

Chapter 4

Results and Discussion

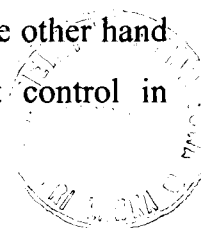
4.1 Processing characteristics

a) Plasticity

Table (4.1) : Plasticity of NR : EPDM blends

Sample No	Plasticity (WPN)
S-10:0	37
S-8:2	31
S-7:3	29
S-5:5	24
S-3:7	23
S-2:8	22
S-0:10	10

The figure (4.1) shows the plasticity values in WPN for various blends of NR & EPDM elastomers. Blends S-0:10 showed the highest wallace rapid plasticity number compared to the blends of NR-EPDM & lowest value of WPN was shown by blend S-10:0. High molecular weight distribution rubbers shows high plasticity values than low molecular weight distribution rubbers. NR has higher molecular weight distribution than the synthetic rubber EPDM. Therefore, Wallace rapid plasticity number increases gradually with increasing NR contents in the blends. In addition, EPDM is manufactured to fix plasticity values as desired by end users. It's tolerance level is narrow. On the other hand NR has highly variable initial plasticity value and need tight control in



mastication to achieve a compatible plasticity value to obtain a highly dispersed homogeneous blend.

Use of fatty acid, soap, tyre dispersing agent with controlled plasticities to achieve workable blends in NR/EPDM is well known.

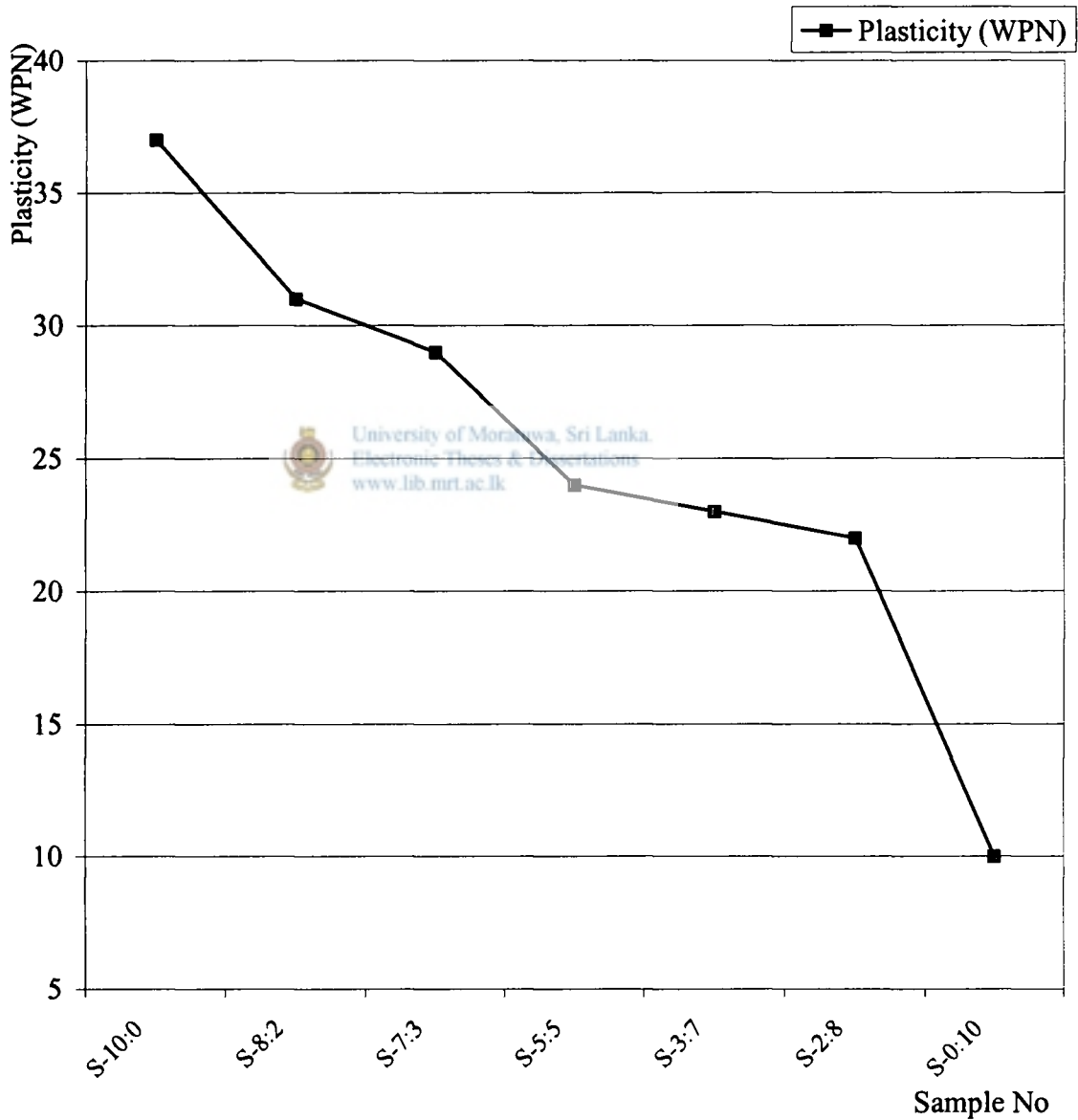


Figure (4.1) : Plasticity of NR : EPDM blends

b) Green tack

In this test, we could notice that the force required to separate each rubber sample increased gradually with increasing NR content of each blends.

Table (4.2) : Green tack of NR : EPDM blends

Sample No	Force (N)
S-10:0	High
S-8:2	Lower than high
S-7:3	Higher than medium
S-5:5	Medium
S-3:7	Lower than medium
S-2:8	Higher than low
S-0:10	Low

Lowest green tack was shown by blends S-0:10 and highest green tack was given by blend S-10:0. The real reason behind this phenomenon is yet to be scientifically proved but the complex molecular mix and structure of NR due to its impurities could be the cause.

