RESEARCH RECORD NO: 248

PAD-BATCH PROCESSING OF SINGLE JERSEY - STARFISH EQUATIONS

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1. INTRODUCTION

Research Record No. 243 describes the cold pad-batch dyeing of a range of experimental single jersey fabrics. This report examines the test results obtained from the samples included in that trial, in order to derive equations from the data which may be incorporated into the STARFISH predictive system.

The fabrics included in this study had a variety of histories, some of which have not previously been documented. For this reason, complete yarn and grey fabric data are included in the Appendix to this report, whether previously reported or not.

A limited comparison is reported between fabrics from this trial and identical winch-processed fabrics from an earlier study (Research Record No. 219), and the data from that study are also included in the Appendix to this report.

2. YARNS AND GREY FABRICS

The fabrics can conveniently be divided into three groups:-

2.1. NTI82. This was a series of 20 fabrics, produced in 1982 for a project with the Norwegian Textile Institute which was subsequently abandoned. Four yarns, Ne 24, 28 and 32 combed and 28 carded were each knitted at five stitch lengths.

Yarn test data for this series were given in Research Record No. 165. Fabric test data was reported in Research Record No. 209 (Appendix).

2.2. SJ86 additional fabrics. A series of 13 fabrics was produced in 1986, to expand the count range covered by the NTI82 fabrics. Three yarn counts, Ne 18, 38 and 50 were included, five fabric constructions being produced from each of the first two counts and three from the 50's yarn.

Yarn test data for these additional fabrics were reported in Research Record No. 209.

The complete series of 33 fabrics was tested in 1986, using fresh samples from the NTI82 set, and the data reported in Research Record No. 243. However, no comparisons were made between the two sets of figures at that time.

2.3. Corah open-end. Our co-operators in the pad-batch dyeing trial, Corah of Leicester, included in the processing a series of fabrics knitted from open-end yarns. Two counts, Ne 30 and 34, each knitted at three stitch lengths, were included. Test data for these yarns and fabrics have not previously been recorded.

A summary of the yarns and fabric manufacturing is given in Table I.

3. GREIGE FABRICS - YARN COUNT AND STITCH LENGTH

The STARFISH predictive routine requires, from the greige fabrics, only grey yarn count and knitted stitch length data in order to construct models for the behaviour of the fabrics after finishing.

Two sets of such data were available for the NTI 82 fabrics, and an examination was undertaken to establish a justification for combining these results.

Mean values for each yarn count, from the fabric as knitted, were calculated, giving the following results:

	tex		
	1982	1986	"t"
Ne 24, combed	24.99	24.97	0.132
Ne 28, combed	22.06	22.00	0.646
Ne 32, combed	18.26	18.36	0.957
Ne 28, carded	21.07	21.18	1.054

The "t" test for the differences between the means was carried out, with the results shown above. No significant variations were indicated and therefore the overall mean values were calculated as 24.98, 22.03, 18.31 and 21.13 respectively.

Measurements of yarn count had also been carried out for each yarn from the packages prior to knitting, and therefore combined average yarn count values were then calculated, as follows:-

Yarn	Tex from package	Tex from fabric	Mean Tex
Ne 18	32.63	32.15	32.39
Ne 24	24.88	24.98	24.93
Ne 28 combed	21.76	22.03	21.89
Ne 32	18.36	18.31	18.33
Ne 38	15.38	15.42	15.4
Ne 50	11.79	11.75	11.77
Ne 28 carded	21.17	21.13	21.15
Ne 30 O-E	19.94	19.51	19.72
Ne 34 O-E	17.37	17.14	17.25

These mean values were used in the subsequent construction of the model.

Two sets of knitted stitch length results were similarly available for the NTI 82 fabrics. Although the "t" test procedure did not indicate such good agreement ("t" ranged from 0.28 to 4.69), it was considered that neither set could be regarded as less accurate, and that therefore mean values could be calculated for use in subsequent analysis. This view was reinforced by the facts that the differences, even if significant, are still small (see following table); and the later measurements are, if anything, longer than the earlier, so that yarn relaxation is unlikely to be a contributory factor.

Stitch Length mm

Fabric	1982	1986	"t"	Mean
24/306	3.08	3.09	3.55	3.08
24/321	3.23	3.24	1.78	3.23
24/337	3.39	3.39	0.28	3.39
24/354	3.57	3.57	0.65	3.57
24/372	3.74	3.74	2.12	3.74
28/291	2.93	2.94	2.00	2.94
28/306	3.07	3.09	4.41	3.08
28/321	3.22	3.23	2.94	3.22
28/337	3.38	3.40	3.73	3.39
28/354	3.55	3.57	3.54	3.56
32/276	2.80	2.80	1.51	2.80
32/291	2.96	2.94	1.98	2.95
32/306	3.05	3.07	3.09	3.06
32/321	3.21	3.22	0.96	3.22
32/337	3.39	4.00	1.98	3.39
28C306	3.07	3.08	1.12	3.08
28C321	3.20	3.23	3.64	3.22
28C337	3.38	4.00	3.54	3.39
28C354	3.56	3.57	0.65	3.56
28C372	3.72	3.74	4.69	3.73

4. STARFISH PREDICTIVE MODELS

4.1. Step One: Yarn Count and Stitch Length

Research Record No. 246 describes the processing of these fabrics by pad-batch methods. Successive pad-batch bleaching and dyeing stages were carried out, with intermediate drying.

Samples of all fabrics were obtained for testing:-

a) after bleaching and drying
b) after dyeing and finishing

The bleached and dried samples were, of course, without softener. White fabrics, for which bleaching would be the only wet process, would normally receive a softener application. To try to establish the effects, if any, of the presence of softener, a set of the bleached and dried fabrics was washed with a fabric softener (Comfort) in the laundering liquor.

Full test results on these fabrics are recorded in the Appendix.

Construction of a STARFISH predictive model from this database was carried out in two stages, following the procedure used for earlier models.

In Step One, relationships are deduced between the yarn counts and stitch lengths of the finished fabrics (in the Reference State) on the one hand, and the knitted yarn counts and stitch lengths on the other, using the equation form $Y = aX$.

The resulting equations are given in Table II. Correlation between the equations and the data is excellent ($r^2 > 0.997$ in each case).

4.2. Step Two: Course and Wale Densities, Stitch Density and Weight

In the second stage of the mathematical treatment of test data regression equations are constructed linking finished fabric dimensions, in the Reference State, to yarn count and stitch length.

For course and wale density prediction, the equations used are of the form:-

$$Y = a + bX_1 + cX_2$$

where X_1 is the reciprocal of stitch length and X_2 is the square root of the yarn count, in tex; both measurements being in the finished, Reference State.

Equations for the prediction of stitch density and fabric weight have also been calculated, although these are not used in the current model.

The stitch density equation is of the same form as course and wale density but in this case X_1 is the square of the stitch length reciprocal and X_2 is the yarn count, in tex units.

The fabric weight equation is of the form $Y = a + bX$, where X is the yarn count (tex) divided by the stitch length.

A preliminary treatment of the data along these lines showed that, while the fabrics which were constructed from ring-spun, combed yarns could be modelled in this way, with good correlation, attempts to include the fabrics from carded or open-end yarns led to significant reductions in the correlation coefficients, especially for the prediction of wale density. The final versions of the Step Two equations, which are reported here, were therefore produced using only the data for the fabrics constructed from ring-spun, combed yarns.

The equations are given in Table III. Correlation is again excellent, with the lowest value of r^2 fractionally under 0.98.

Figures 1-36 show the degree of correlation of the equations with the measured data, for each yarn count, including those (carded and open-end) which were excluded from the regression analysis.

The coefficients shown in Table III have been incorporated into a development version of the STARFISH computer programme (version 87:4.4).

5. EFFECT OF FINISHING ROUTE ON FABRIC PROPERTIES

This development version incorporates several finishing routes for single jersey fabric, so that pad-batch processing can be compared with, say, winch or jet processing. For example, in January 1986, we reported on a variability study carried out on a Corah single jersey fabric, quality 3169, with the following specification:

24 gauge, 26" (1932 needles) or 30" (2268 needles) from 1/30's combed cotton. Stitch length 2.8mm.

Finished weight per sq.m.	140g ± 5%
Finished courses per 3cm	54
Finished wales per 3cm	42.5

By means of the STARFISH models, predictions of finished fabric shrinkage have been obtained for this fabric after simulated processing in three different ways, finishing in each case with 54 courses and 42.5 wales per 3cm. A typical STARFISH print-out is given in Table IV.

The predictions are:

	Shrinkage		Weight
	length	width	gsm
1. Winch dyed (deep)	11.0%	8.2%	137
2. Rotostream dyed (med)	9.2	5.9	134
3. Pad-batch dyed (pale)	4.3	9.9	133

Scouring and bleaching losses, and dyestuff additions, will have contributed to the weight variations; the shrinkage differences are a function of the processing conditions, and show a striking example of the effect of the finishing route on fabric shrinkage. Some finishers have reported difficulty in obtaining specified course densities on pad-batch processed goods, and these figures confirm the view that new specifications may be necessary for fabrics which are processed by this technique

To show in another way how the processing conditions have influenced fabric dimensional properties, the data for Reference State measurements (yarn count, stitch length, course/wale densities and weight) have been averaged across all 33 fabrics in the SJ86 series. The results are shown in Table V.

These figures could be used to calculate Finishing Factors. For example, the course factor for pad-batch dyeing would be 49.7/56.0 = 0.8875, whereas that for winch dyeing would be 53.7/56.0 = 0.9589.

6. FURTHER STUDIES

The main purpose of this report was to derive model equations for pad-batch processing which could be incorporated into the STARFISH predictive system. This has been done, but during the course of the analysis certain trends became apparent in other properties. These will be analysed in detail at a later date, but the preliminary impressions are worth reporting now. They relate to shrinkage, spirality and colour.

6.1. Shrinkage

In the report on on the pad-batch processing of these fabrics it was noted that during drying in the Kiefer Rotoswing, the bleached fabrics appeared to be in a completely relaxed state. The measured shrinkages, however, contradict that observation. Average length shrinkages were; after one wash/tumble cycle, 14.5%, after five cycles 18%. From the processing measurements reported in Research Record 243, shrinkages in the dryer were of the order of 10-12%. To conform to modern shrinkage requirements, this level would have to be increased to around 20%, probably much more than the machine has been designed to achieve.

6.2. Spirality

Average spirality angles, after five wash/tumble cycles, for the SJ86 series and the Corah open-end yarn series, are given below:

	SJ86	Corah OE
Grey	20.0	12.1
Winch bleached	13.6	-
Winch dyed	13.3	-
Pad-batch bleached	15.5	9.4
Pad-batch dyed	13.3	10.1

average tightness factors not the same!

The effect of wet processing on the reduction of spirality can be seen. Pad-batch processing shows no advantages over winch processing. The open-end yarns, despite high twist factors, are shown again to give less spirality than ring yarns.

6.3. Colour

Colour measurements were carried out on the pad-batch processed fabrics using the ICS Micromatch 2000. These are recorded in the Appendix as X, Y, Z chromaticity co-ordinates, and even in this form an examination of the data indicates that there may be a correlation with fabric construction, particularly stitch length. This is easily confirmed by visual assessment. Conversion of the data into the Kubelka-Munk function, K/S, shows the correlation much more clearly. An example is given in Figure 37 for the Ne38 series pad-batch dyed. The difference in colour (delta E) between the shortest and longest stitch length samples is 3.46 CIELAB units.

At least part of this difference is due to colour yield variation. Colour measurement carried out on the unravelled yarn still showed a difference, this time of 1.99 CIELAB units. The cause of this is open to speculation, but may be due to variations in wet pick-up.

7. CONCLUSIONS

The philosophy of the STARFISH research programme is that the properties of a finished cotton knitted fabric are controlled not only by the knitter's choice of yarn and stitch length, but also by the wet processing conditions applied in dyeing and finishing. This study has demonstrated that pad-batch processing can give results which are quite different from other wet processing techniques, and that a predictive model based on the STARFISH principles can be a valuable tool to establish satisfactory knitting and finishing procedures which incorporate pad-batch dyeing methods.

TABLE 1

YARN AND FABRIC PRODUCTION

Ne	Spinner	Knitted At	Gauge	Diam	Feeders	Needles
18	Courtaulds LCW	IIC	18 Camber Velnit	26"	36	1500
24	Courtaulds KCW	IIC	24 Monarch XL-JS	26"	60	1920
28 combed	Courtaulds KCW	IIC	24	26"		1920
28 tandem carded	Courtaulds	IIC	24	26"		1920
32	Courtaulds KCW	IIC	24	26"		1920
38	Courtaulds LW	Camber	28 Camber Quattro	26"	78	2280
50	Courtaulds Swan Lane	Top Jersey	28 Camber Cheminit	26"	60	2304
30 O-E	Maple Mill	Corah	28	26"		2232
34 O-E	an der Lorze*	Corah	28	26"		2232

* Spinnerei an der Lorze 6340 Baar Switzerland.
(UK agents - Tencellars Limited, 2nd Floor, Kimberley House, 47 Vaughan Way, Leicester 0533-532751).

TABLE II

YARN COUNT

Average Yarn Counts (tex)

Nominal Count (Ne)	Greige	Reference State	
		Bleached	Dyed
18 combed	32.39	30.76	31.32
24 "	24.93	23.74	23.99
28 "	21.89	21.10	21.26
32 "	18.33	17.41	17.67
38 "	15.40	14.73	14.73
50 "	11.77	11.27	11.26
28 carded	21.15	20.37	20.36
30 open-end	19.72	19.09	18.94
34 open-end	17.25	16.32	16.45

$Y = aX$

	a	r^2
Bleached	0.95540	0.9992
Dyed	0.96337	0.9997

TABLE II Cont'd

STITCH LENGTH (cm)

Fabric Identifier	Greige	Reference State	
		Bleached	Dyed
18/327	0.328	0.326	0.322
18/344	0.345	0.338	0.336
18/362	0.361	0.359	0.353
18/380	0.381	0.380	0.374
18/399	0.400	0.394	0.388
24/306	0.308	0.306	0.303
24/321	0.323	0.321	0.316
24/337	0.339	0.336	0.330
24/354	0.357	0.351	0.350
24/372	0.374	0.368	0.367
28/291	0.294	0.288	0.290
28/306	0.308	0.306	0.303
28/321	0.322	0.320	0.315
28/337	0.339	0.335	0.330
28/354	0.356	0.350	0.350
32/276	0.280	0.275	0.273
32/291	0.295	0.289	0.287
32/306	0.306	0.303	0.303
32/321	0.322	0.319	0.316
32/337	0.339	0.335	0.331
38/246	0.248	0.245	0.246
38/259	0.262	0.259	0.258
38/273	0.275	0.272	0.269
38/287	0.287	0.285	0.281
38/301	0.302	0.300	0.298
50/230	0.234	0.231	0.229
50/243	0.245	0.241	0.239
50/264	0.265	0.262	0.261

TABLE II Cont'd

Fabric Identifier	Greige	Reference State	
		Bleached	Dyed
28C 306	0.308	0.304	0.304
28C 321	0.322	0.321	0.318
28C 337	0.339	0.336	0.332
28C 354	0.356	0.352	0.351
28C 372	0.373	0.371	0.368
30R 270	0.268	0.267	0.264
30R 284	0.282	0.277	0.275
30R 298	0.299	0.293	0.291
34R 264	0.263	0.263	0.258
34R 277	0.275	0.275	0.270
34R 290	0.286	0.286	0.283

$Y = aX$

	a	r^2
Bleached	0.98957	0.9978
Dyed	0.98065	0.9982

TABLE III

COEFFICIENTS AND CORRELATION

Yarn count (tex)

Model $Y = aX$

	a	r^2
Bleached	0.95540	0.9992
Dyed	0.96337	0.9997

Stitch Length (cm)

Model $Y = aX$

	a	r^2
Bleached	0.98957	0.9978
Dyed	0.98065	0.9982

Course Density (courses per cm)

Model $Y = a + b/l + c\sqrt{tex}$

	a	b	c	r^2
Bleached	-9.60258	6.43805	1.24813	0.9946
Dyed	-9.93103	6.40693	1.24385	0.9917

Wale Density (wales per cm)

Model $Y = a + b/l + c\sqrt{tex}$

	a	b	c	r^2
Bleached	14.58767	2.38495	-1.72115	0.9799
Dyed	14.17569	2.47591	-1.71472	0.9852

TABLE III Cont'd

Stitch Density (stitches per square cm)

Model $Y = a + b/l^2 + c.tex$

	a	b	c	r^2
Bleached	44.09920	21.17081	-0.99781	0.9910
Dyed	34.38316	21.14904	-0.90867	0.9947

Weight (g per square m)

Model $Y = a + b.tex/l$

	a	b	r^2
Bleached	5.44180	2.22418	0.9882
Dyed	9.10925	2.10369	0.9918

TABLE IV

I.I.C.	STARFISH MODEL PREDICTIONS [Version 87:4.4]	AUGUST-10-1988 13:52	SOURCE I.I.C.

