Chemical structure of p-Aramid fiber	26
Figure 2.6	Processing of material, R <sub>1</sub>	37
Figure 2.7	Initial test piece	42
Figure 2.8	Separated fiber and rubber portions	43
Figure 2.9	Test specimen for measuring specific gravity	44
Figure 3.0	Dimensions of dumbbell test piece	45
Figure 3.1	Average values of specific gravities of R <sub>1</sub> -R <sub>8</sub> with fiber content	56
Figure 3.2	Average values of hardness of R <sub>1</sub> -R <sub>8</sub> with fiber content	58
Figure 3.3	Average values of tensile strength of R <sub>1</sub> -R <sub>8</sub> with fiber content	59
Figure 3.4	Average values of elongation at break of R <sub>1</sub> -R <sub>8</sub> with fiber content	60
Figure 3.5	Average values of moisture content of R <sub>1</sub> -R <sub>8</sub> with fiber content	62
Figure 3.6	Average values of t <sub>s2</sub> and t <sub>c90</sub> of R <sub>1</sub> -R <sub>8</sub> with fiber content	63
Figure 3.7	Average values of M <sub>L</sub> of R <sub>1</sub> -R <sub>8</sub> with fiber content	64

	Page
Figure 3.8	Average values of $M_H$ with average hardness values of $R_1$ - $R_8$ 65
Figure 3.9	Average specific gravities of blends (No: 1- No: 5) with weight of $R_2$ sample 68
Figure 4.0	Average hardness of blends (No: 1-No: 5) with weight of $R_2$ Sample 69
Figure 4.1	Average tensile strength of blends (No: 1-No: 5) with weight of $R_2$ sample 70
Figure 4.2	Average elongation at break of blends (No: 1-No: 5) with weight of $R_2$ sample 71
Figure 4.3	Average moisture content of blends (No: 1-No: 5) with weight of $R_2$ sample 72
Figure 4.4	Average specific gravity of blends (No: 1 and No: 6-No: 9) with weight of $R_5$ sample 75
Figure 4.5	Average hardness of blends (No: 1 and No: 6-No: 9) with weight of $R_5$ sample 76
Figure 4.6	Average tensile strength of blends (No: 1 and No: 6-No: 9) with weight of $R_5$ sample 77
Figure 4.7	Average elongation at break of blends (No: 1 and No: 6-No: 9) with weight of $R_5$ sample 78
Figure 4.8	Average moisture content of blends (No: 1 and No: 6-No: 9) with weight of $R_5$ sample 79
Figure 4.9	Specific gravity of blends with blend No 85
Figure 5.0	Hardness of blends with blend No 86
Figure 5.1	Tensile strength of blends with blend No 87
Figure 5.2	Elongation at break of blends with blend No 88
Figure 5.3	Moisture content of blends with blend No 89

## LIST OF TABLES

	Page	
Table 1.0	Preparation of blends (No: 1-No: 5)	38
Table 1.1	Preparation of blends (No: 6-No: 9)	39
Table 1.2	Preparation of blend No: 10	40
Table 1.3	Preparation of blends (No: 11-No: 14)	40
Table 1.4	Formulations of rubber compounds	41
Table 1.5	First stage mixing cycle for compounding in internal mixer	41
Table 1.6	Second stage mixing cycle for compounding in two roll mill	42
Table 1.7	Fiber contents of materials (R <sub>1</sub> -R <sub>8</sub> )	49
Table 1.8	Rheological properties of raw material, R <sub>1</sub>	50
Table 1.9	Physical properties of raw material, R <sub>1</sub>	50
Table 2.0	Rheological properties of raw material, R <sub>2</sub>	50
Table 2.1	Physical properties of raw material, R <sub>2</sub>	51
Table 2.2	Rheological properties of raw material, R <sub>3</sub>	51
Table 2.3	Physical properties of raw material, R <sub>3</sub>	51
Table 2.4	Rheological properties of raw material, R <sub>4</sub>	52
Table 2.5	Physical properties of raw material, R <sub>4</sub>	52
Table 2.6	Rheological properties of raw material, R <sub>5</sub>	52
Table 2.7	Physical properties of raw material, R <sub>5</sub>	53
Table 2.8	Rheological properties of raw material, R <sub>6</sub>	53
Table 2.9	Physical properties of raw material, R <sub>6</sub>	53
Table 3.0	Rheological properties of raw material, R <sub>7</sub>	54
Table 3.1	Physical properties of raw material, R <sub>7</sub>	54
Table 3.2	Rheological properties of raw material, R <sub>8</sub>	54
Table 3.3	Physical properties of raw material, R <sub>8</sub>	55
Table 3.4	Properties of blend No: 1	66
Table 3.5	Properties of blend No: 2	66



	Page	
Table 3.6	Properties of blend No: 3	67
Table 3.7	Properties of blend No: 4	67
Table 3.8	Properties of blend No: 5	67
Table 3.9	Properties of blend No: 6	73
Table 4.0	Properties of blend No: 7	74
Table 4.1	Properties of blend No: 8	74
Table 4.2	Properties of blend No: 9	74
Table 4.3	Properties of blend No: 10	80
Table 4.4	Properties of blend No: 11	82
Table 4.5	Properties of blend No: 12	83
Table 4.6	Properties of blend No: 13	83
Table 4.7	Properties of blend No: 14	83
Table 4.8	Specifications of FRC-1 for solid tire base layer	89
Table 4.9	Rheological characteristics of compounds filled with Friction cords	91
Table 5.0	Properties of compounds filled with friction cords	92