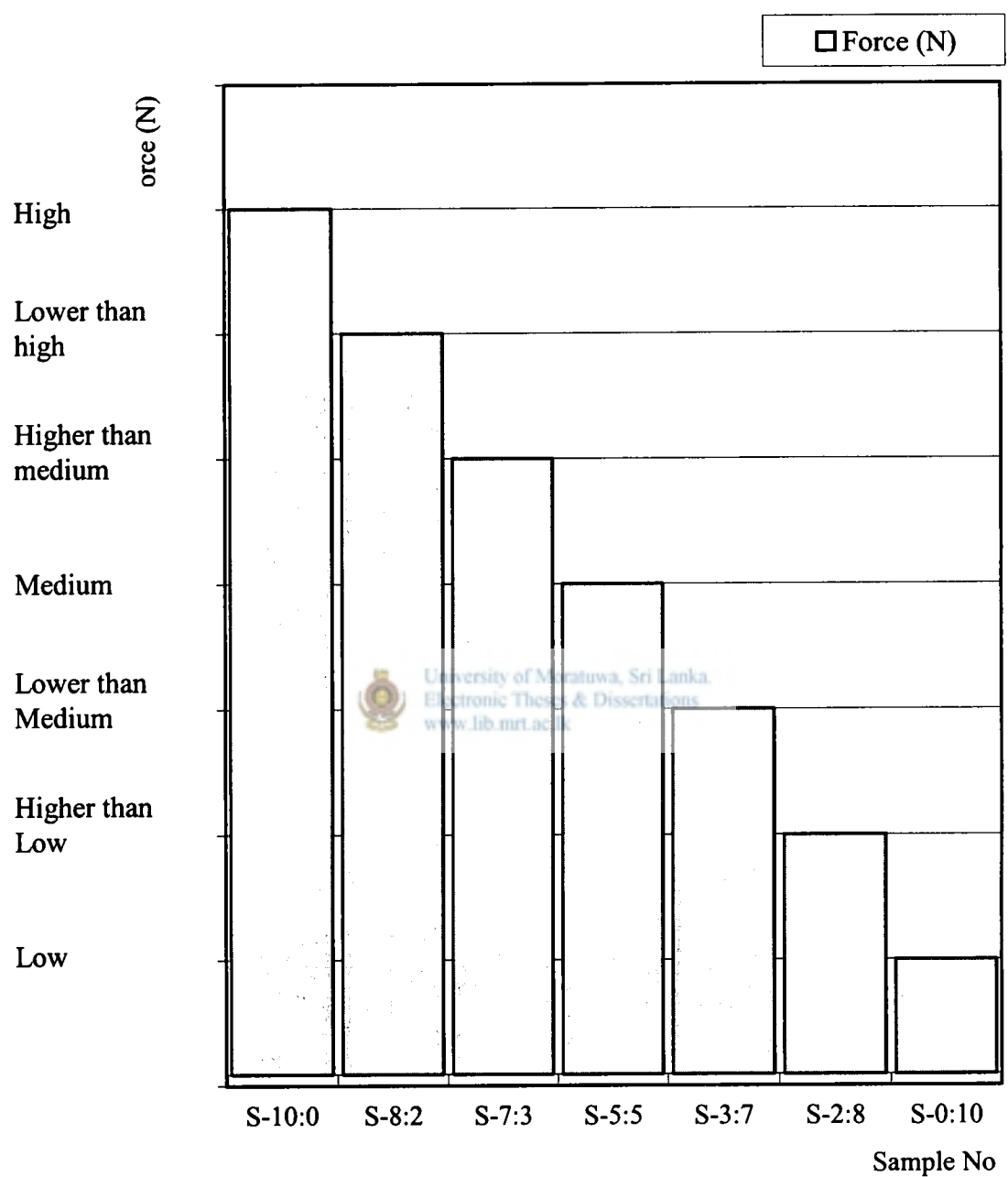


Figure (4.2): Green tack of NR : EPDM blends

c) **Cure characteristics**

Table (4.3) : Cure characteristics of NR : EPDM blends

Samples No.	T_{s2} (minutes)	T_{c90} (minutes)
S-10:0	0.54	4.31
S-8:2	1.6	3.1
S-7:3	1.14	3.8
S-5:5	1.21	3.55
S-3:7	1.4	8.14
S-2:8	1.5	9.37
S-0:10	3.48	12.1

 University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Blend S-10:0 indicates lower value of scorch time and blend S-0:10 shows the higher value of scorch time. Also, blend S-10:0 shows fast cure rate and S-0:10 shows slow cure rate. This is due to blend S-10:0 has high degree of unsaturation (Double bonds) and S-0:10 has lower degree of unsaturation. When increasing unsaturation rubber (Natural rubber) scorch time decreases and cure rate increases gradually.