FABRIC : PLAIN SINGLE JERSEY [SINGLES, combed ring yarns]
PROCESS : PAD BATCH DYED (PALE), OPEN WIDTH
TARGETS : Finished Courses & Wales

Average KNITTED values				Average DELIVERED values				Shrinkage 5(W+TD)	
Yarn Ne	StLen mm	C.Len cm	Tness Factor	courses 3cm	wales 3cm	weight g/m²	width cm(O)	Length %	Width %
[MACHINE (A) 24 Gauge 26 inch Diameter 1932 Needles]									
30.0	2.800	541.0	15.8	54.0	42.5	133	136.4	-4.3	-9.9
[MACHINE (B) 24 Gauge 30 inch Diameter 2268 Needles]									
30.0	2.800	635.0	15.8	54.0	42.5	133	160.1	-4.3	-9.9

Predictions marked with an [E] are EXTRAPOLATIONS outside the database
Qualities marked with [*] have unreasonable FINISHING TARGETS
Shrinkage convention is [+] for growth,[-] for contraction
Yarn counts are given as Resultant for FOLDED YARNS
Tightness factor is Square root(Tex)/Stitch Length in cm
ESTIMATES ARE GIVEN IN GOOD FAITH BUT WITHOUT WARRANTY OR LIABILITY

TABLE V

SINGLE JERSEY 86 - MEAN REFERENCE STATE DATA

(Averaged over 33 fabric constructions)

	Yarn Count (tex)	Stitch Length (cm)	Courses/ 3cm	Wales/ 3cm	Weight gsm
Grey	21.0	0.314	56.0	42.8	163.6
Winch bleached	20.7	0.312	53.7	42.5	150.0
Winch dyed	21.1	0.312	53.7	42.7	152.7
Pad-batch bleached	20.4	0.314	50.5	43.5	147.5
Pad-batch dyed	20.6	0.312	49.7	43.4	146.0
Pad-batch bleached (washed with softener)	20.6	0.314	51.1	44.3	-