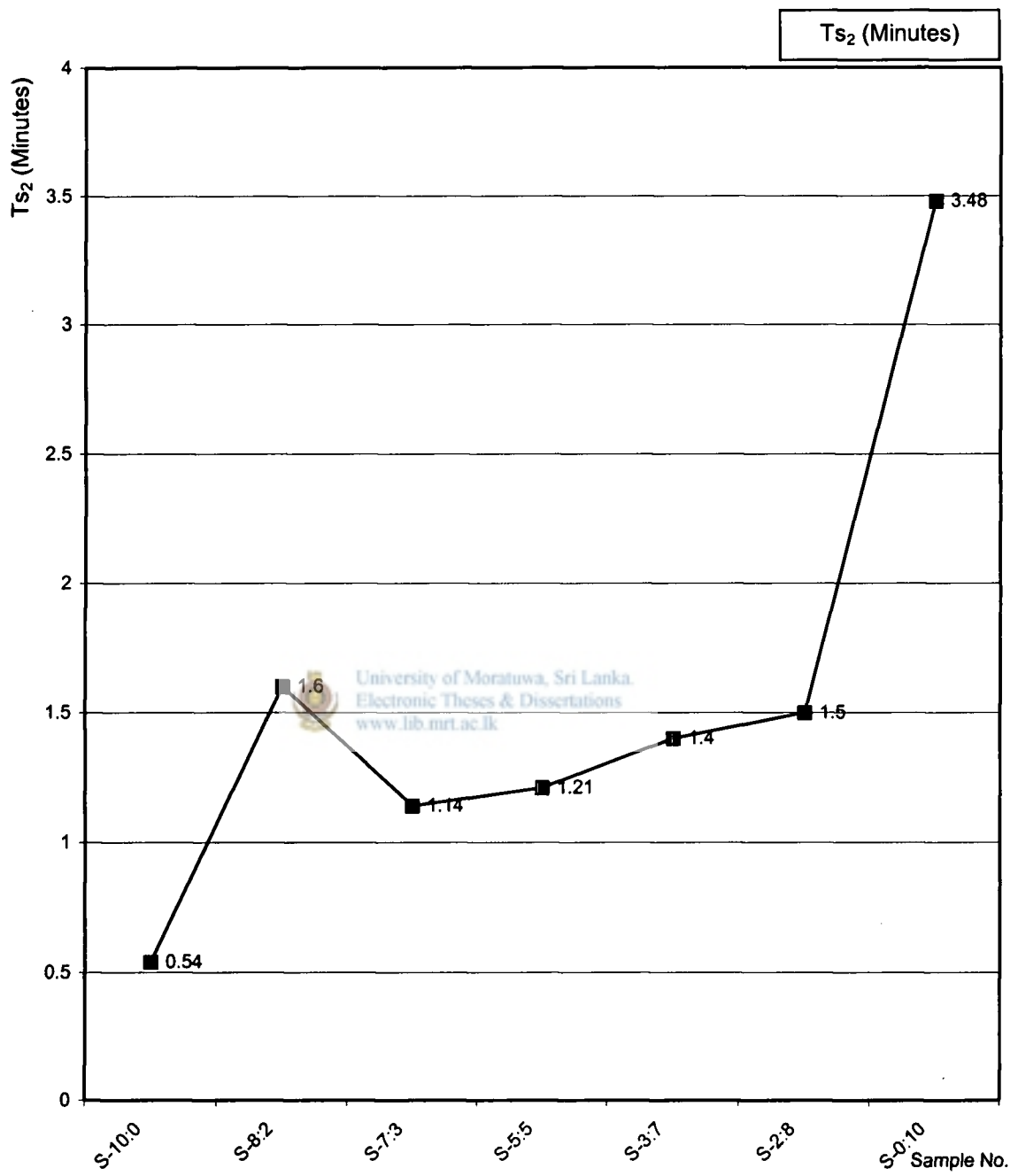


Figure (4.3a) : TS₂ of NR : EPDM blends

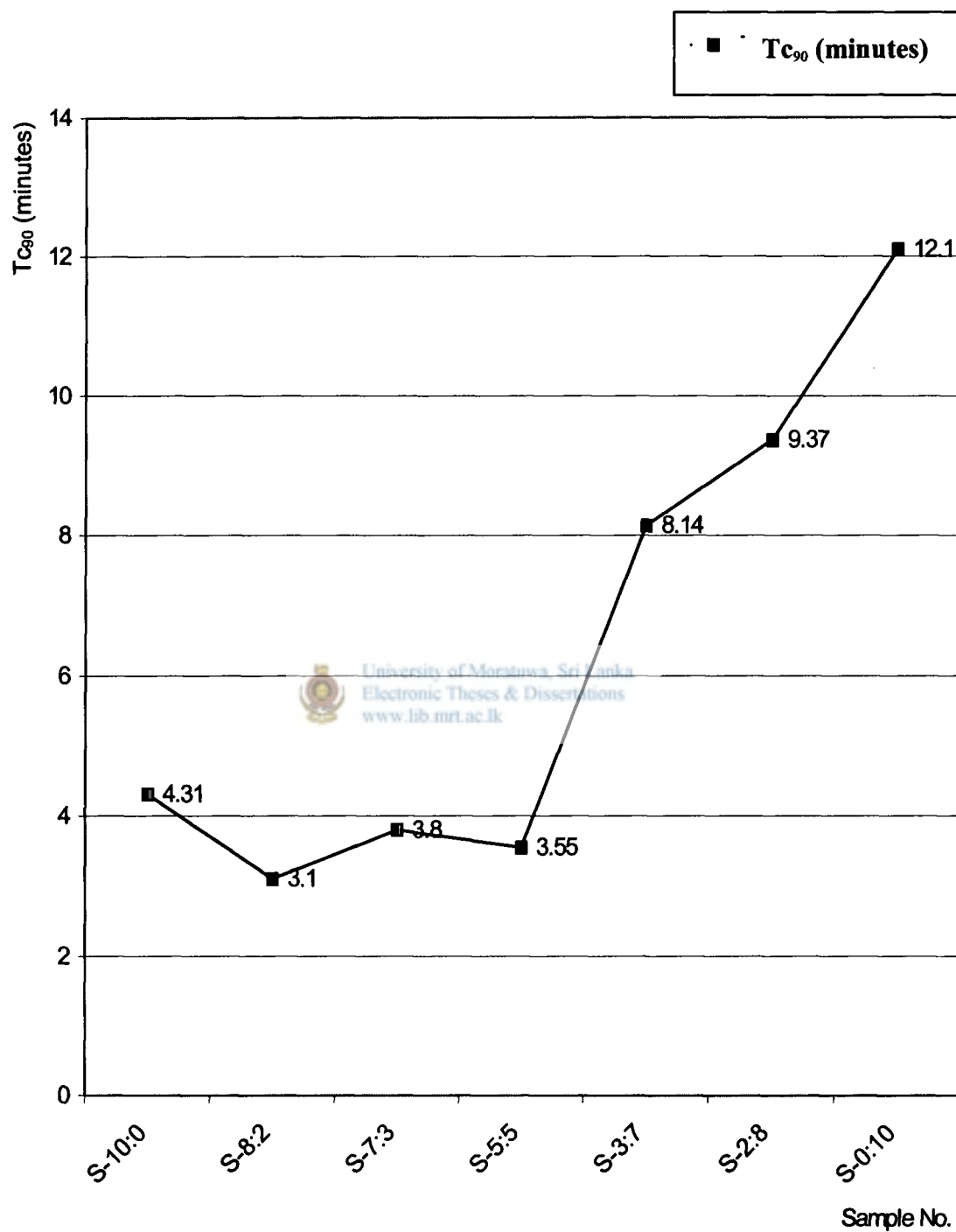
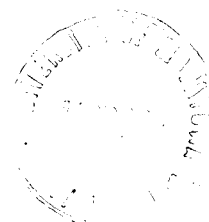


Figure (4.3b) : TC_{90} of NR : EPDM blends



4.2 Physical properties

a) Hardness

Table (4.4) : Hardness of NR : EPDM blends

Sample No	Hardness (JIS)
S-10:0	64
S-8:2	62
S-7:3	61
S-5:5	64
S-3:7	67
S-2:8	67
S-0:10	68

The figure (4.4) shows the variation of hardness of the vulcanizate of blends of NR and EPDM .In this case, highest hardness value was given by blend (S-0:10) due to high carbon black loading. High Carbon black loading can be done in to the EPDM than NR. Therefore , when increasing EPDM content, carbon black loading also increases and therefore, increases the hardness.

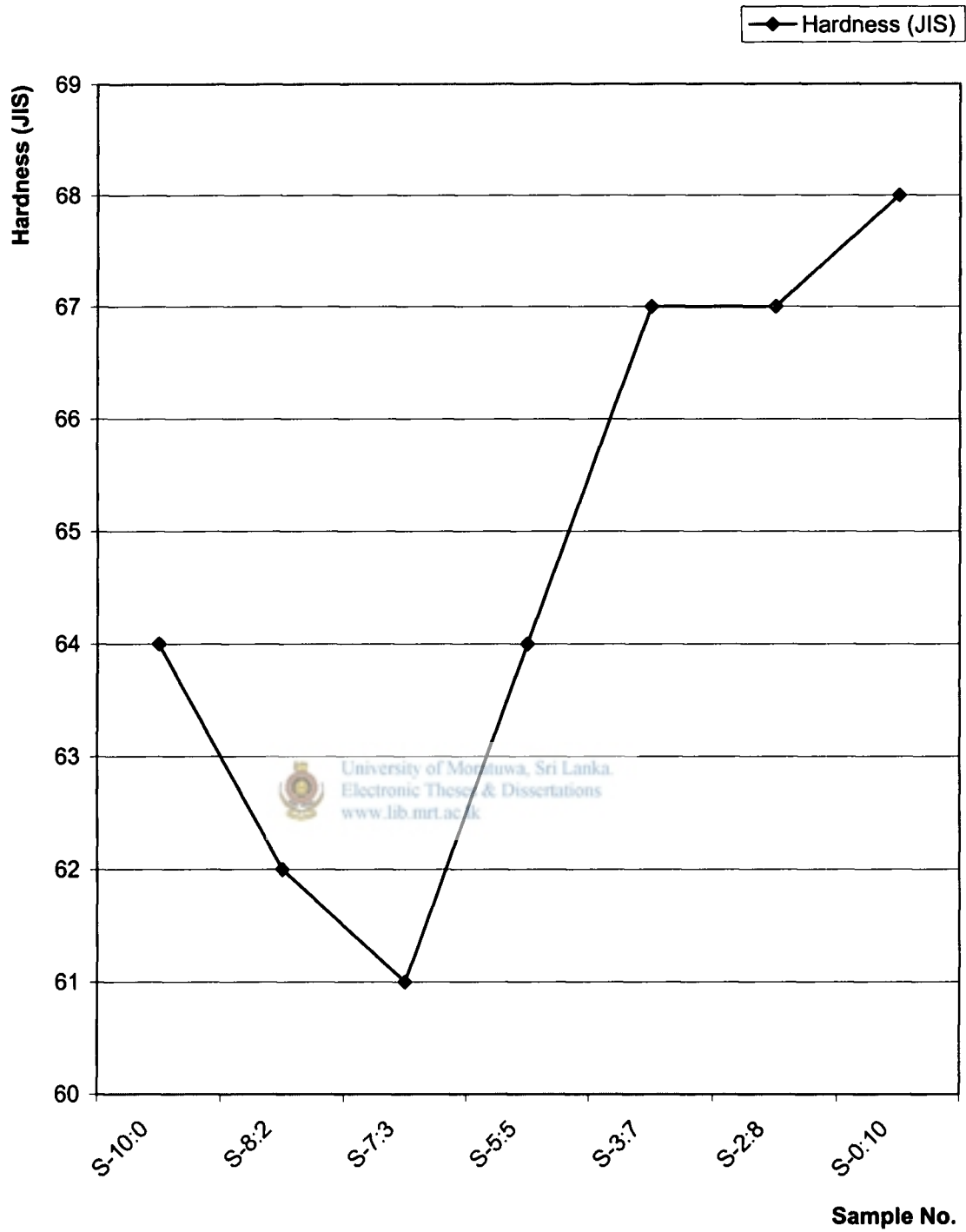


Figure (4.4) : Hardness of NR : EPDM blends

b) Flexing (Fatigue)

Table (4.5): Flexing of NR : EPDM blends

Sample No.	Flexing (kilo cycles)
S-10:0	483.12
S-8:2	273.75
S-7:3	368.8
S-5:5	40.5
S-3:7	18.7
S-2:8	58.5
S-0:10	72

In this case, highest flexing value was given by blend S-10:0 vulcanizates. Blend S-8:2 and blend S-7:3 vulcanizates also gave comparatively high flexing values. In general, the flexing of polymer vulcanizates increase with increasing unsaturation, since a more unsaturation polymer can produce more sulphur bonds. Also the vulcanizing system is conventional. Therefore, conventional vulcanizing system gives more polysulphidic sulphur bonds which lead to high blending or flexing property .In addition, NR molecules show the high rotation and segmental motion than EPDM and therefore, it shows the high flexing property. Blend-8:2 shows sudden decrease of flexing . This may be due to sample is not fully vulcanized during vulcanization or improper mixing of ingredients

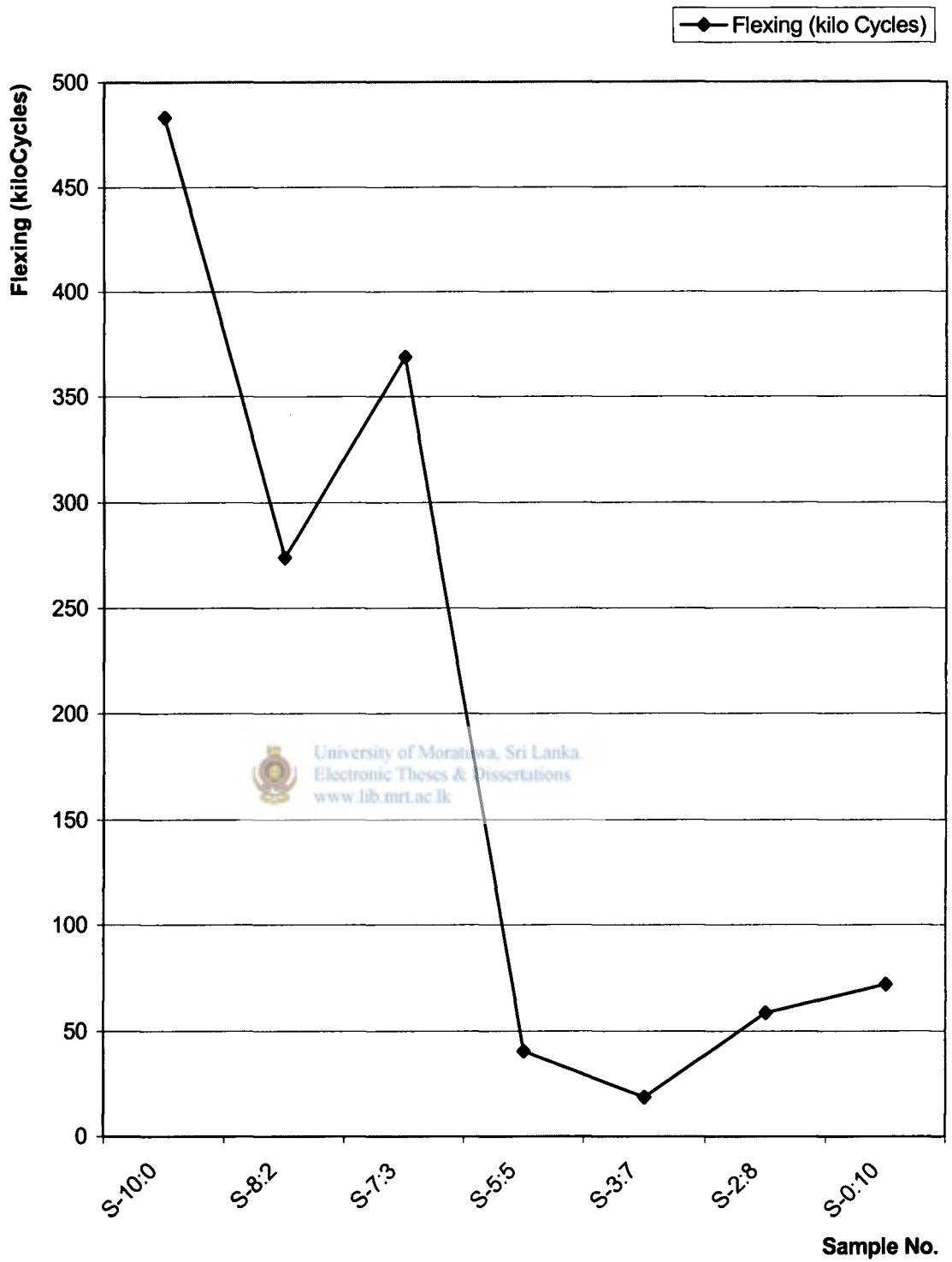
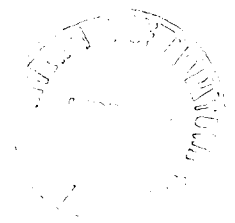


Figure (4.5): Flexing of NR : EPDM blends



c) Tensile Strength

Table (4.6): Tensile strength of NR : EPDM blends.

Sample No	Tensile Strength Mpa (Breaking load/ Area x 10.197)
S-10:0	19.1
S-8:2	14
S-7:3	13.1
S-5:5	6.2
S-3:7	6.2
S-2:8	6.8
S-0:10	7

The figure (4.6) shows the tensile relations for various blends of NR and EPDM under same conditions. The NR vulcanizate has the highest tensile strength compared to blend of NR and EPDM. This is due to its inherent property of strain induced crystallinity. Therefore, Tensile strength has decreased with increasing EPDM content of the blends of NR:EPDM. Also, blends S-8:2 and S-7:3 was shown comparatively higher tensile strength values than the other vulcanizates, but lower the mix S-10:0. Reason for this is disturbance of regular ordered arrangement of isoprene molecules of NR by EPDM molecules and therefore, shows low strain induced crystallinity.