Fig.1. Pad-Batch Bleached - Measured Courses & Prediction

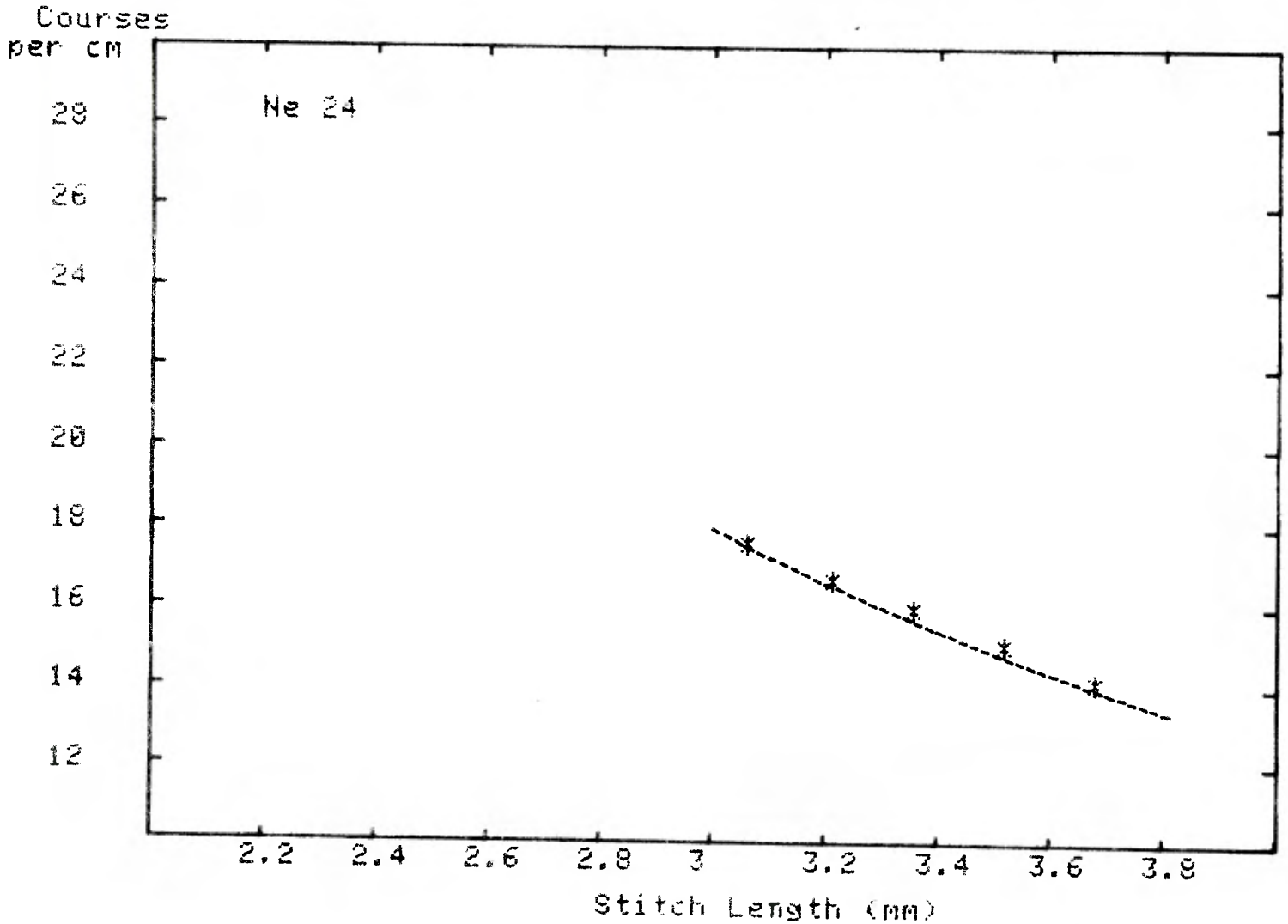

Fig.2. Pad-Batch Bleached - Measured Courses & Prediction

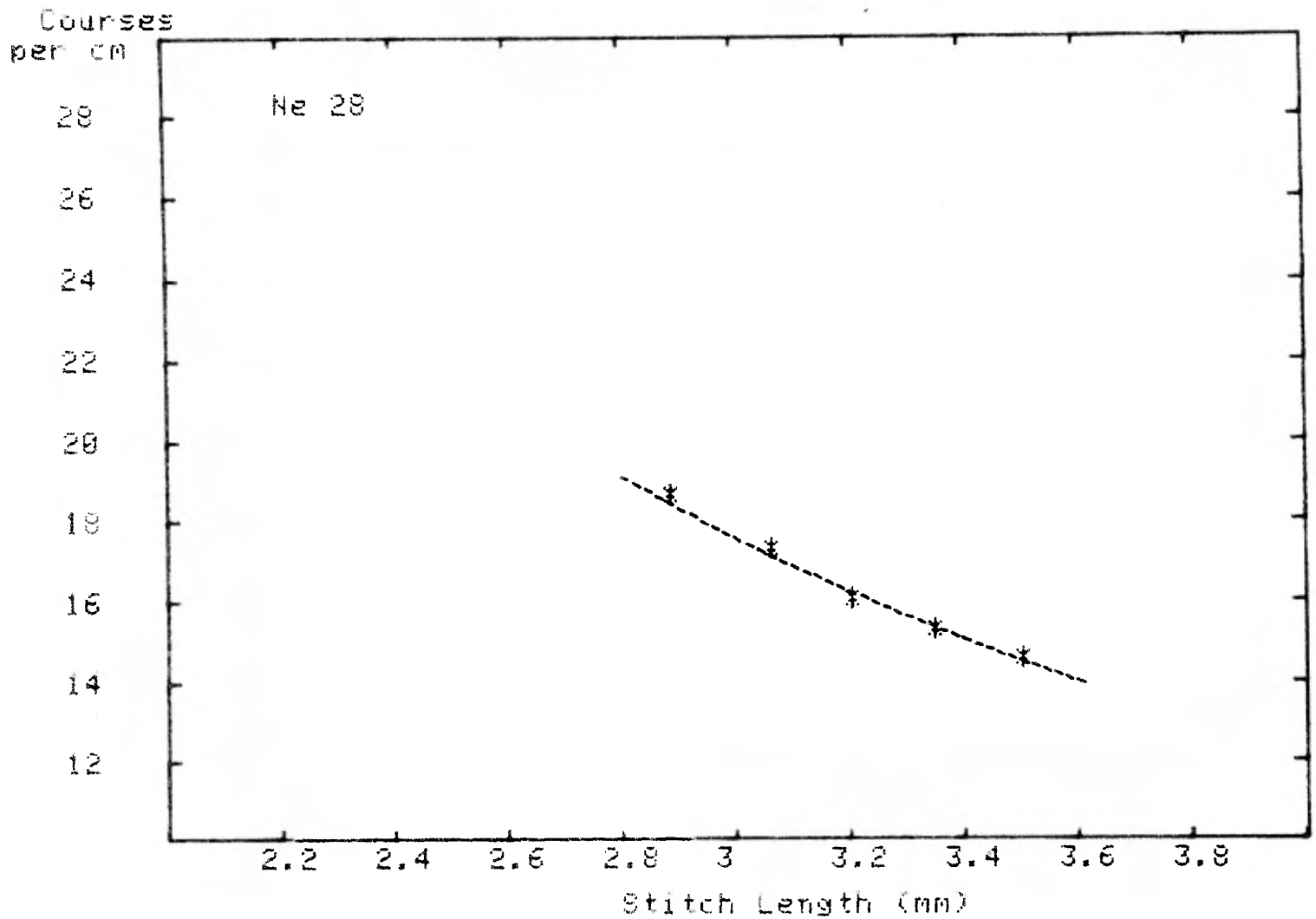

Fig.3. Pad-Batch Bleached - Measured Courses & Prediction

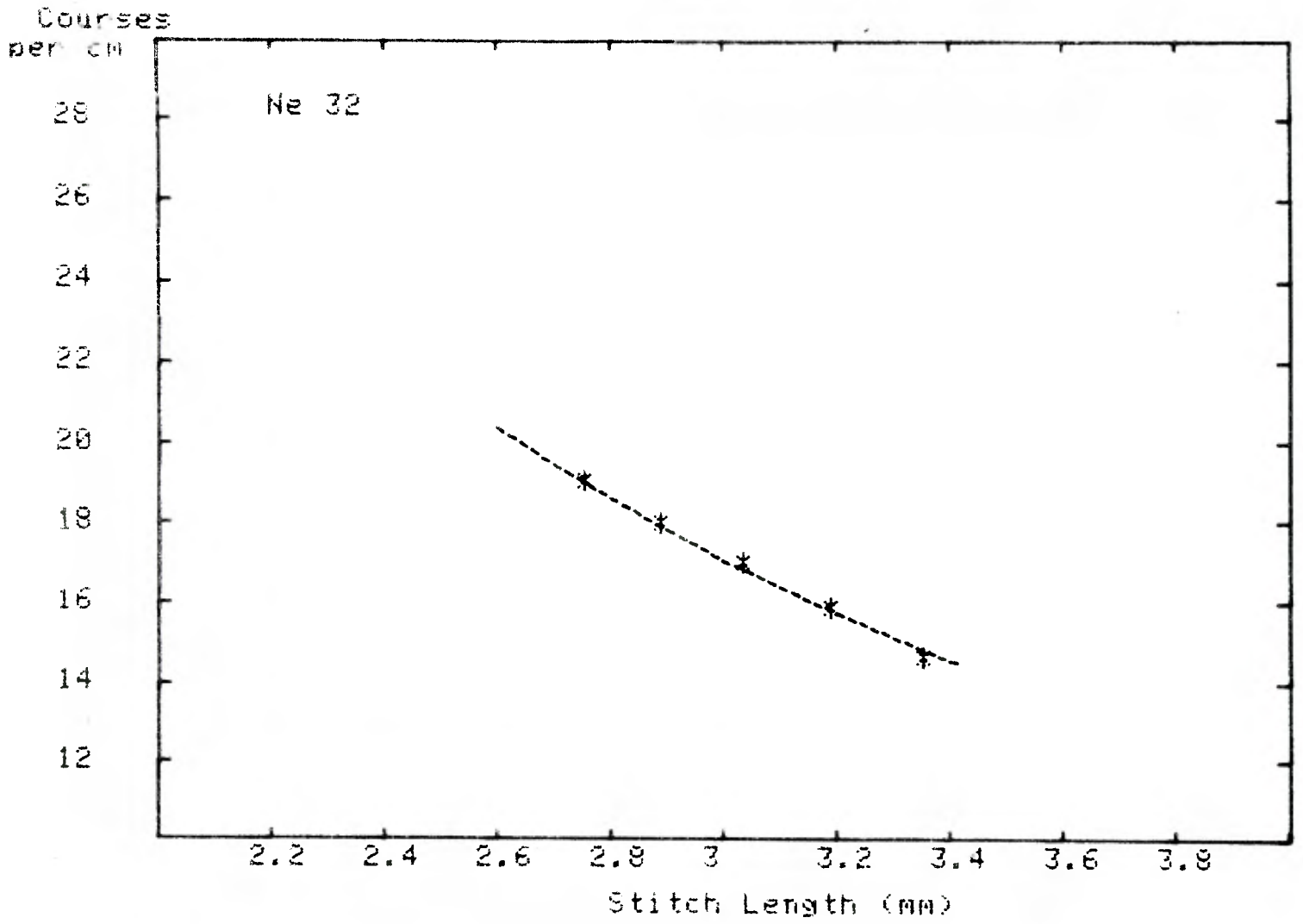

Fig.4. Pad-Batch Bleached - Measured Courses & Prediction

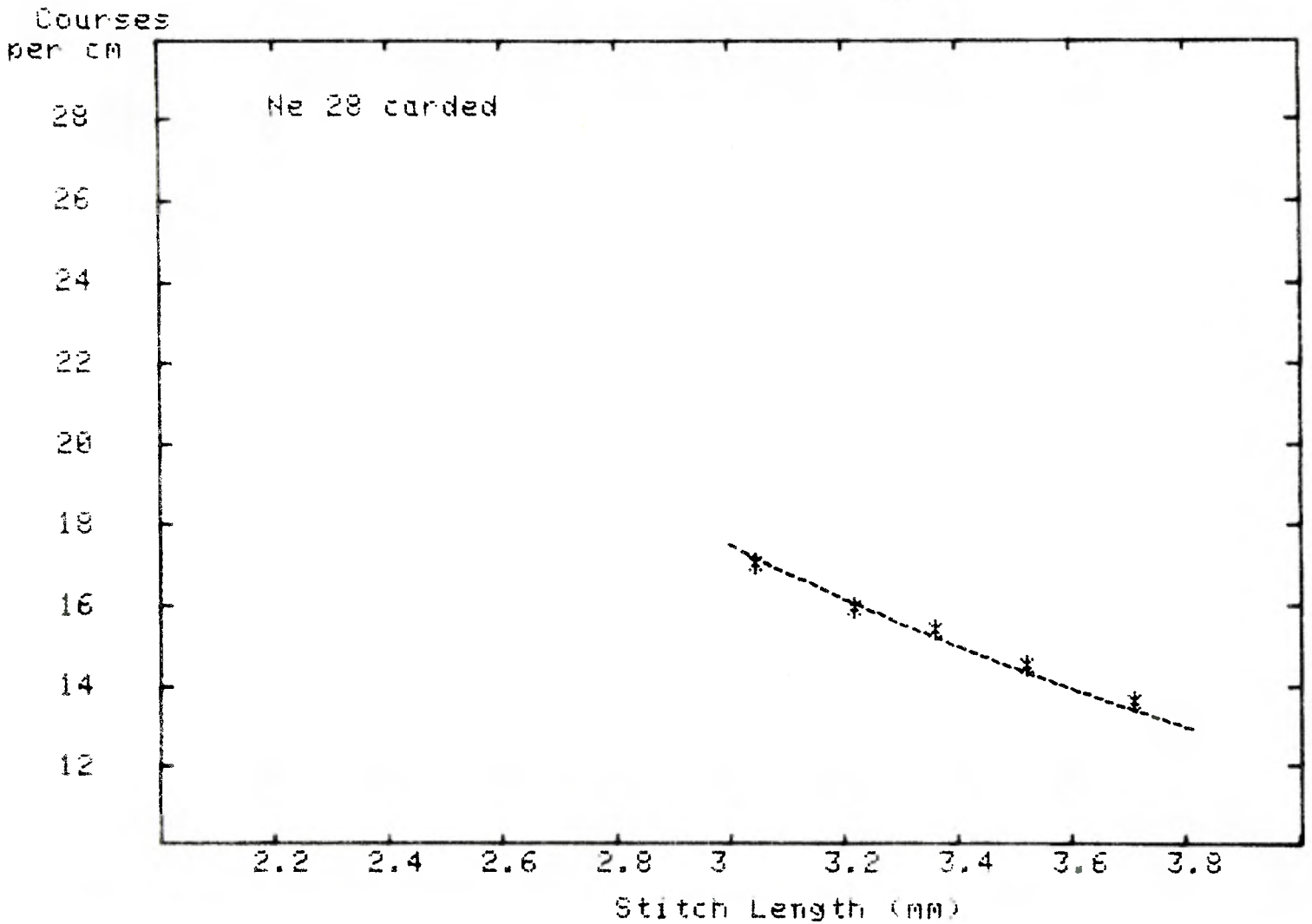

Fig.5. Pad-Batch Bleached - Measured Courses & Prediction

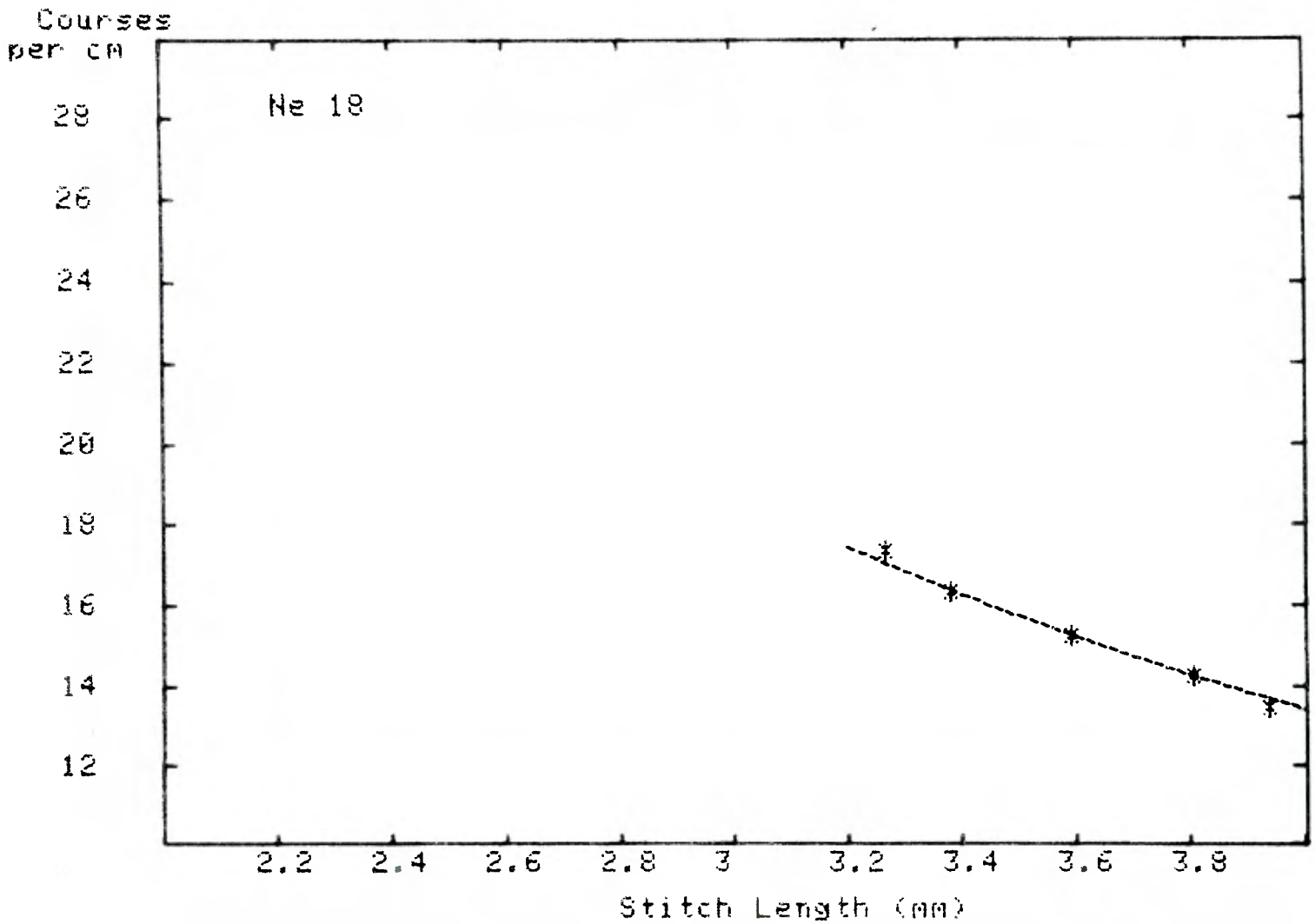

Fig.6. Pad-Batch Bleached - Measured Courses & Prediction

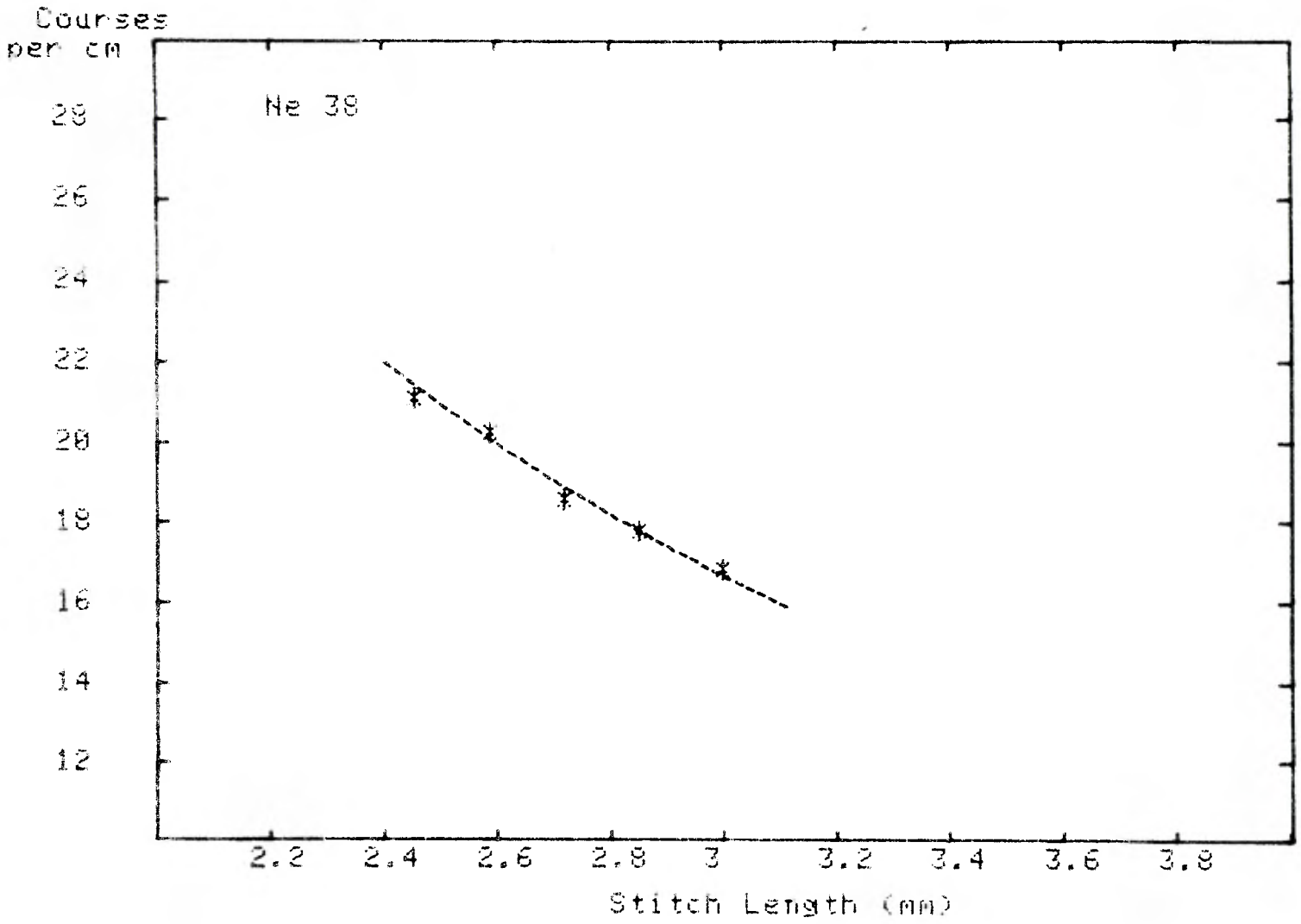

Fig.7. Pad-Batch Bleached - Measured Courses & Prediction

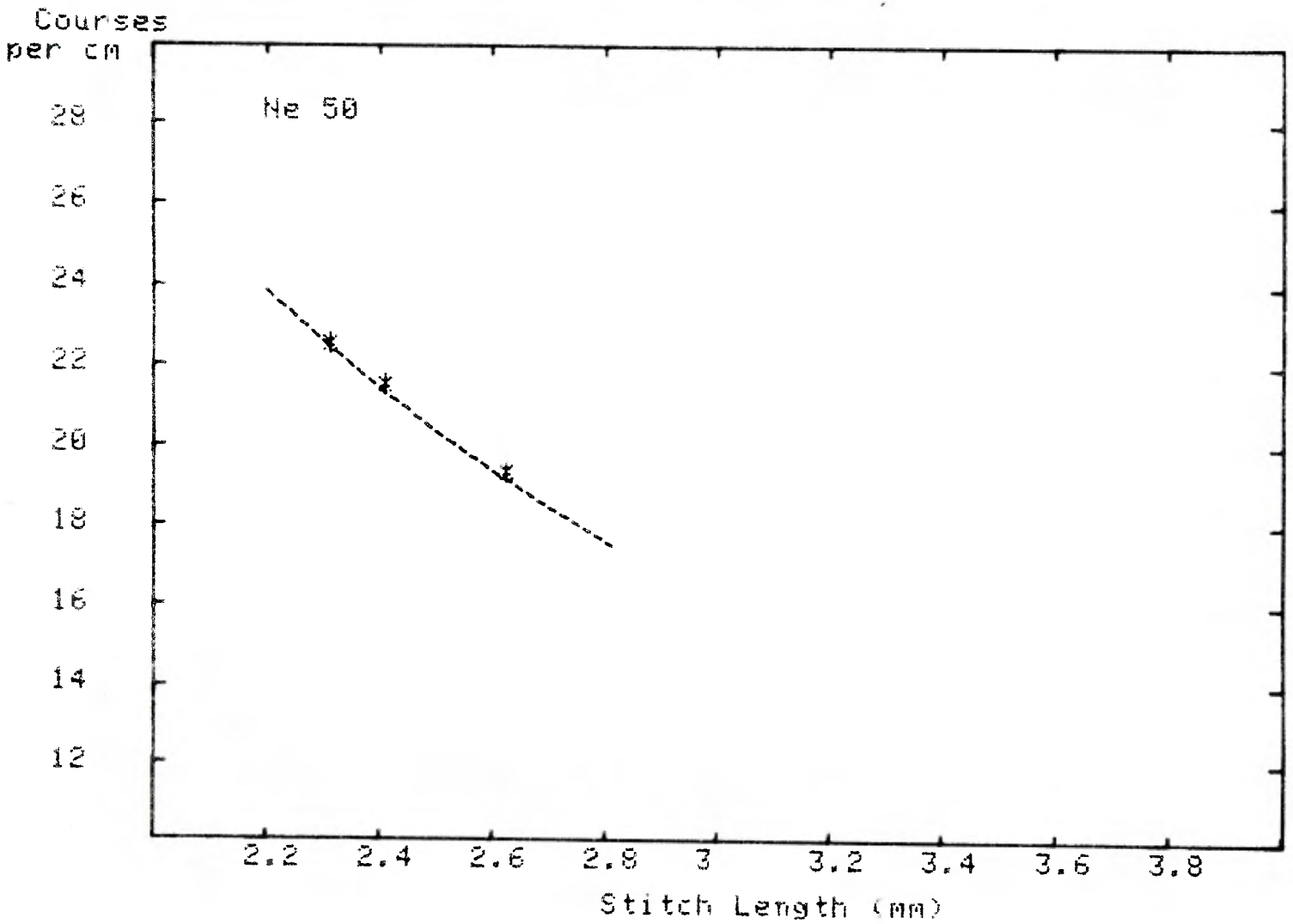

Fig.8. Pad-Batch Bleached - Measured Courses & Prediction

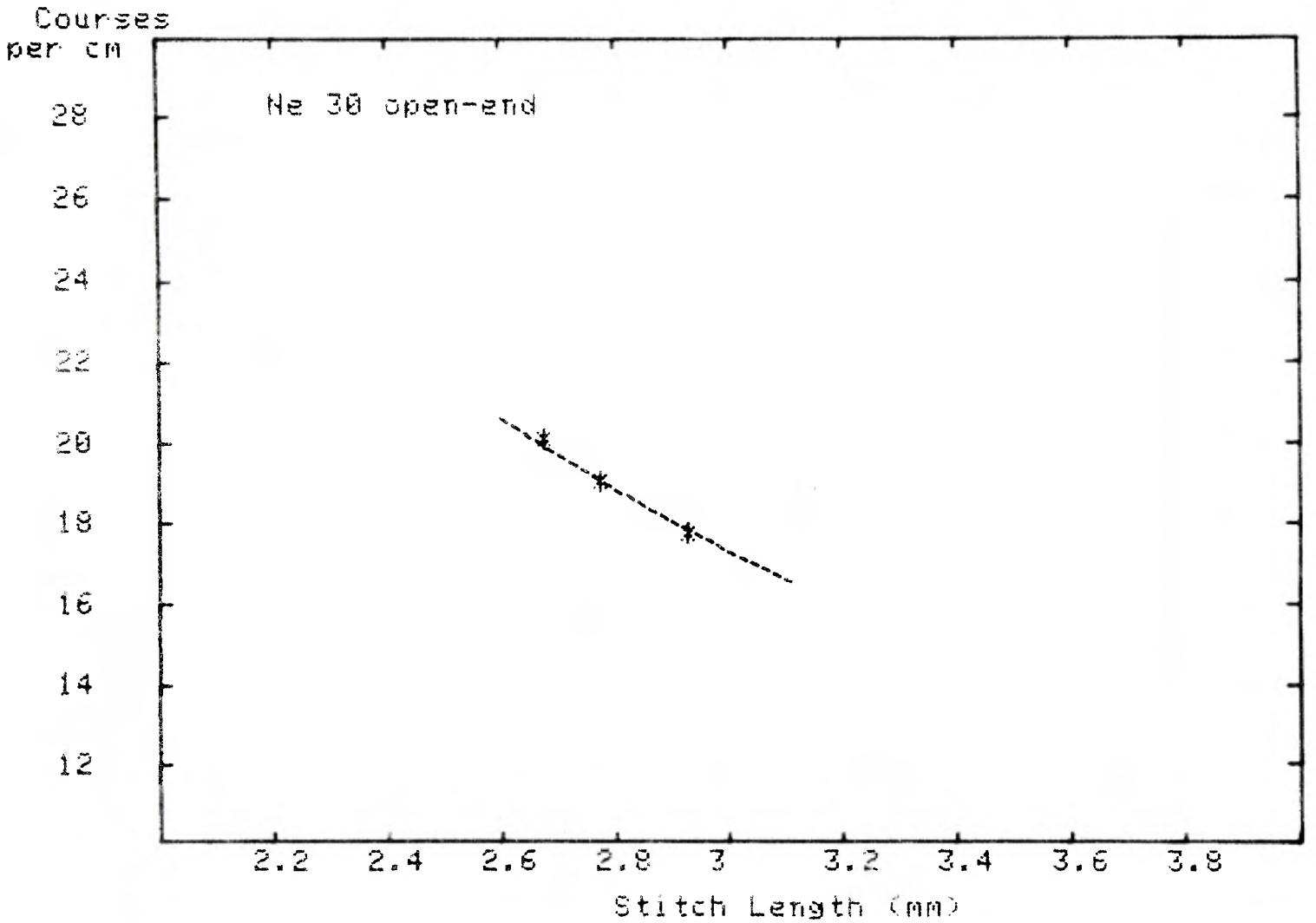

Fig.9. Pad-Batch Bleached - Measured Courses & Prediction

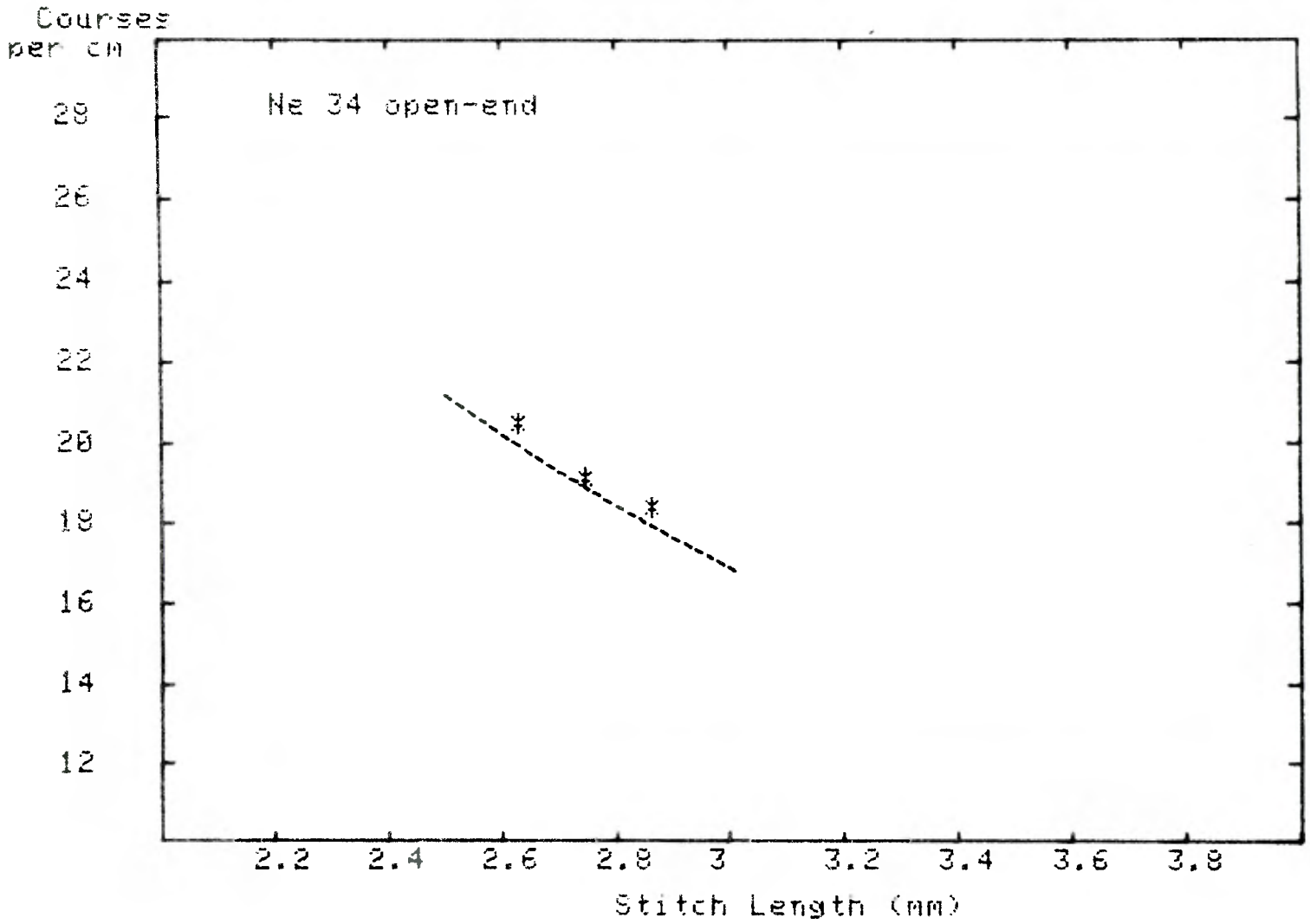

Fig.10. Pad-Batch Bleached - Measured Wales & Prediction

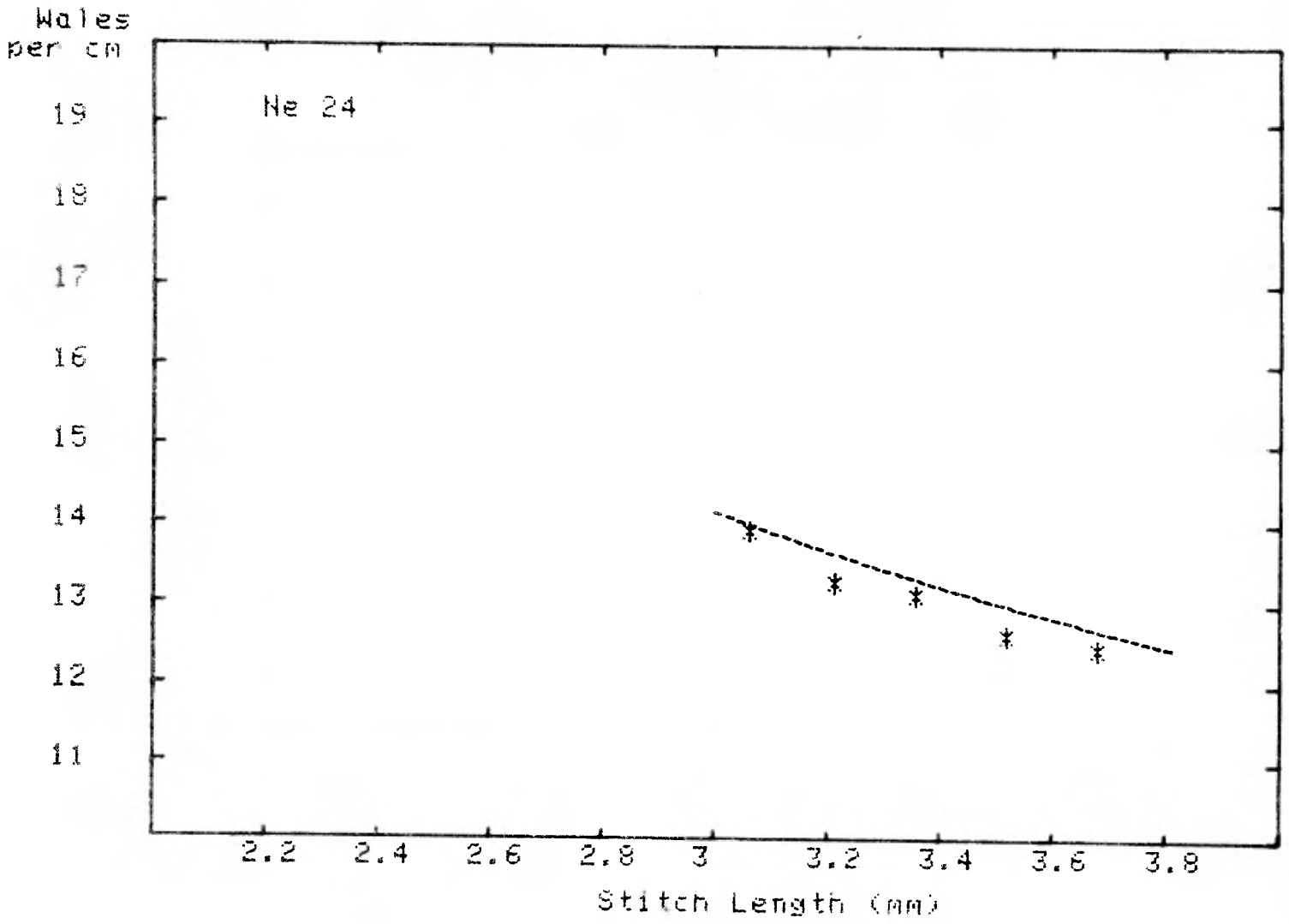

Fig.11. Pad-Batch Bleached - Measured Wales & Prediction

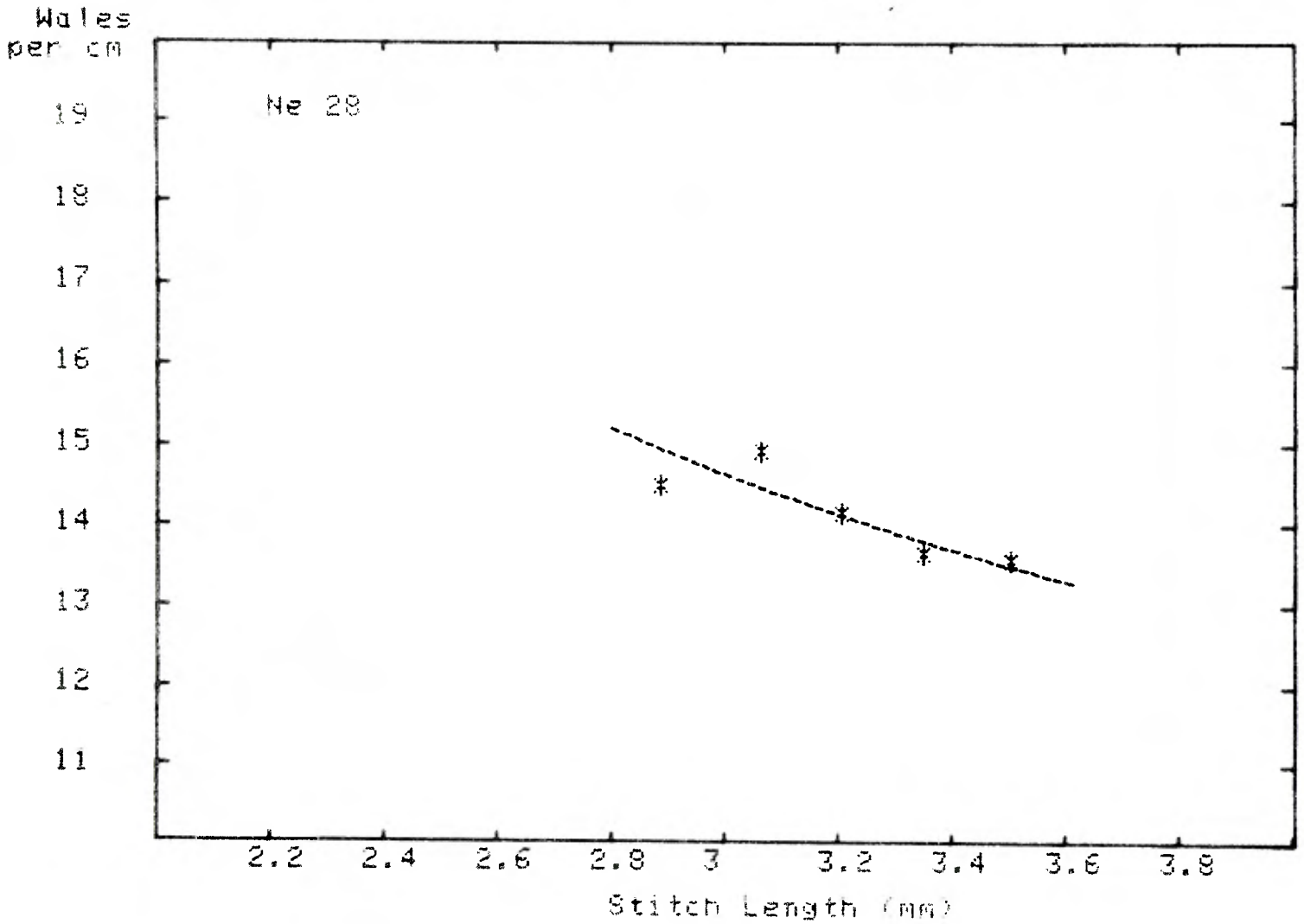

Fig.12. Pad-Batch Bleached - Measured Wales & Prediction

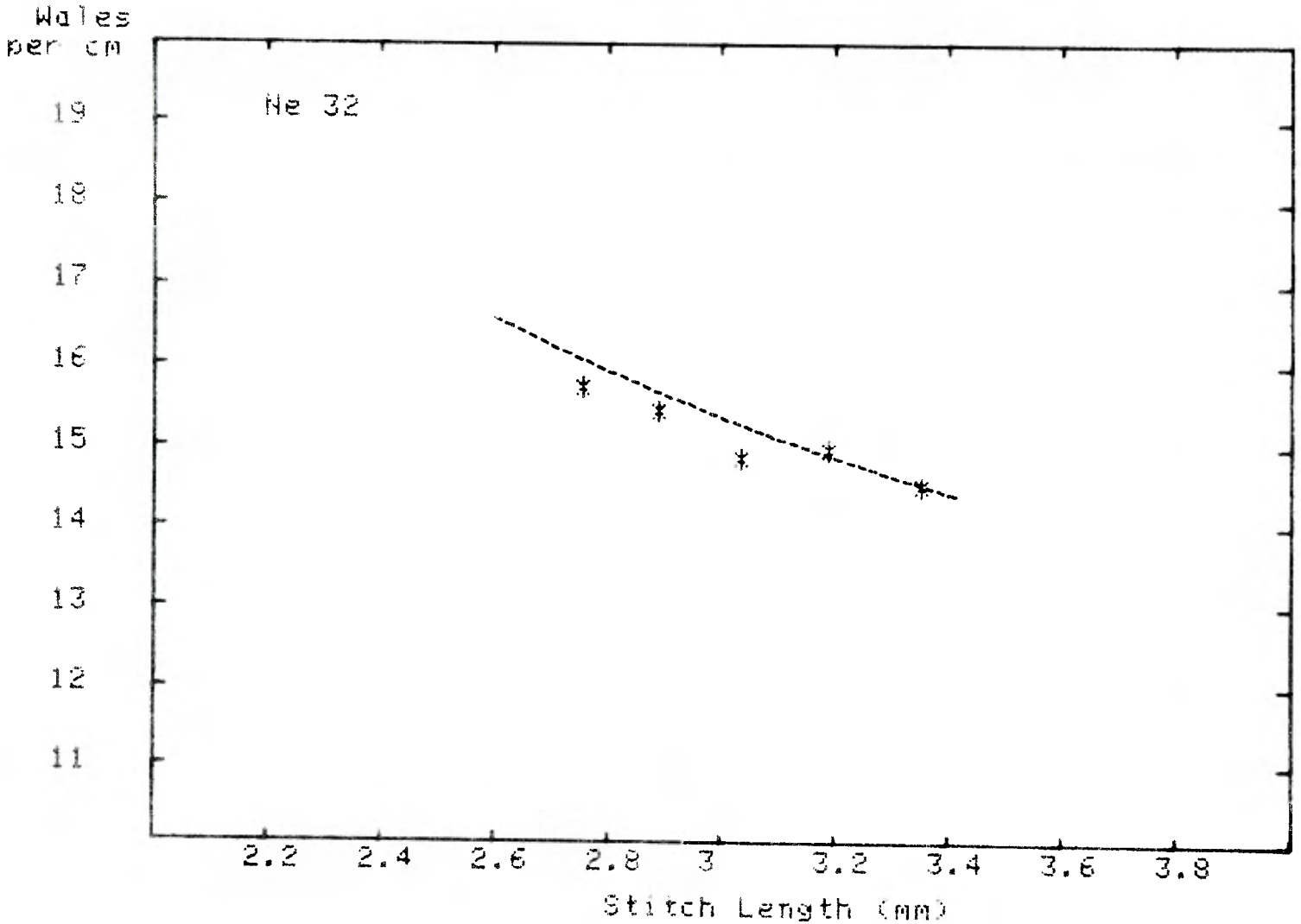