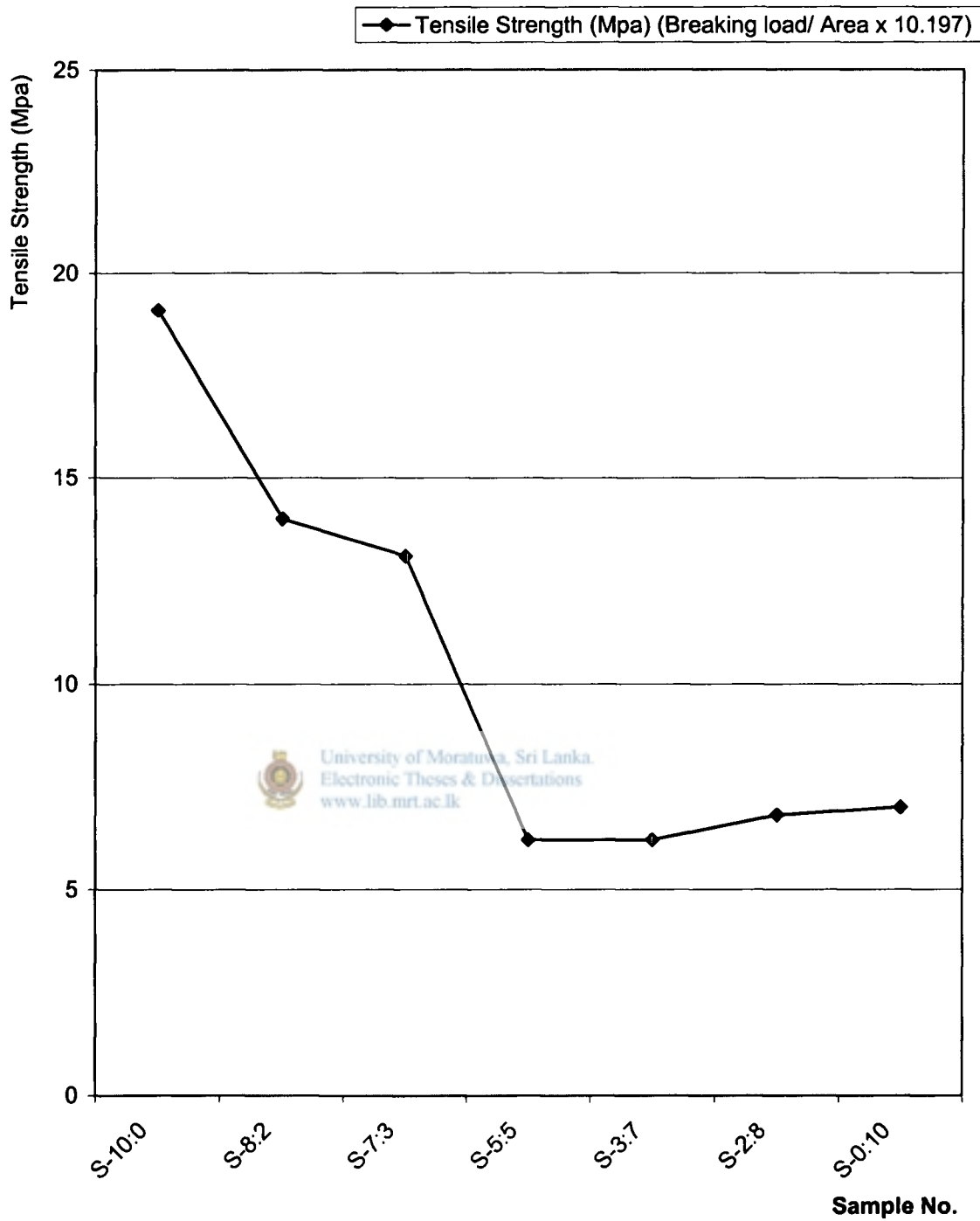


Figure (4.6) : Tensile strength of NR : EPDM blends

d) **Modulus at 300% elongation**

Table (4.7) : Modulus of NR :EPDM blends

Sample No	300% Modulus Mpa Load at 300% elongation/ Area x 10.197
S-10:0	3.2
S-8:2	3.0
S-7:3	2.7
S-5:5	3.1
S-3:7	3.1
S-2:8	3.2
S-0:10	3.4

The figure (4.7) shows the variation of modulus at 300% elongation of the vulcanizate of NR : EPDM blends . A gradual increase in modulus at 300% elongation was observed with increasing EPDM content of blends. This gradual increase of modules may be due to the decreasing of the number of isoprene units in polymer backbone as described under the section on tensile strength.

Sudden decrease of modulus of blend of (S-7:3) can not be explained only by looking at physical properties. Reasons for sudden decrease of modulus may be due to, test specimen may not be vulcanized properly or improper mixing of ingredients.

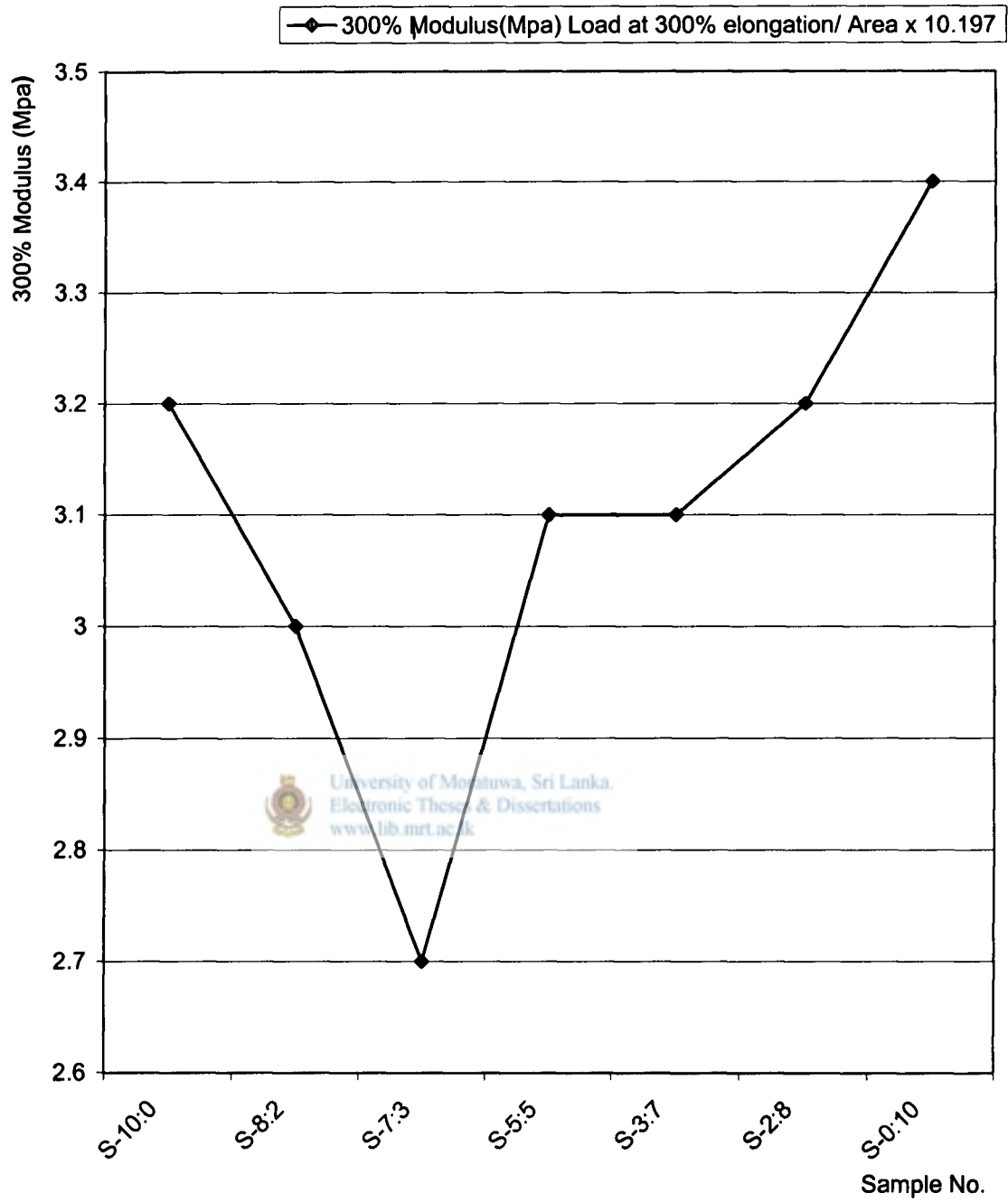


Figure (4.7) : Modulus of NR : EPDM blends

e) **Elongation at break**

Table (4.8): Elongation at break of NR : EPDM blends

Sample No	Elongation at break % (Final elongation – initial gauge mark) × 100 Initial gauge mark
	S-10:0
S-8:2	400
S-7:3	373
S-5:5	364
S-3:7	360
S-2:8	380
S-0:10	312

In general, it is observed that elongation at break increases when NR percentage of blend increases as shown in figure (4.8). This is due to its inherent property of strain-induced crystallinity. In addition, when increasing unsaturation of the blend with increasing NR content, Sulphur bond content also increase and therefore, elongation at break increases.