Fig.13. Pad-Batch Bleached - Measured Wales & Prediction

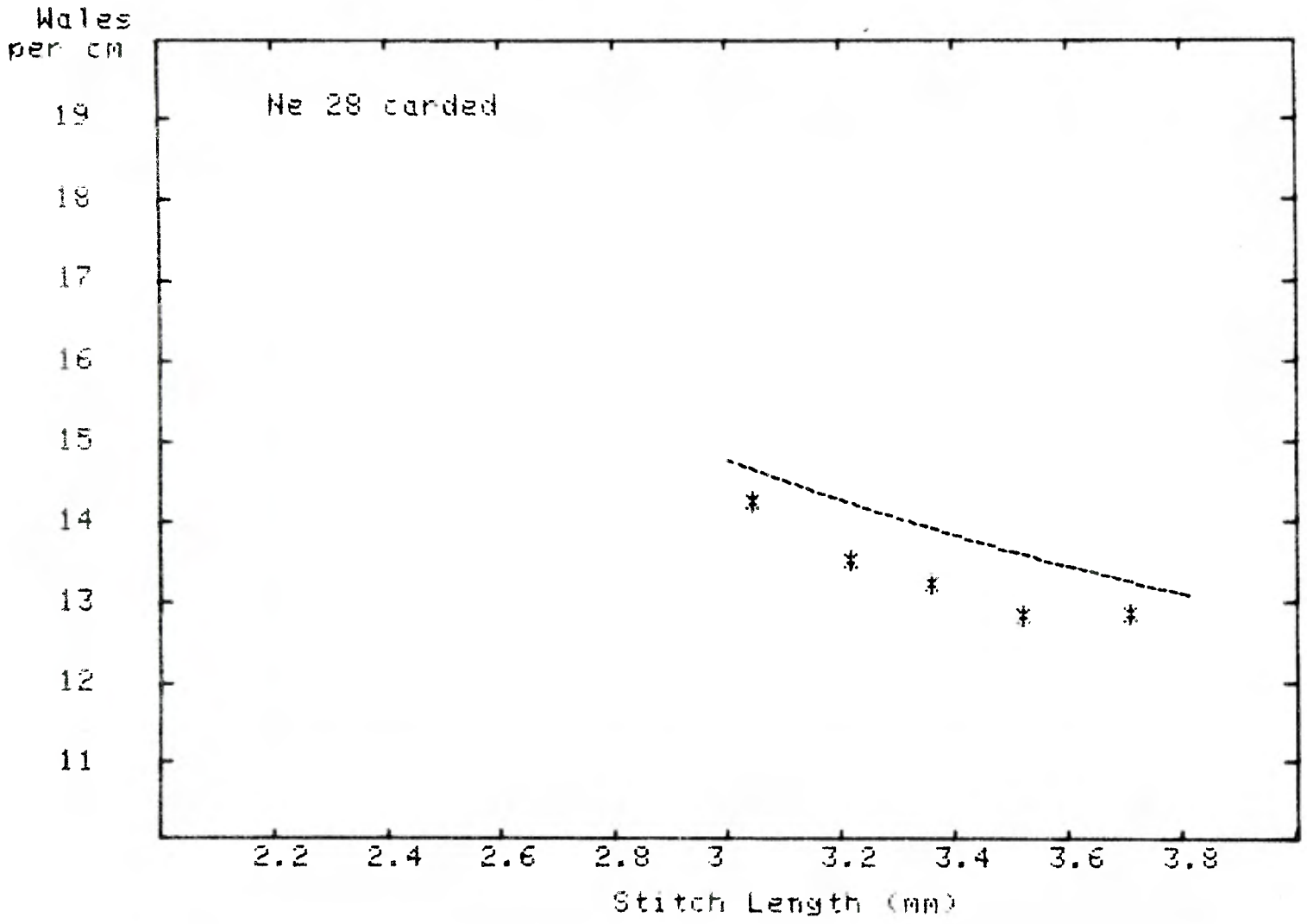

Fig.14. Pad-Batch Bleached - Measured Wales & Prediction

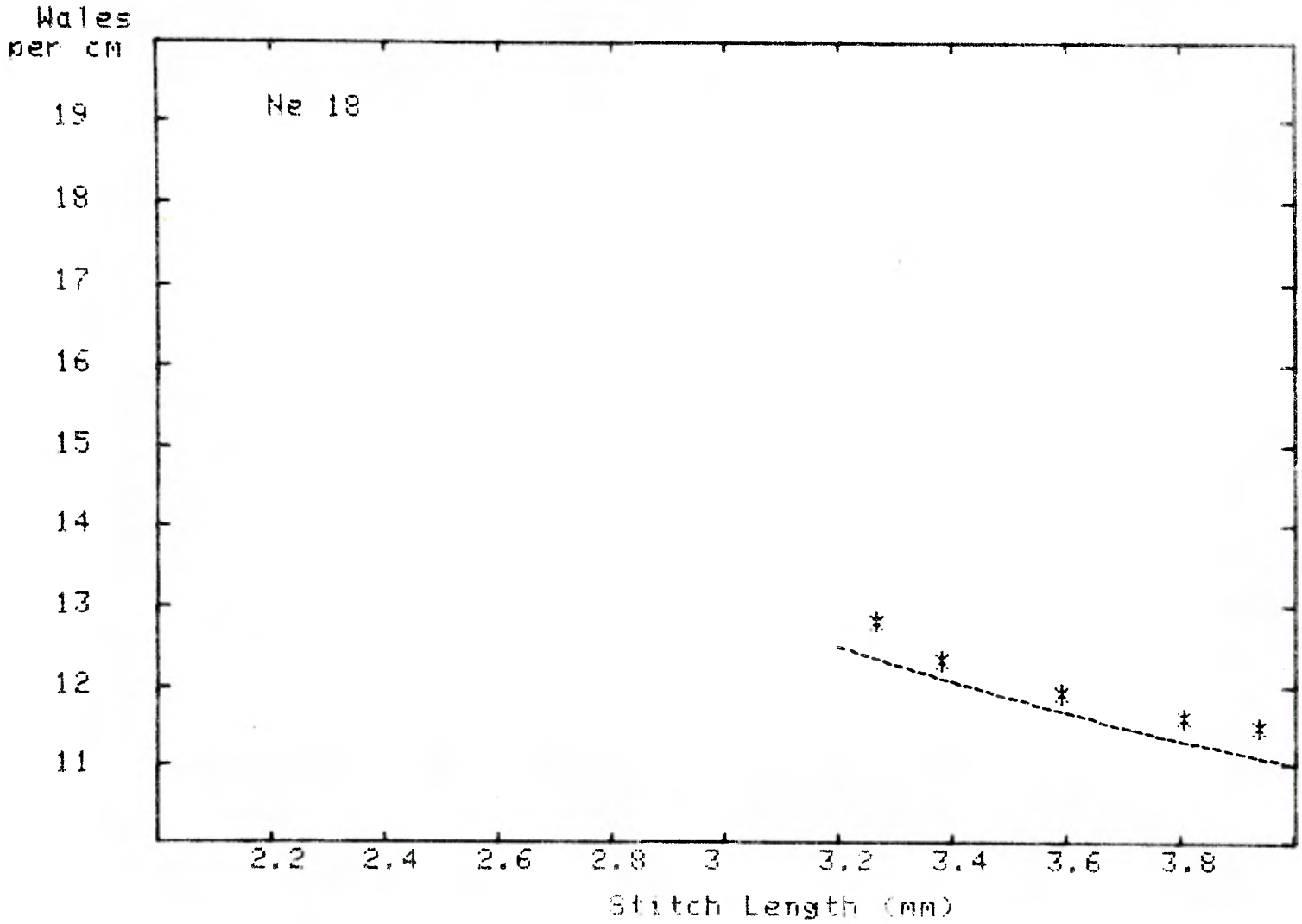

Fig.15. Pad-Batch Bleached - Measured Wales & Prediction

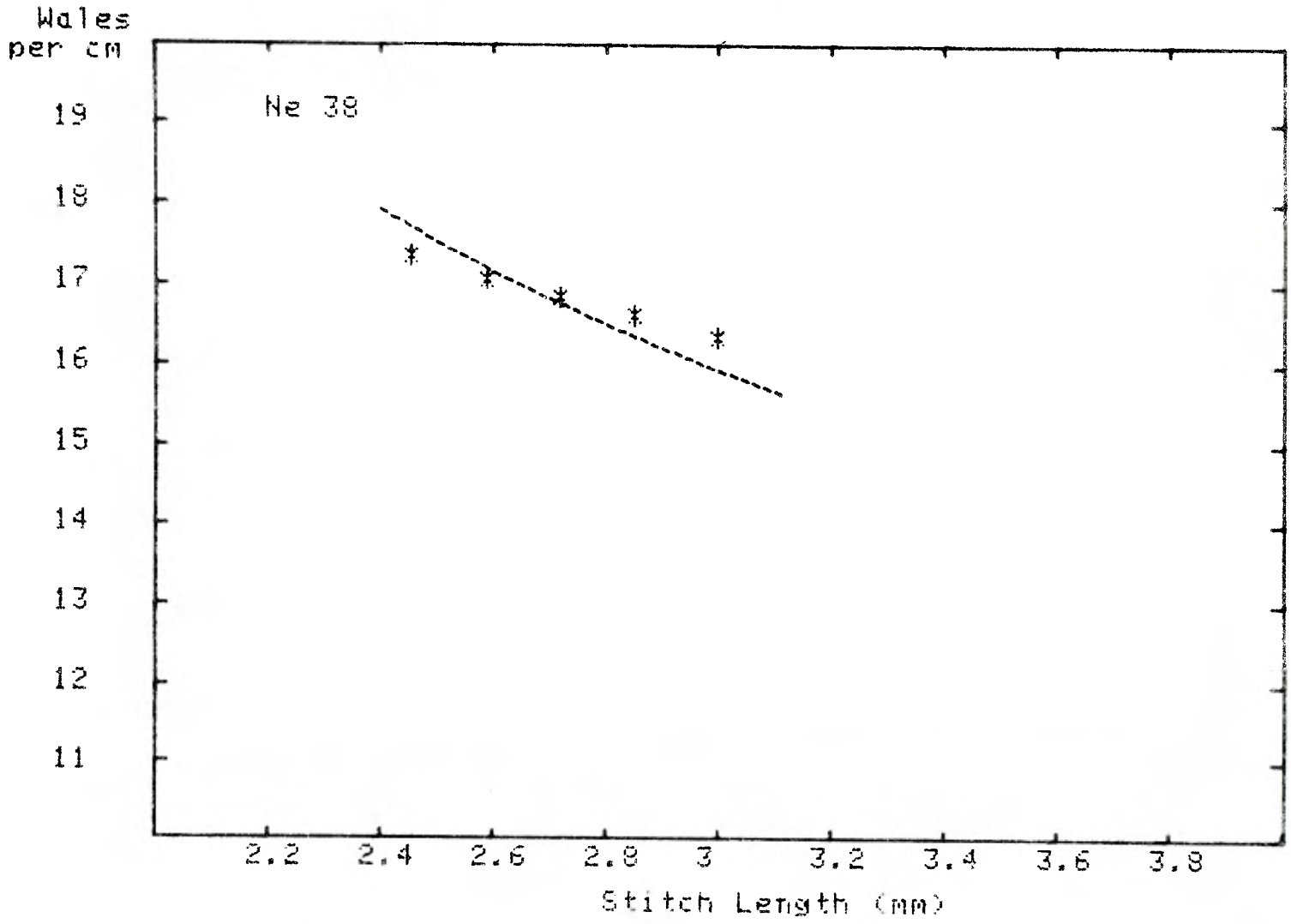

Fig.16. Pad-Batch Bleached - Measured Wales & Prediction

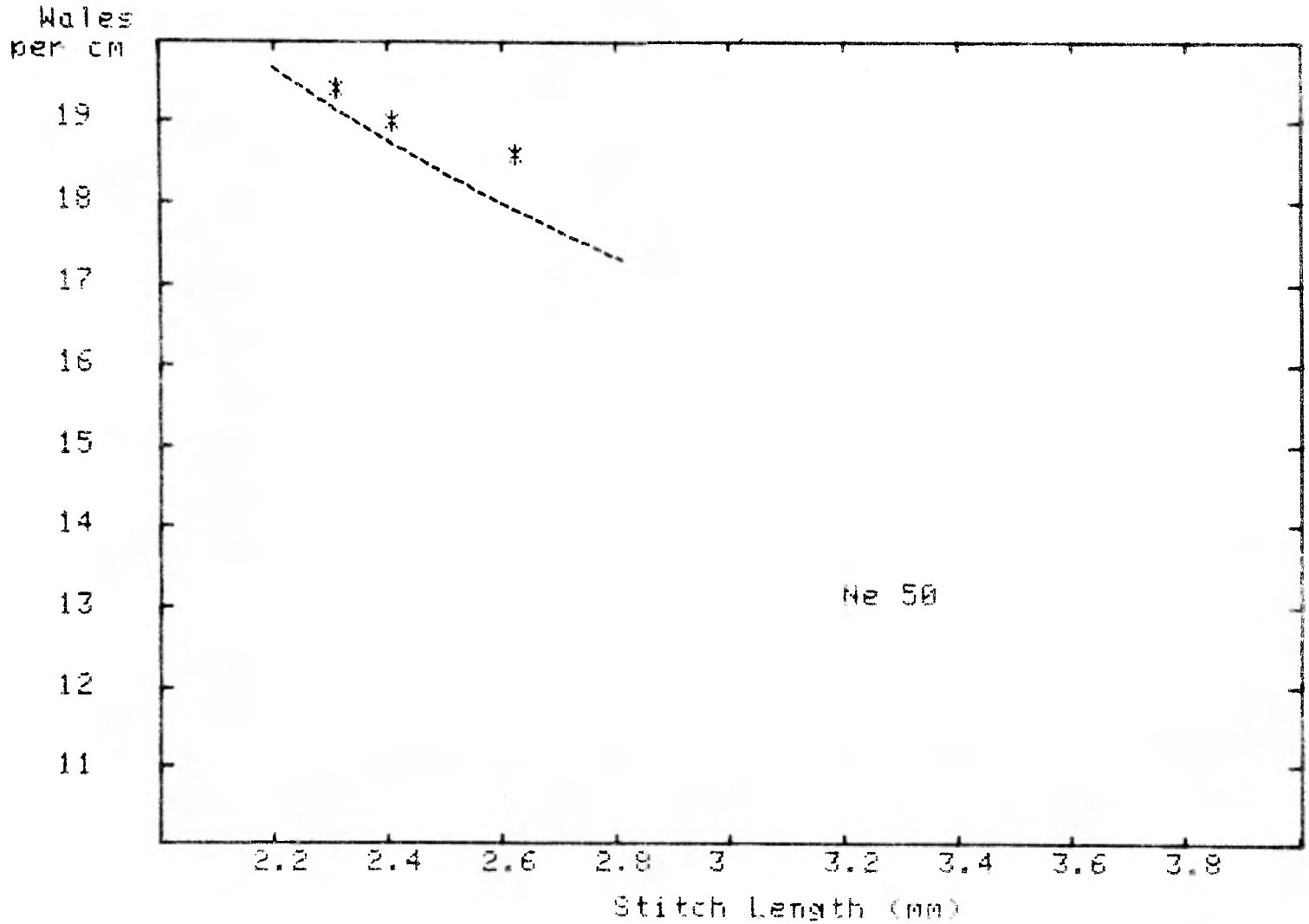

Fig.17. Pad-Batch Bleached - Measured Wales & Prediction

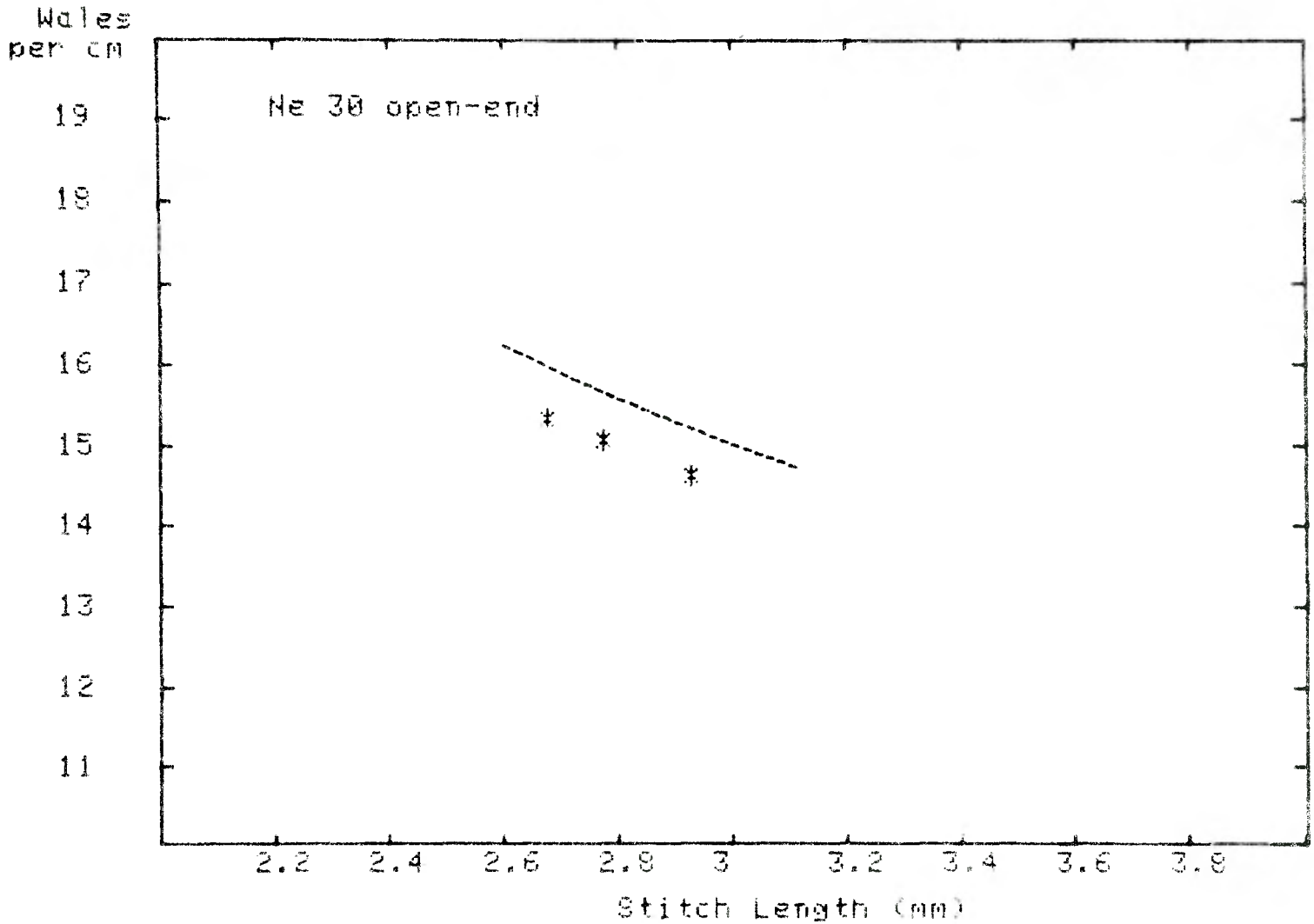

Fig.18. Pad-Batch Bleached - Measured Wales & Prediction

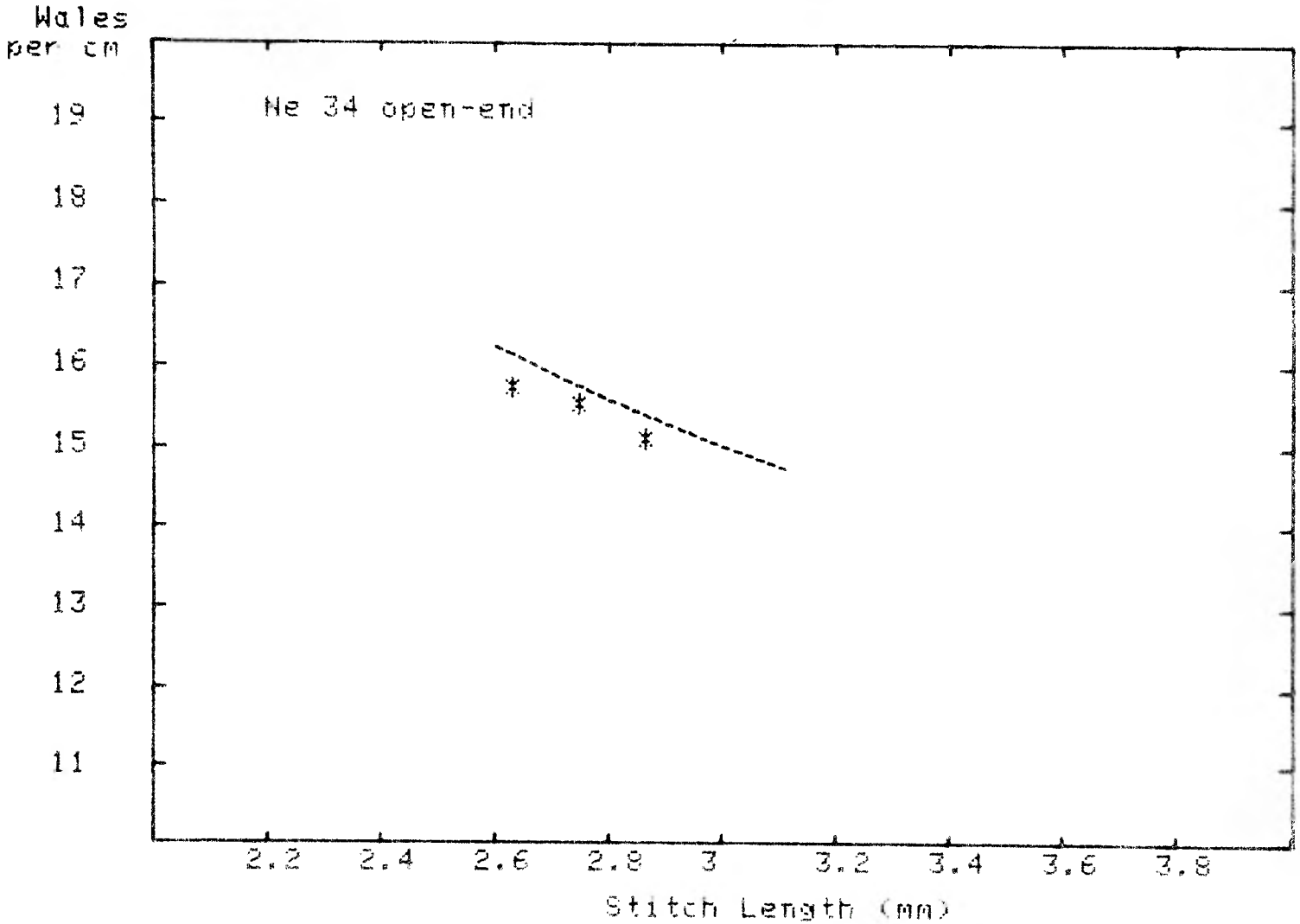

Fig.19. Pad-Batch Dyed - Measured Courses & Prediction

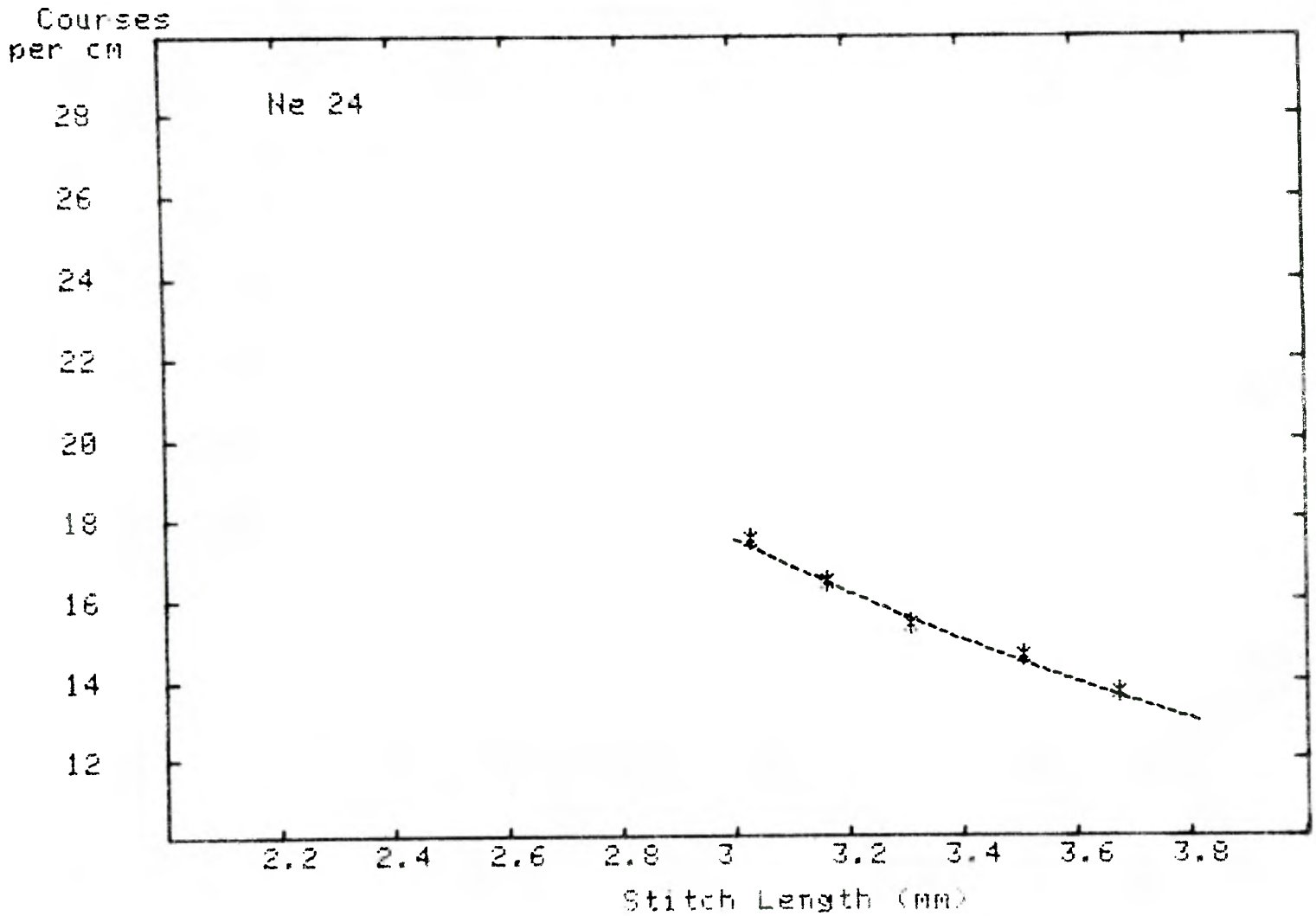

Fig.20. Pad-Batch Dyed - Measured Courses & Prediction

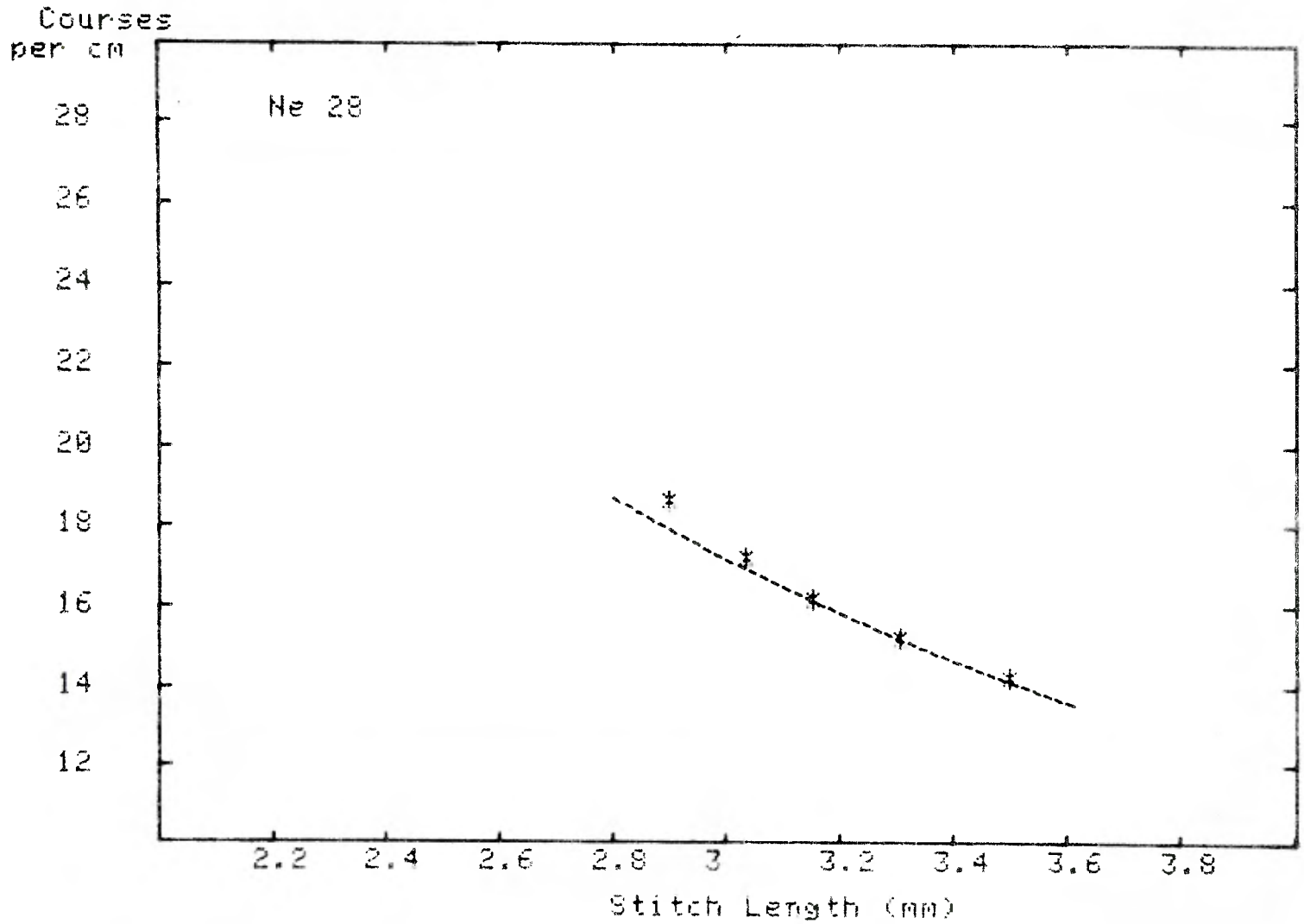

Fig.21. Pad-Batch Dyed - Measured Courses & Prediction

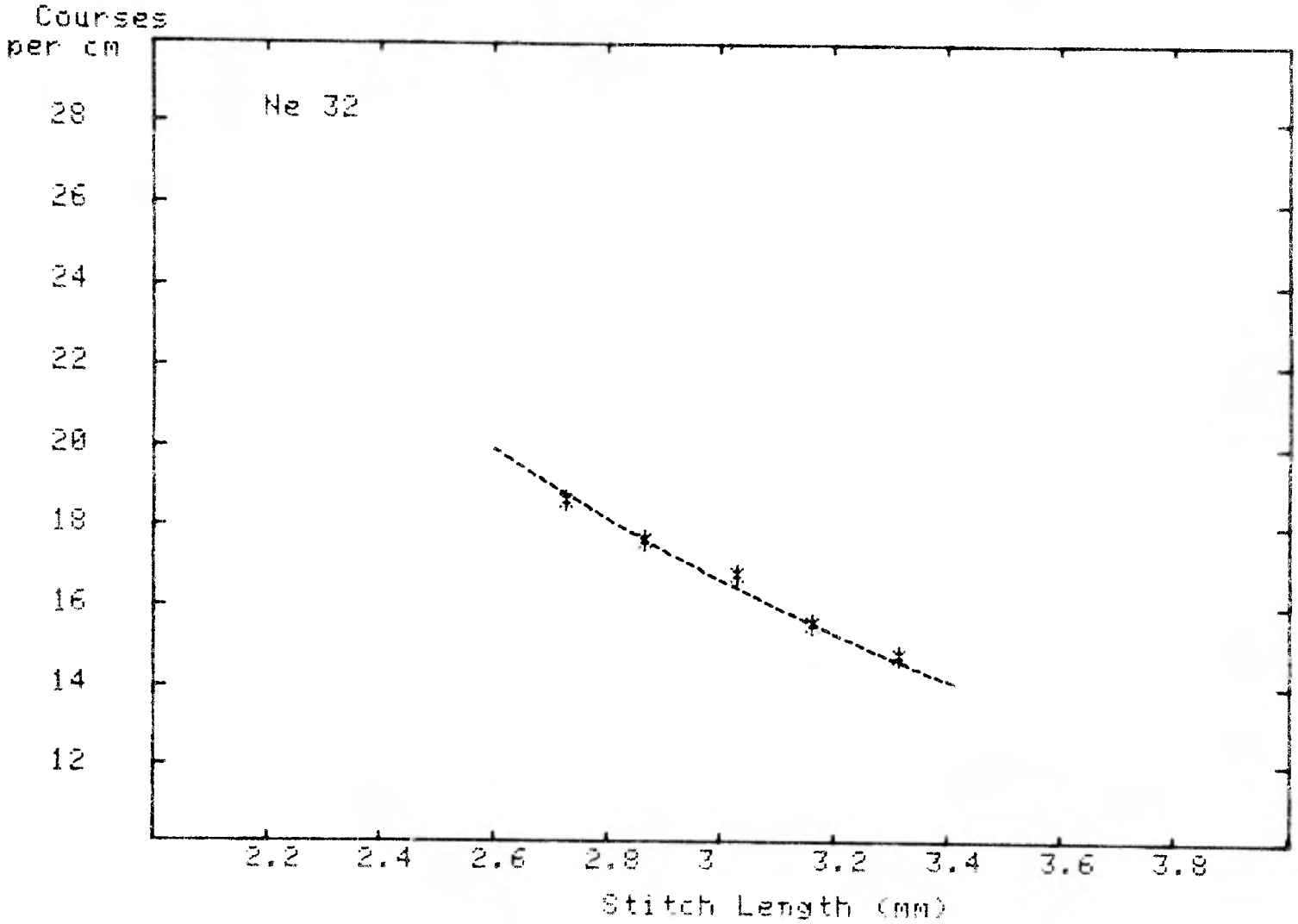

Fig.22. Pad-Batch Dyed - Measured Courses & Prediction

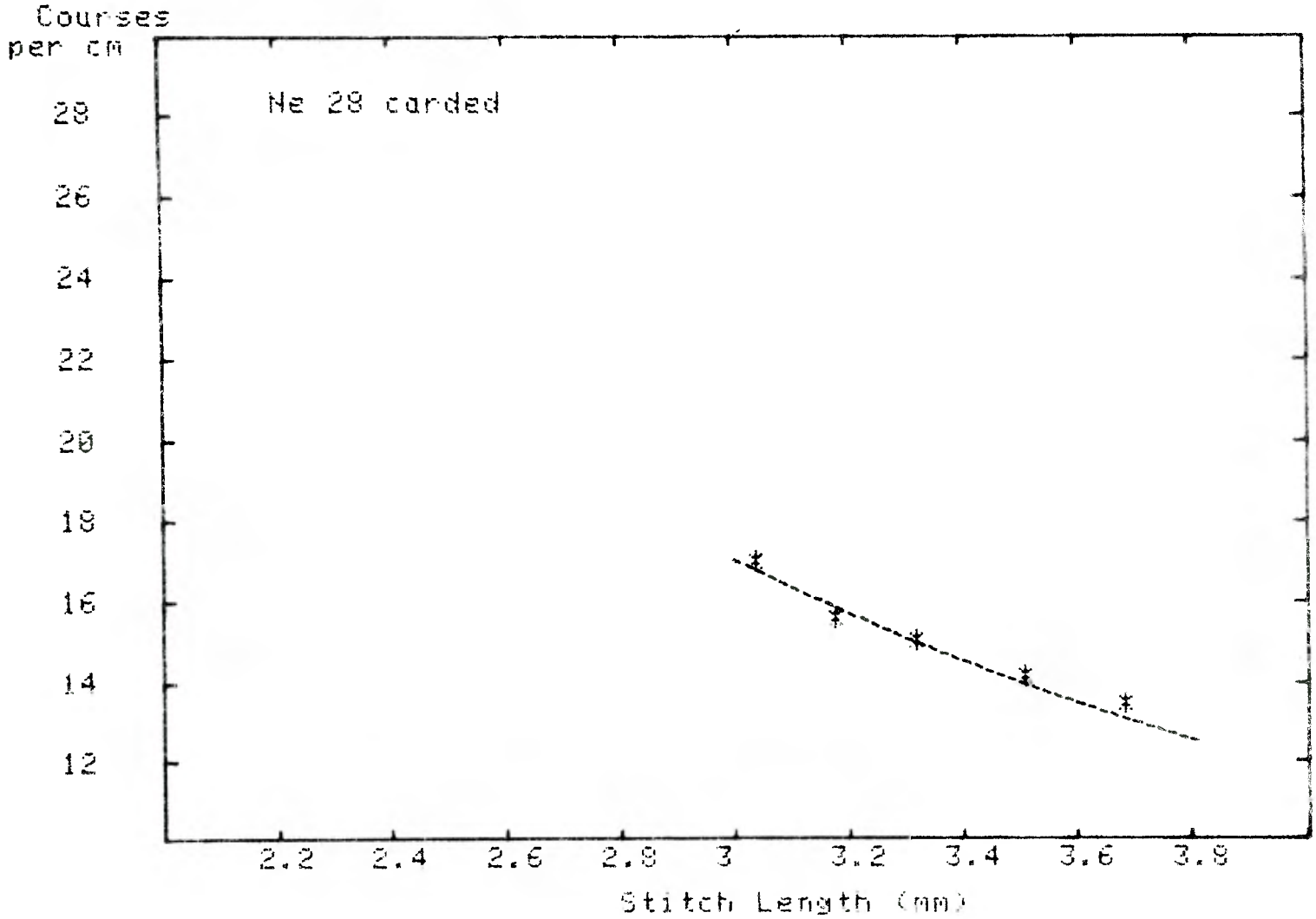

Fig.23. Pad-Batch Dyed - Measured Courses & Prediction

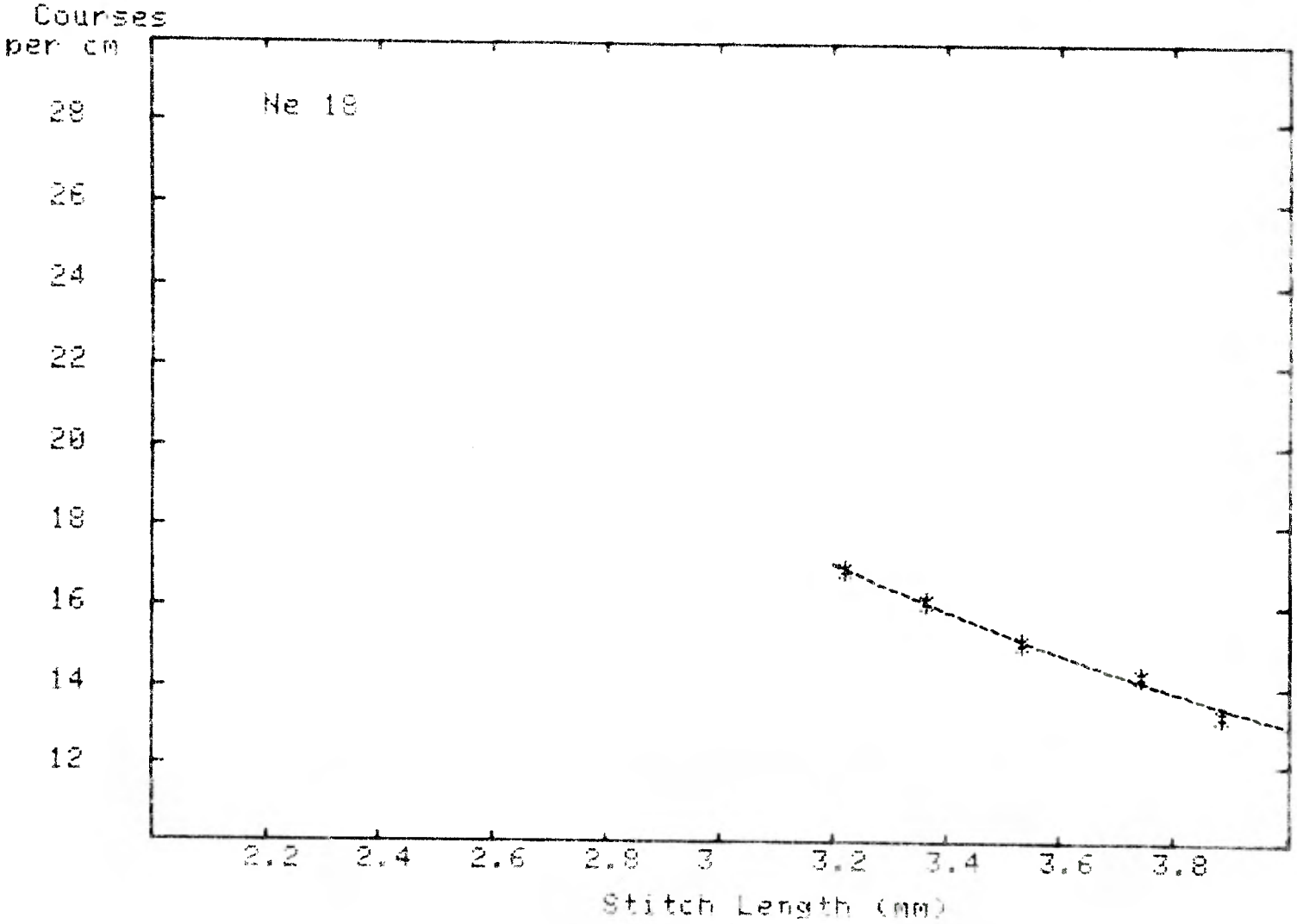

Fig.24. Pad-Batch Dyed - Measured Courses & Prediction

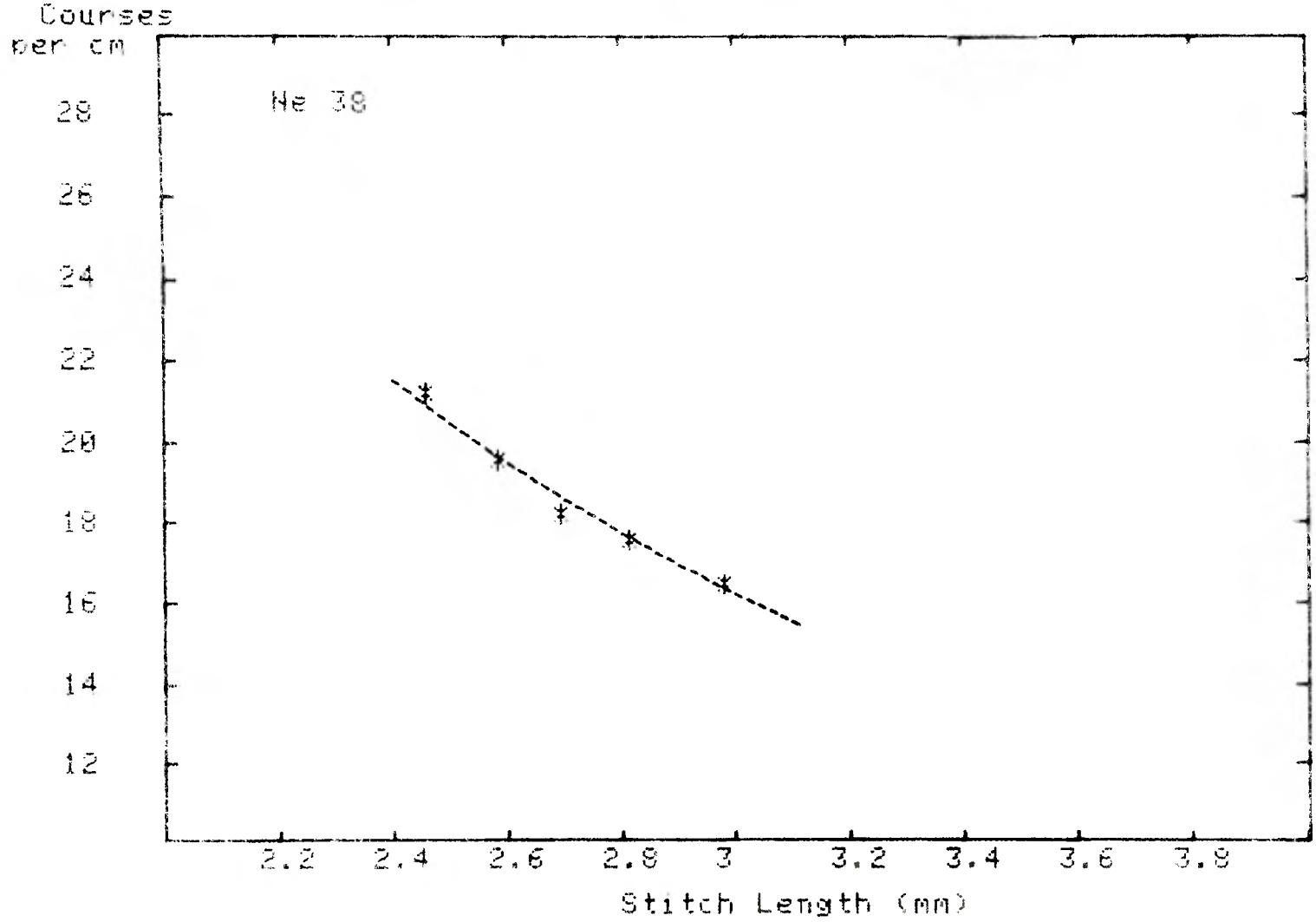