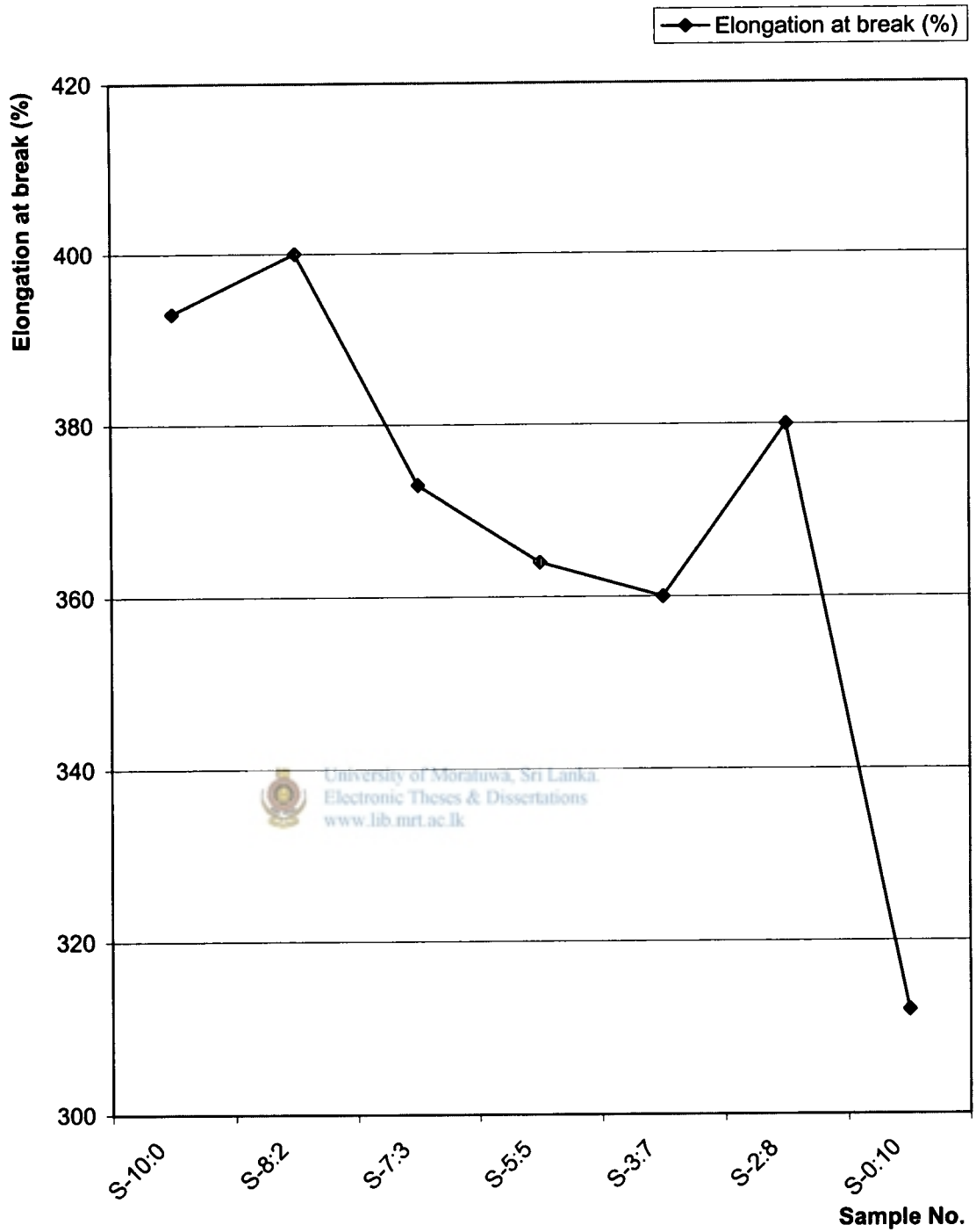


Figure (4.8): Elongation at break of NR : EPDM blends



f) Tear strength

Table (4.9) : Tear strength of NR : EPDM blends

Sample No	Tear Strength (kg/cm) (Maximum load/ Thickness)*10.197
S-10:0	195.1
S-8:2	147.7
S-7:3	142.7
S-5:5	78.3
S-3:7	82.1
S-2:8	576.4
S-0:10	90.7

Figure (4.9) shows that tear strength of vulcanizates of blends of NR:EPDM gradually decrease S-10:0 to S-0:10. Reason for this general decrease of tear strength is that considerably reducing of NR content of the blends. When reducing NR content, unsaturation also go down and it leads to reduce the amount of sulphur cross-link and therefore, decrease tear strength. In addition, NR shows high tear strength due to high rotation and segmental motion of the NR molecules.

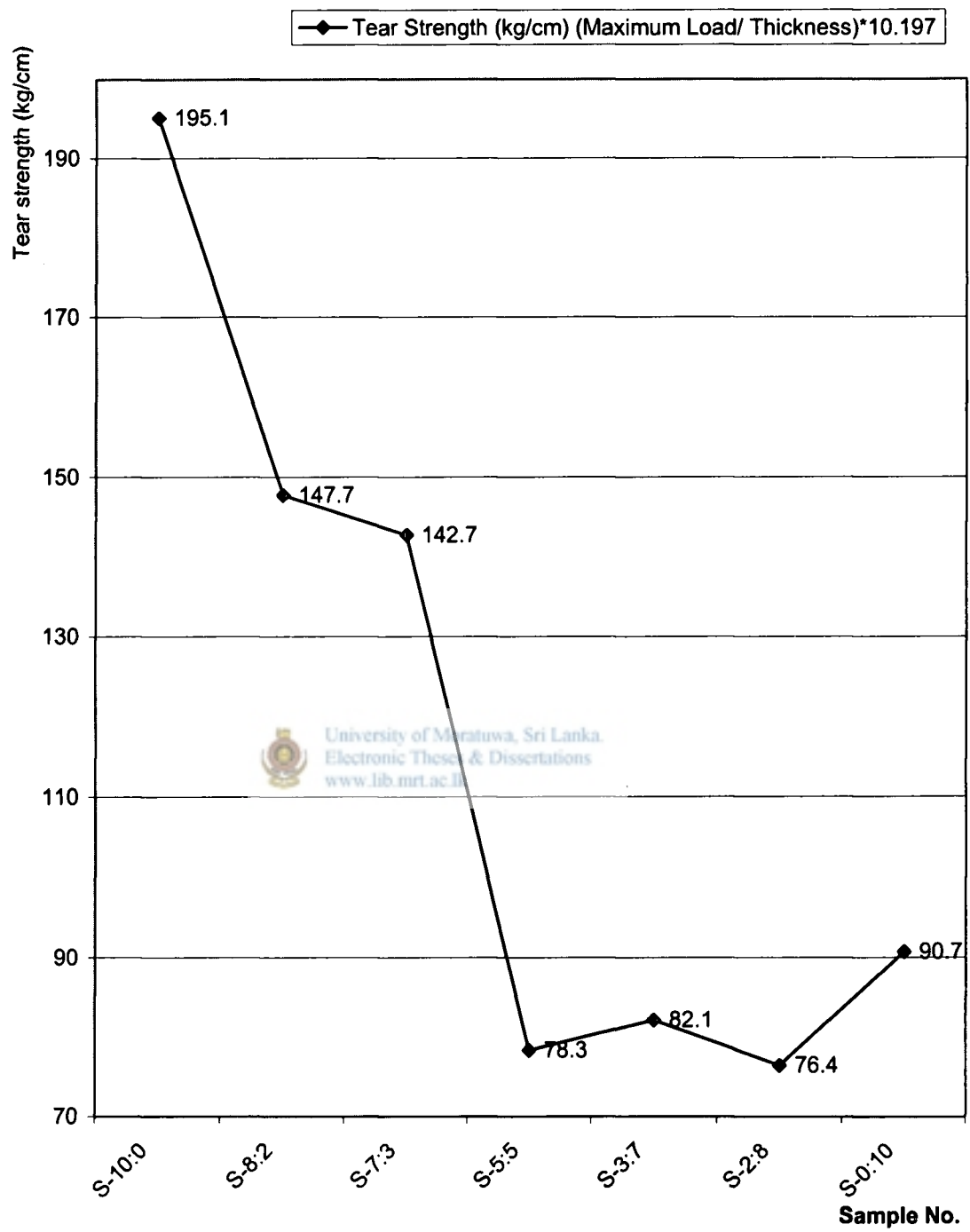


Figure (4.9) : Tear strength of NR : EPDM blends

g) Tension set

Table (4.10) : Tension set of NR : EPDM blends

Sample No	Tension set (%) [(Final length- Ini length) / Ini length] × 100
S-10:0	12.8
S-8:2	12.8
S-7:3	12
S-5:5	13.2
S-3:7	14
S-2:8	14.8
S-0:10	16

Tension set of vulcanizates of blend of NR:EPDM gradually increase from S-10:0 to S-0:10. This is mainly because of decreasing the NR content of the blends from S-10:0 to S-0:10. High unsaturation of the NR gives high cross links & this leads to low set property. Also, Ethylene Propylene back bones are plastic backbones and therefore blend S-0:10 shows high plastic properties.