Fig.25. Pad-Batch Dyed - Measured Courses & Prediction

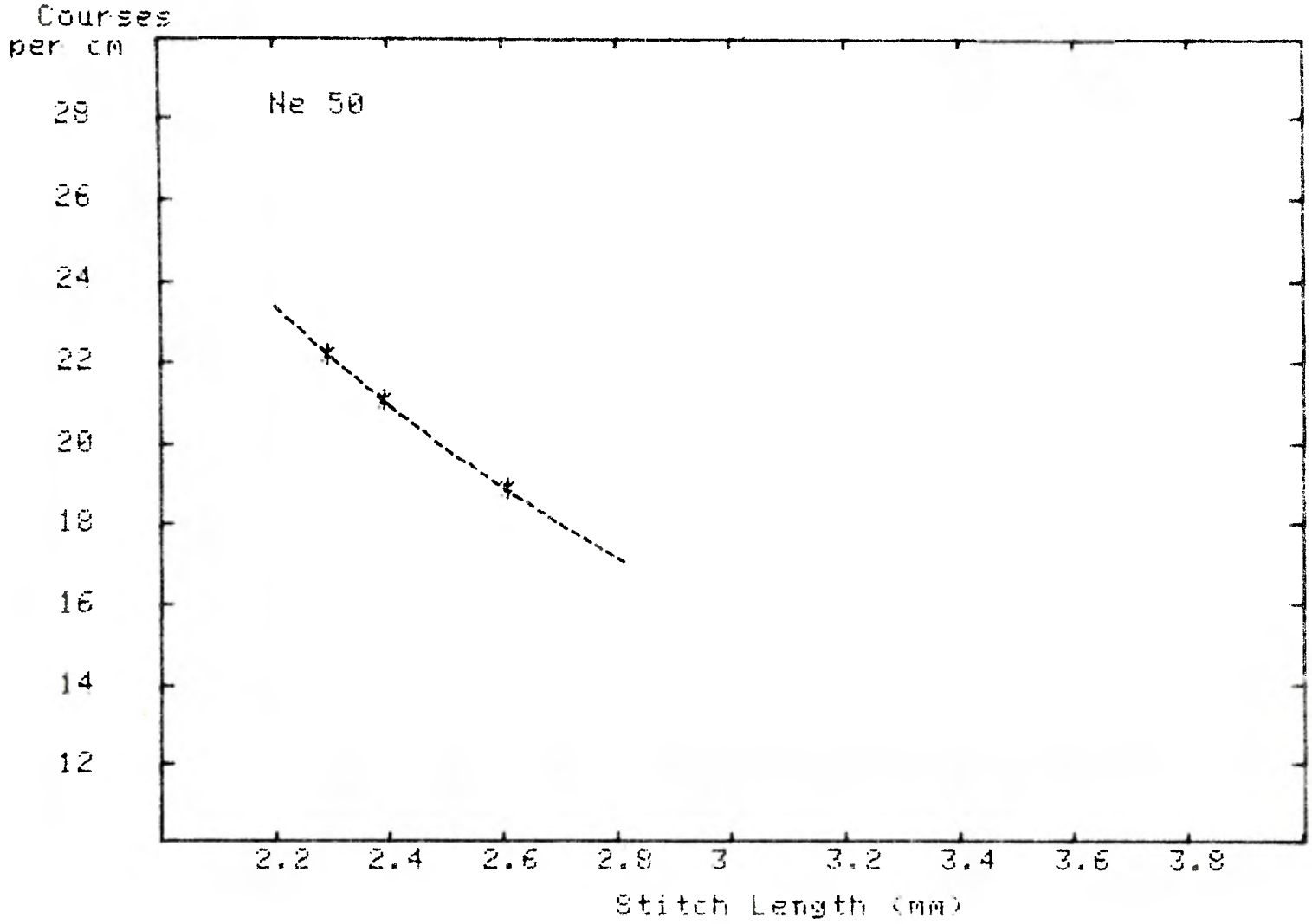

Fig.26. Pad-Batch Dyed - Measured Courses & Prediction

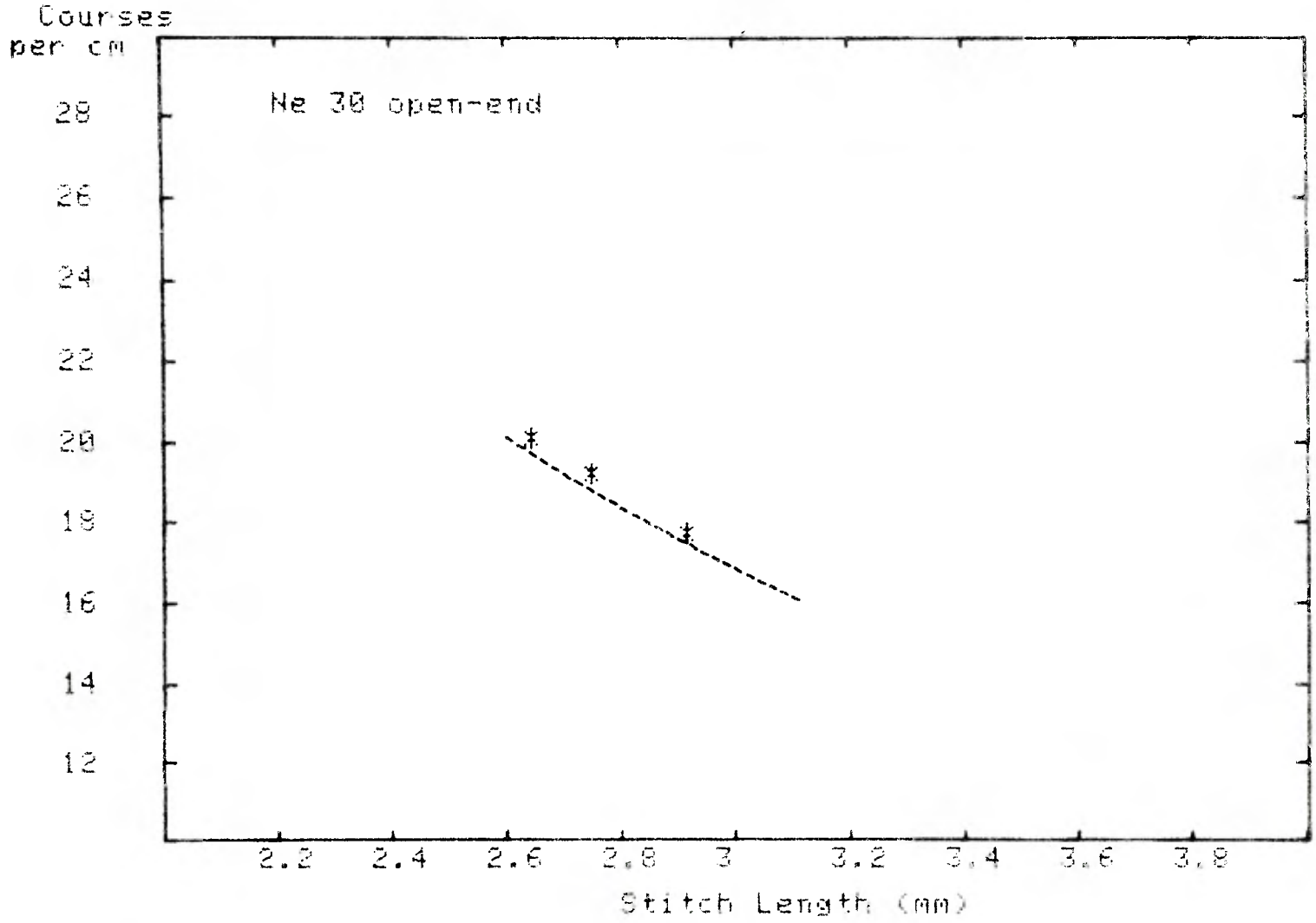

Fig.27. Pad-Batch Dyed - Measured Courses & Prediction

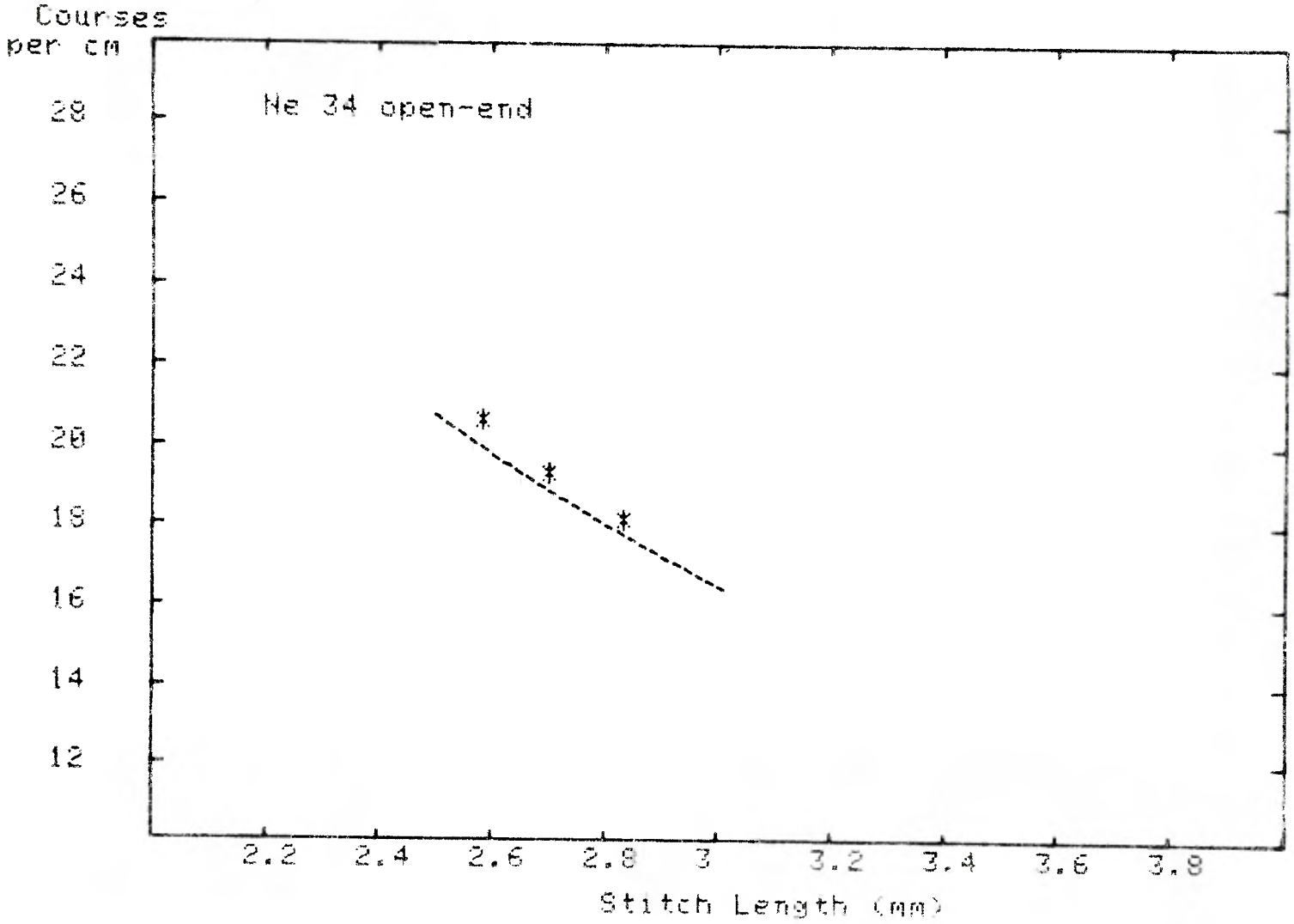

Fig.28. Pad-Batch Dyed - Measured Wales & Prediction

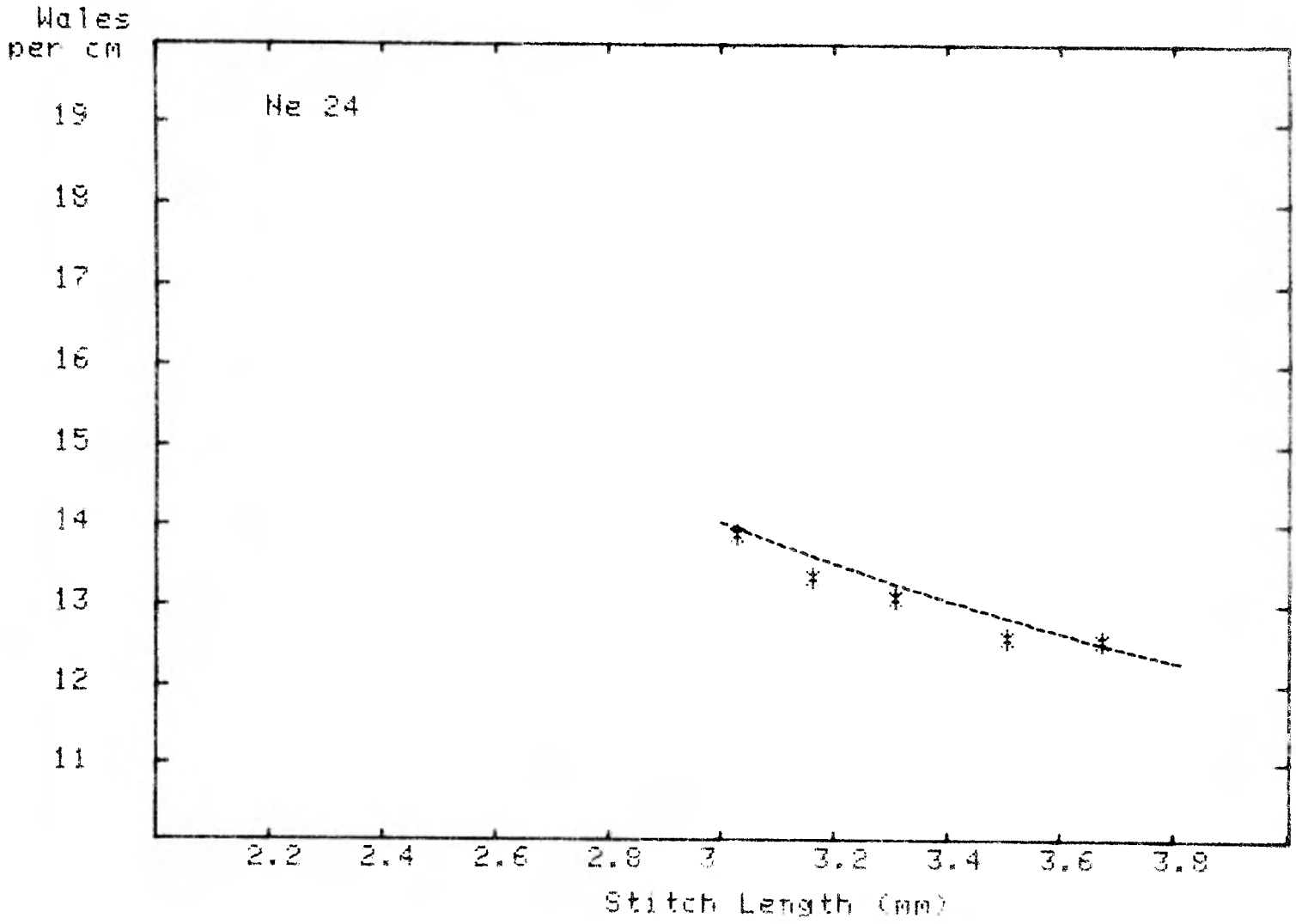

Fig.29. Pad-Batch Dyed - Measured Wales & Prediction

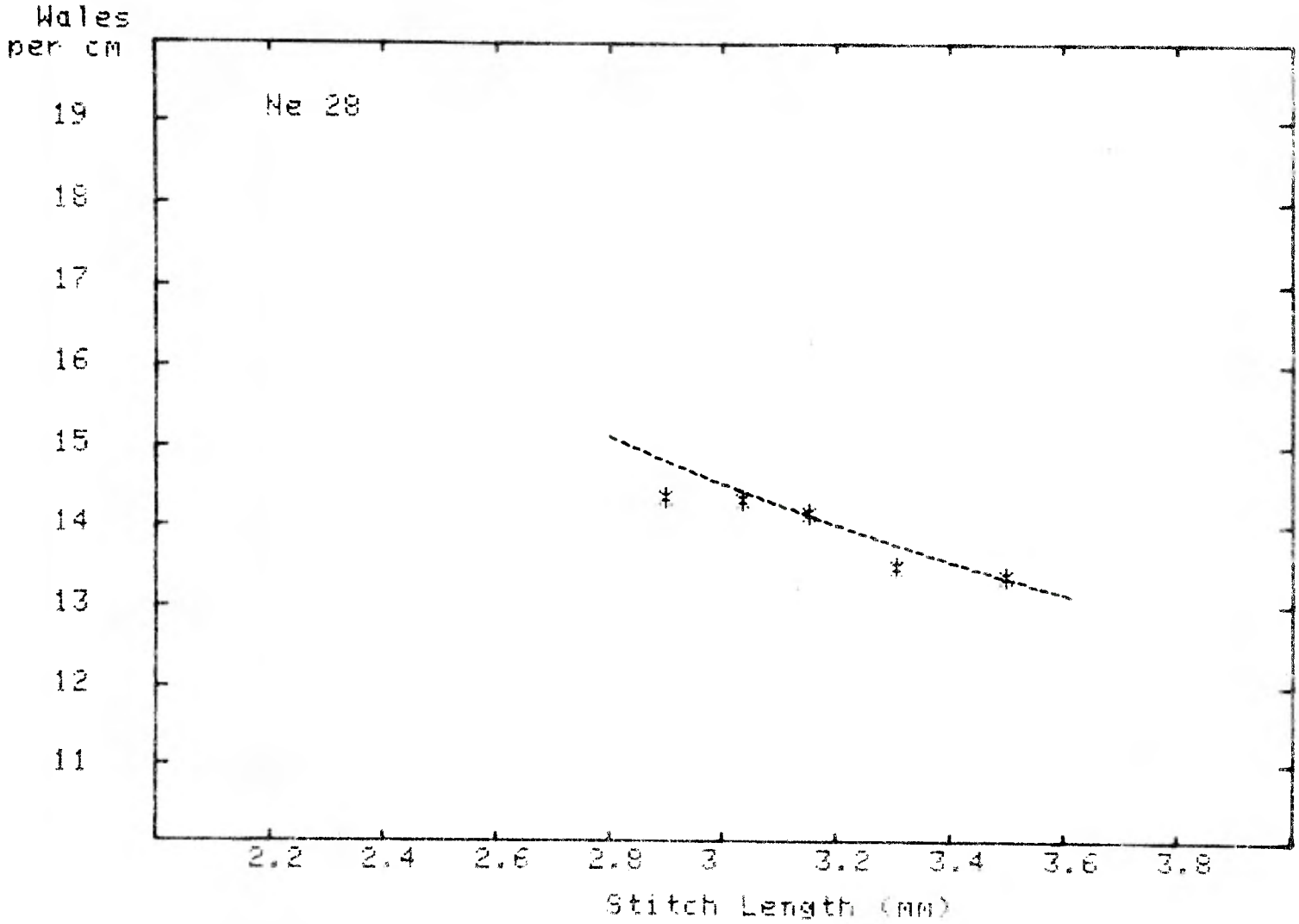

Fig.30. Pad-Batch Dyed - Measured Wales & Prediction

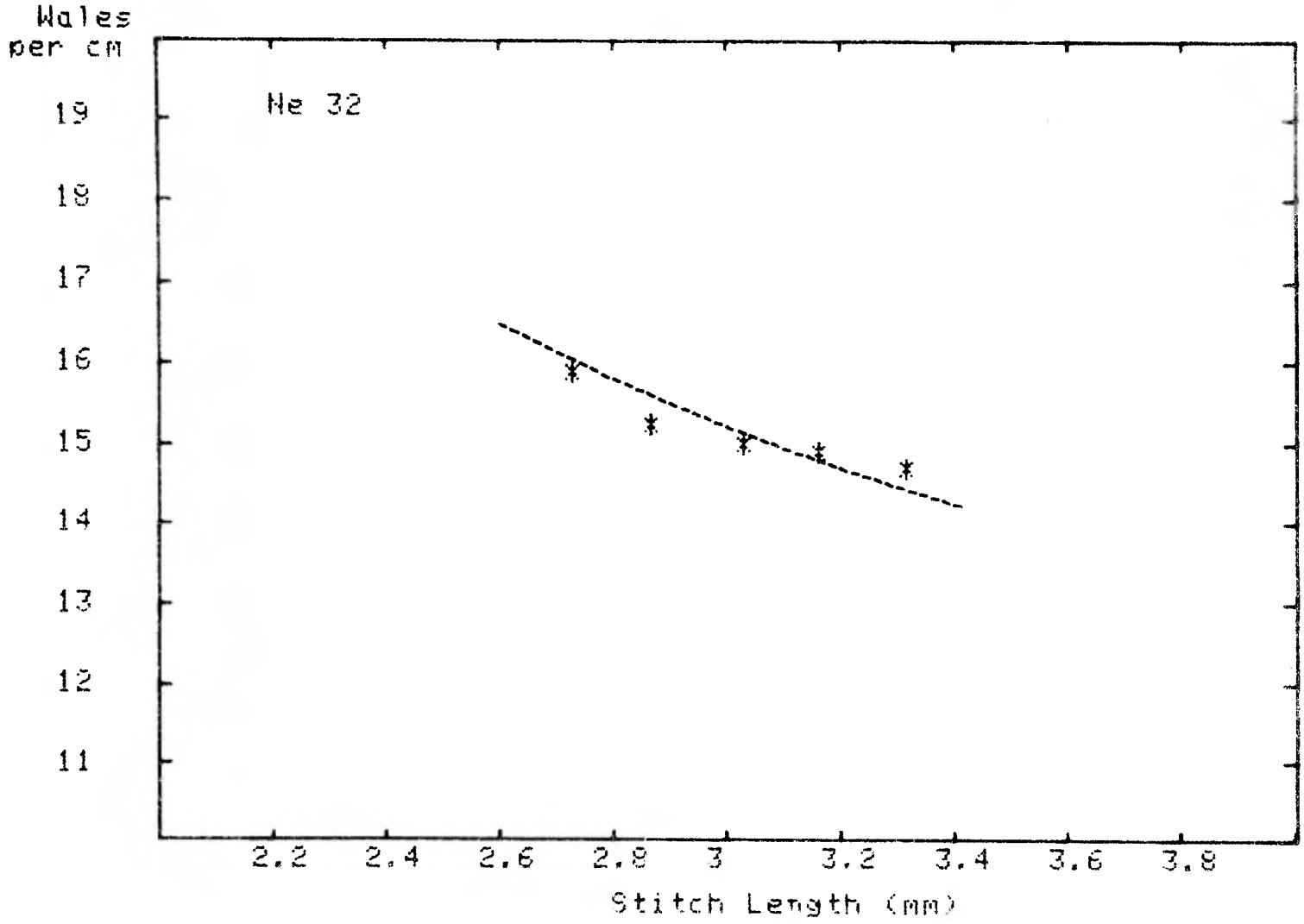