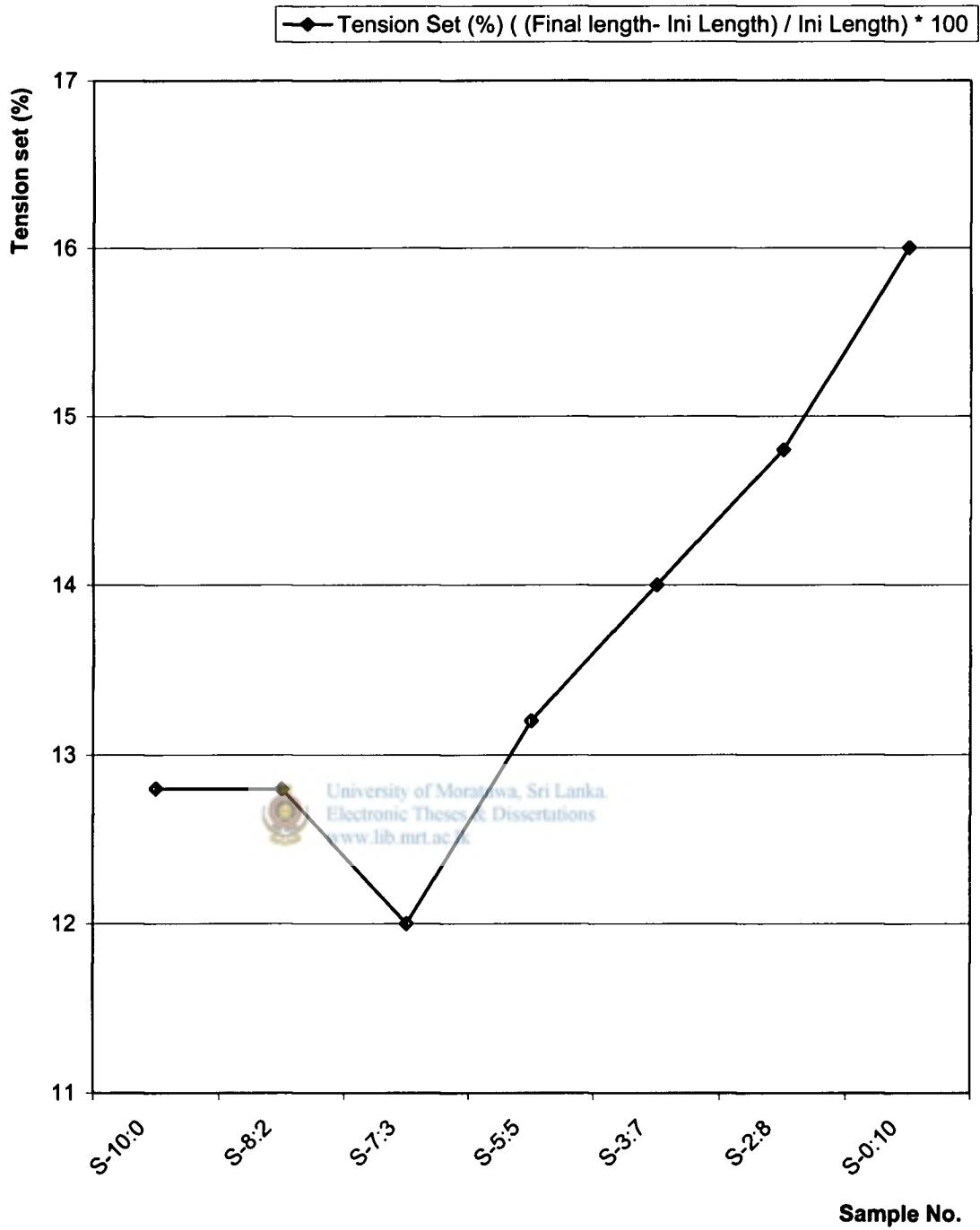


Figure (4.10) : Tension set of NR :EPDM blends

h) Abrasion

Table (4.11) : Abrasion of NR : EPDM blends

Sample No.	Abrasion (Wt loss/ S.G×2)
S-10:0	0.0472
S-8:2	0.0759
S-7:3	0.0988
S-5:5	0.3734
S-3:7	0.3153
S-2:8	0.3353
S-0:10	0.3052

Figure (4.11) shows that abrasion loss for vulcanizate of blends increases gradually with increasing EPDM content. When increasing EPDM content of the blends, unsaturation also decrease and therefore, sulphur cross links too decrease and that is a reason for low abrasion. In addition, NR it self is a good polymer which has highest abrasion resistance due to high rotation and segmental motion of the molecules.

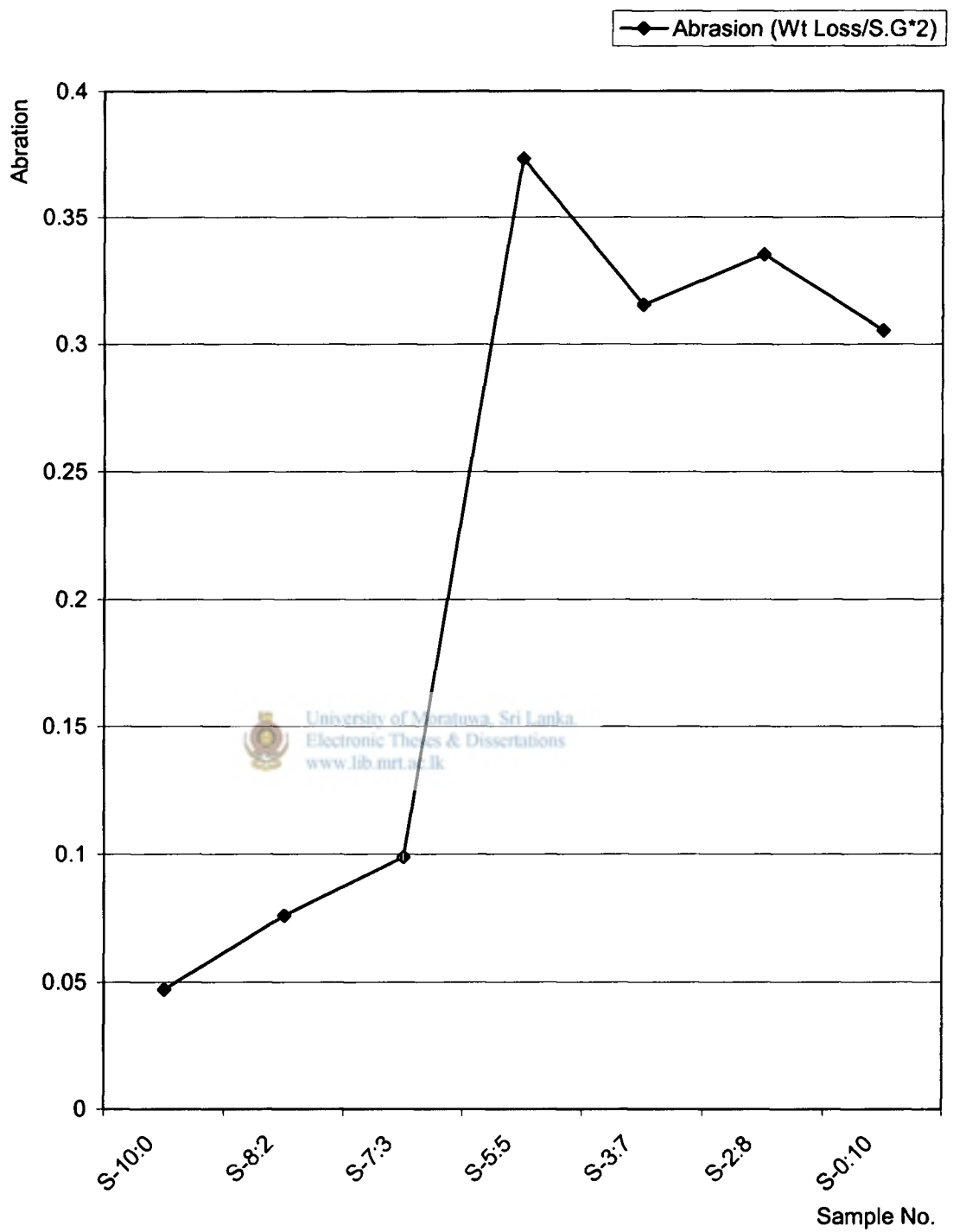


Figure (4.11) : Abrasion of NR : EPDM blends

i) Ozone resistance

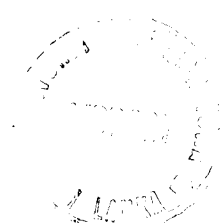
The following results were obtained in this test.

Results of Step 1

i) Static test

***Table (4.12a) : Results of ozone resistance
under static condition. (Ozone con. 50 pphm)***

Sample	Time period (Hours)
S-10:0	(0-72) Surface cracks
S-8:2	(0-72) No cracks
S-7:3	(0-72) No cracks
S-5:5	(0-72) No cracks
S-3:7	(0-72) No cracks
S-2:8	(0-72) No cracks
S-0:10	(0-72) No cracks



ii) **Dynamic test**

Table (4.12b) : Results of ozone resistance under dynamic condition. (Ozone con. 50 pphm)

Sample	Time period (Hours)
S-10:0	(0-72) Surface cracks
S-8:2	(0-72) Slight edge cracks
S-7:3	(0-72) No cracks
S-5:5	(0-72) No cracks
S-3:7	(0-72) No cracks
S-2:8	(0-72) No cracks
S-0:10	(0-72) No cracks

Results of Step II



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

i) **Static test**

Table (4.12c): Results of ozone resistance under static condition. (Ozone con. 150 pphm)

Sample	Time period (Hours)
S-10:0	(0-72) Surface cracks
S-8:2	(0-72) Edge cracks
S-7:3	(0-72) Edge cracks
S-5:5	(0-72) No cracks
S-3:7	(0-72) No cracks
S-2:8	(0-72) No cracks
S-0:10	(0-72) No cracks

ii) **Dynamic test**

**Table (4.12d) : Results of ozone resistance
under dynamic condition. (Ozone con. 150 pphm)**

Sample	Time Period (Hours)
S-10:0	(0-72) Large Surface cracks
S-8:2	(0-72) Edge cracks
S-7:3	(0-72) Edge cracks
S-5:5	(0-72) Slight edge cracks
S-3:7	(0-72) No cracks
S-2:8	(0-72) No cracks
S-0:10	(0-72) No cracks

Highest ozone resistance was shown by vulcanizate of S-0:10, S-2:8 and S-3:7 blends. Lowest was S-10:0 which gave large surface crack in both dynamic & static test. S-5:5 was no cracks in static test but slight edge cracks was shown in dynamic test. S-8:2 & S-7:3 gave only edge cracks in both dynamic & static test. (Table 4.12 a, 4.12 b, 4.12 c & 4.12 d).

In general, the ozone resistance of polymers increases with decreasing unsaturation of the polymers. Therefore, when increasing saturated polymer (e.g.-EPDM) content of the polymer blend, ozone resistance also increases gradually.

In addition to this, anti ozonant (6PPD) & wax form a protective film on the surface of the rubber. This may be either by rubber anti ozonant complex or by wax or any other film. During test conditions these form a layer on the surface of the product & it does not allow ozone to come in contact with rubber. By this way too, the rubber will be protected.

4.3 Conclusions

In analysing above test results we could arrive at a conclusion that,

- I. When EPDM percentage of the blend is increased, ozone resistance of vulcanizate also increases respectively. Although ozone resistance of S-8:2 & S-7:3 is lower than that of the blends which have high content of EPDM, S-8:2 & S-7:3 too have shown considerably high values.
- II. Tensile properties of the vulcanizates increase with increasing NR content of the blends. S-10:0 (100% NR) vulcanizate shows the highest tensile properties. Also, High Tensile Properties have been shown by blend vulcanizates of S-8:2 and S-7:3 too.
- III. Abrasion resistance & Tear resistance were better with increasing NR content of the blends. High values were shown by S-10:0 (100% NR), S-8:2 and S-7:3 blend vulcanizates.
- IV. Highest flexing value was given by S-10:0 (100% NR). Blend vulcanizates of S-8:2 & S-7:3 also have comparatively highest values.
- V. Hardness & Tension set were in better ranges in blend vulcanizates of S-8:2 & S-7:3 blends.
- VI. Processing characteristics were also found to be comparatively better in S-8:2 & S-7:3 blend vulcanizates.

According to the above observations we can conclude that the S-8:2 & S-7:3 NR : EPDM blend ratios are better for bicycle tire sidewall.

4.4 Suggestions for further work.

- I. Due to the limitation of time & facilities available, it was not possible to evaluate the best accelerator system, which gives

better cure properties. Higher alkyl substituted accelerators greatly enhance cured properties of EPDM – diene rubber blends.


- II. Combination of paraffin & microcrystalline waxes improves the ozone resistance of the rubber compound considerably. Therefore, to enhance the ozone resistance of the side wall compound over the widest possible temperature range, blend of paraffin & microcrystalline waxes need to be used.



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk



Reference

1. SBP Board of Consultants and Engineers "Rubber Technology & Manufacture", Small Business Publications , Roop Nagar , Delhi , P.38-40, 57.
2. Beelen H. J. H. & Maag L. R, "Rubber Asia", **Jan – Feb**, 100 - 101 (1998).
3. Borg E. L, "Rubber Technology", P.226 - 227.
4. Sircar A. K, Lamond T. G. & Pinter P. E, "Rubber Chem & Technol" **47**, 48 (1974)
5. Callan J. E, Hess W.M & Scott C. E, "Rubber Chem & Technol". **44**, 814 - 822 (1971)
6. Kongaror G. S & Bartner G. M, "Rubber Chem & Technol" **46**, 1188 – 1192 (1973).

University of Moratuwa, Sri Lanka
www.lib.mrt.ac.lk
7. Corish P.J, Powell B.D.W., "Rubber Chem & Technol" **47**, 485 – 492, 504 – 505 (1974).
8. Gardiner J. B, "Rubber Chem & Technol" **43**, 370 (1970).
9. Zapp R. L, "Rubber Chem & Technol" **46**, 251 (1973).
10. Tinker A. J, "Blend of Natural Rubber", Chapman & Hall Ltd, London, 1998, P. 2- 5.
11. Sircar A. K. & Lamond T. G. "Rubber Chem & Technol" **46**, 178 (1973).
12. Baranwal K. C. & Son P.N, "Rubber Chem & Technol" **47**, 88 – 93 (1974).

13. Prabhu D. S., Chakraborty S. K. & Press R. R., "Rubber Asia", **Nov- Dec.**, 95-99 (1995).
14. Cook S, "Blends of Natural Rubber", Chapman & Hall Ltd. London, 1998, P.184.
15. Mastromatteo R. P, Mitchell J. M and Brett T. J, "Rubber Chem & Technol" **44**, 1065 – 1066 (1971).
16. Layer R.W. & Lattimer R. P., "Rubber Chem & Technol" **63**, 426-437 (1990).
17. Andries J. C, Ross D. B. & Diem H.E, "Rubber Chem & Technol" **48**, 41, 47-49 (1975).
18. Andrews E. H, Barnard D, Braden M & Gent A. N, "The Chem. & Phy. of Rubber like substances", P. 331–332.



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