Fig.31. Pad-Batch Dyed - Measured Wales & Prediction

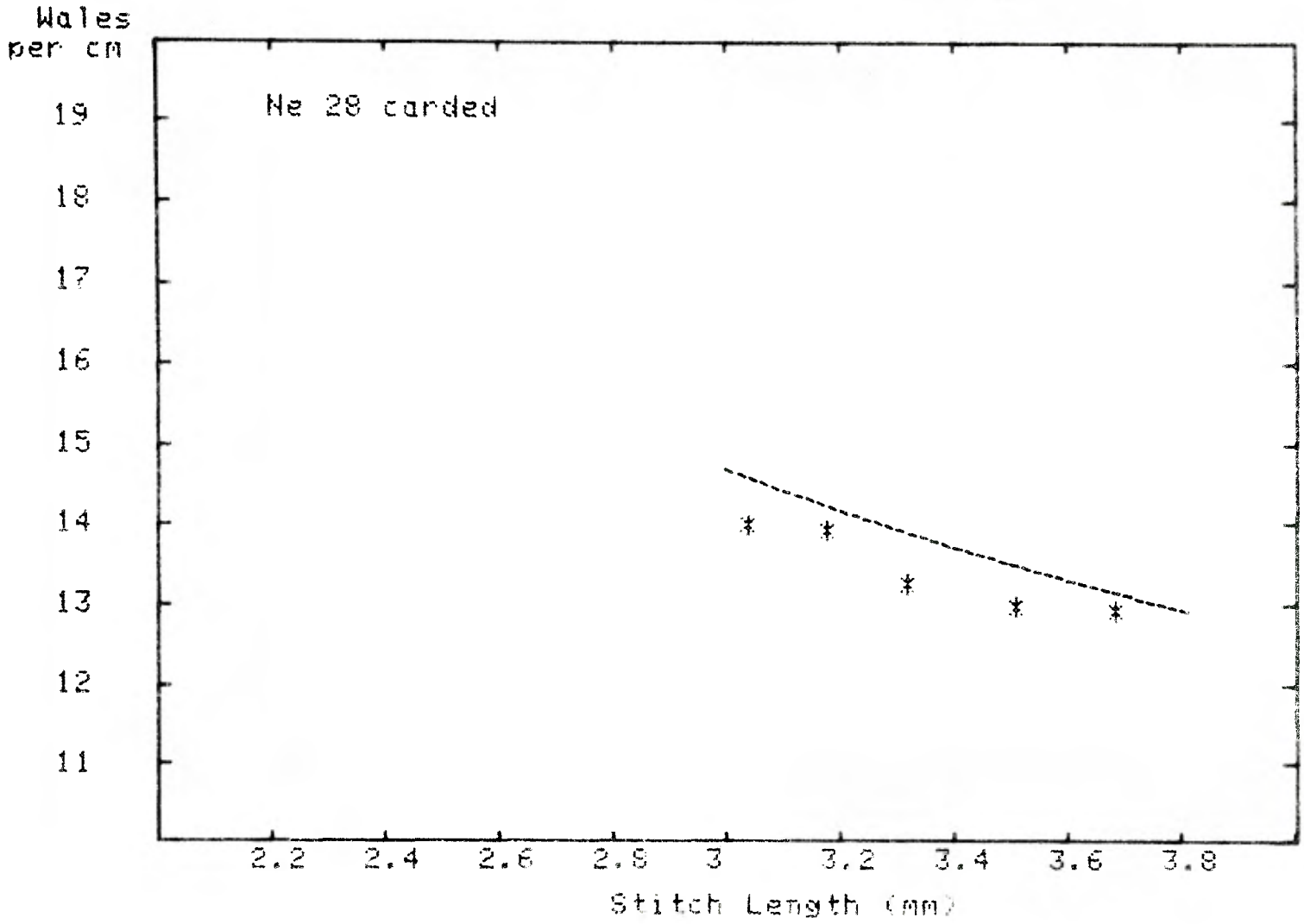

Fig.32. Pad-Batch Dyed - Measured Wales & Prediction

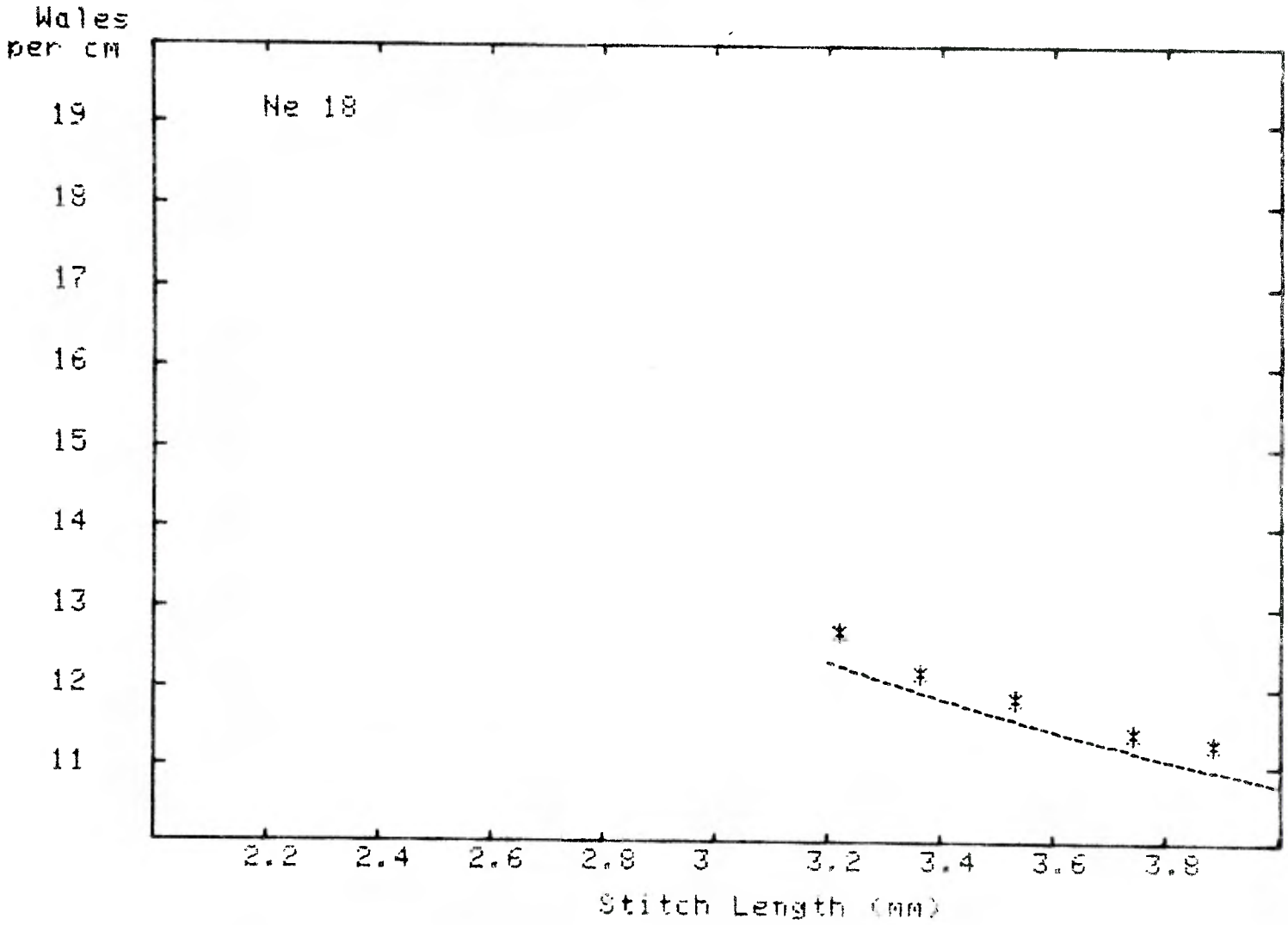

Fig.33. Pad-Batch Dyed - Measured Wales & Prediction

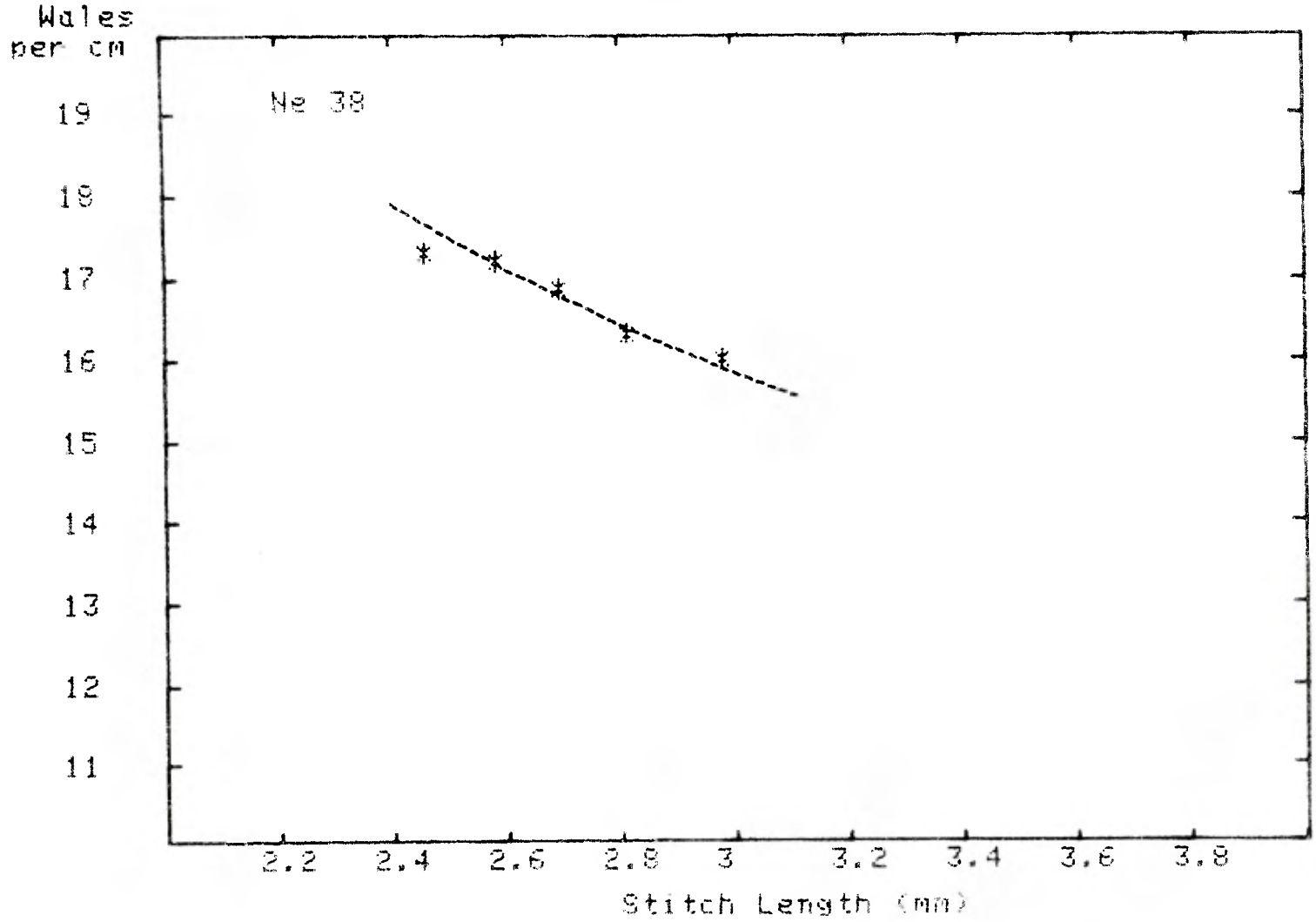

Fig.34. Pad-Batch Dyed - Measured Wales & Prediction

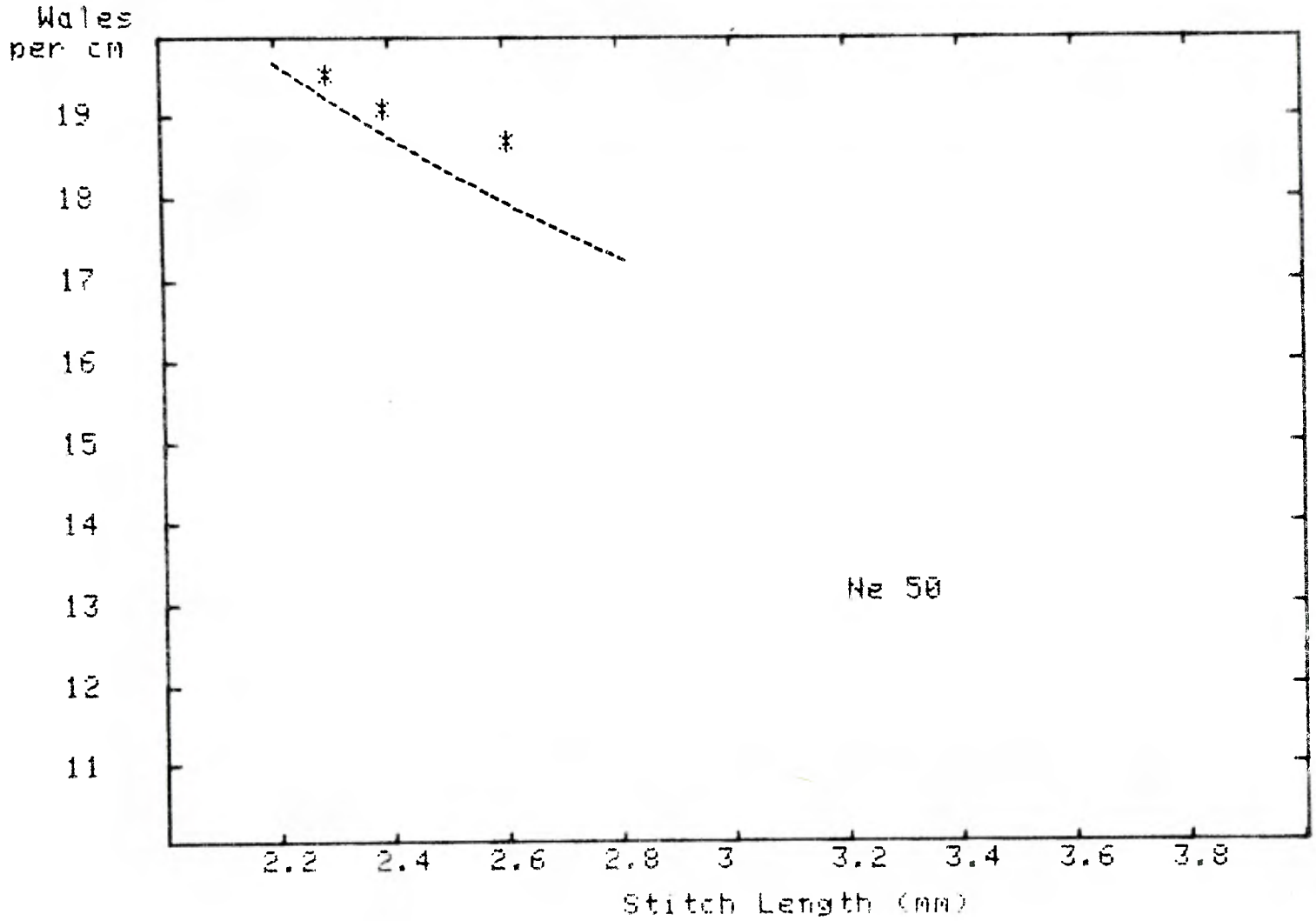

Fig.35. Pad-Batch Dyed - Measured Wales & Prediction

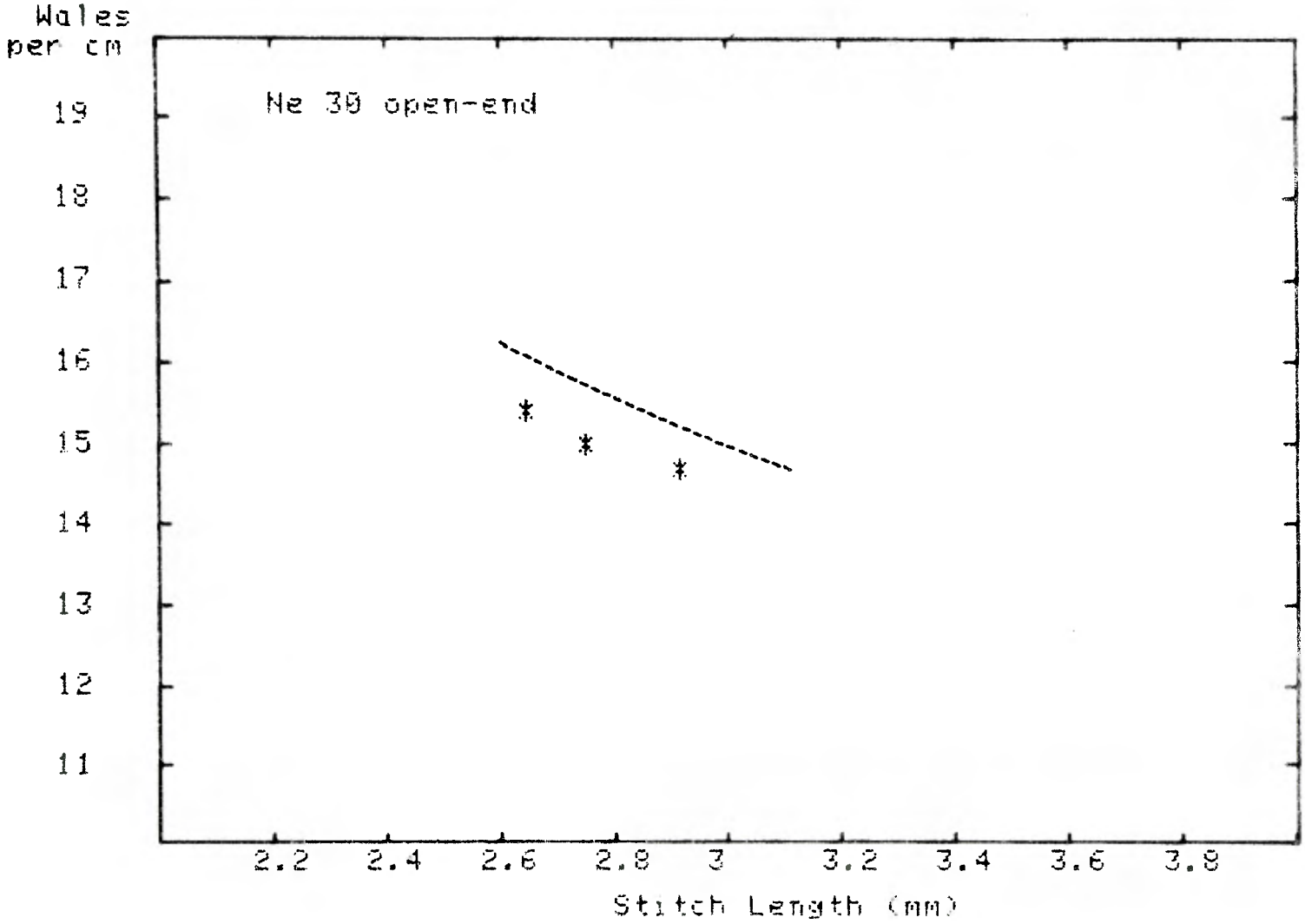

Fig.36. Pad-Batch Dyed - Measured Wales & Prediction

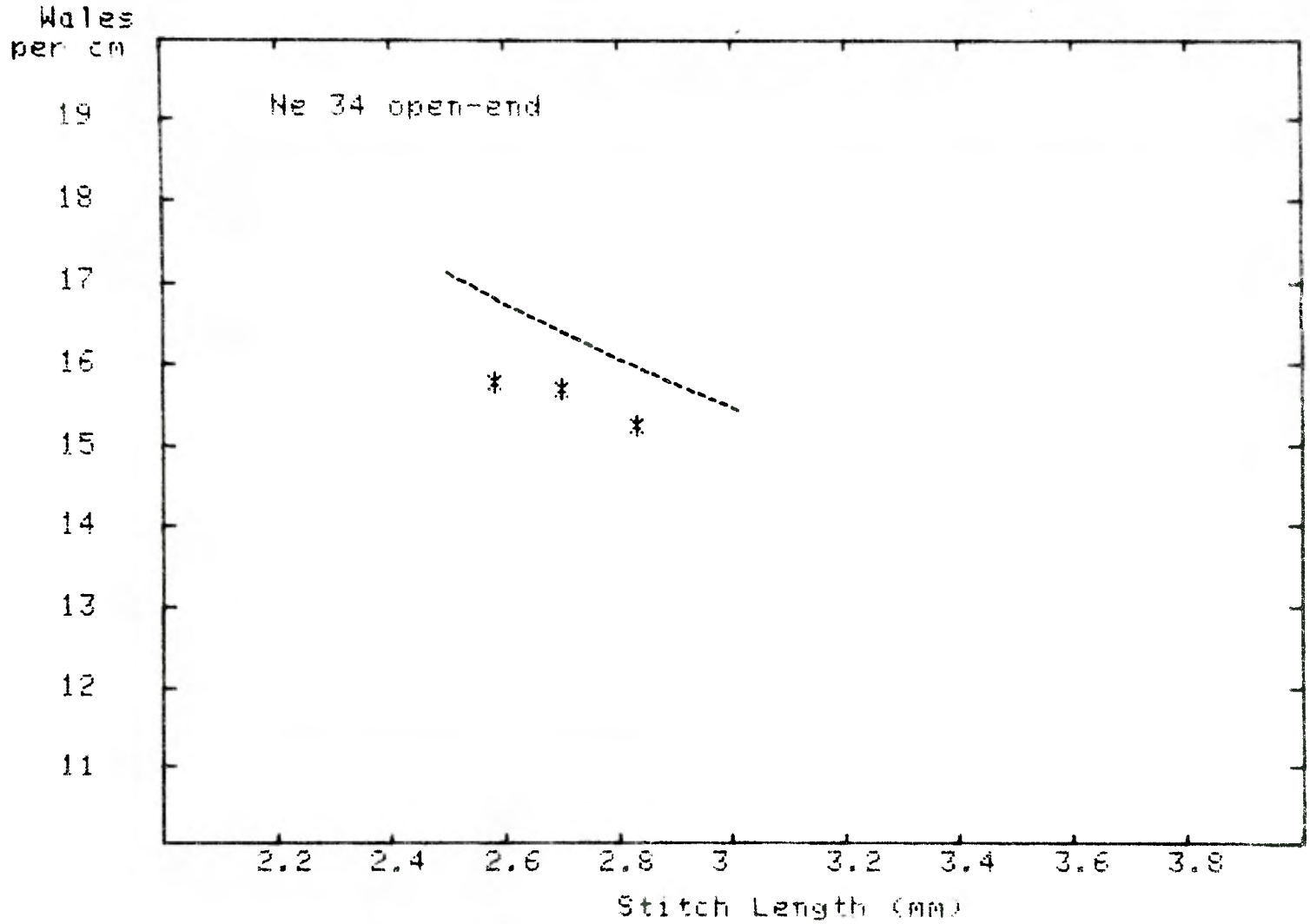

Fig. 37. Stitch length & Depth of Shade (Ne38)