EFFECTS OF REDUCTION, SQUARE ROOT OF THICKNESS AND SPREAD CONSTANT ON SPREAD FOR HOT FLAT ROLLED STEEL (HC SS316)

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ABSTRACT

The increasing tendency towards automation of the rolling process together with the trend towards more stringent specifications for hot rolled products, particularly wide strip for subsequent cold rolling, makes it highly desirable to assess the effects reduction, square root of thickness and spread constant have on spread for steels (HC SS316) hot flat rolled at low strain rates.

The spread coefficient (SPECO 1, SPECO 2 and SPECO 3) increased gradually as reduction increased from 8% to 25% with average values of 0.065, 0.057 and 0.039 respectively for both low and high speeds of 9.32mm/s and 133mm/s.

For square root of thickness (SRTHS) varying between 1.04 – 1.16, spread coefficient, SPECO 1 was 0.057 – 0.076; SPECO 2 was 0.048 – 0.069 and SPECO 3 was 0.025 – 0.056 for low and high speeds of 9.32mm/s and 133mm/s.

The effect of spread constant, Z1 on spread coefficient (SPECO 1, SPECO 2 and SPECO 3) is contrary to that of reduction and that of square root of thickness (SRTHS). As spread constant, Z1 increased, spread coefficient decreased for both low and high speeds of 9.32mm/s and 133mm/s.

Keywords: *reduction, square root of thickness, spread constant, spread coefficient, hot flat rolled steel.*

INTRODUCTION

The subsequent cold rolling of slab and strips from hot rolled products makes the assessment of spread produced under hot flat rolling of stainless steel (HC SS316) at low strain rates and low reductions very important.

Various authors have worked on methods of calculating spread under hot flat rolling conditions while formula proposed by El-Kalay and Sparling (1968) and an earlier one where,

w_1, w_2 – initial and final width

h_1, h_2 – initial and final thickness

S – spread coefficient and represents the increase in w_2/w_1 value when the specimen is reduced to zero thickness.

According to Helmi and Alexander (1969), the effective flow stress in terms of the spread coefficient is given as:

$$\delta_{eff} = \delta\sqrt{1 - S + S^2} \qquad (3)$$

where,

δ - flow stress in axi-symmetric compression

δ_{eff} – effective flow stress

S – spread coefficient

Various authors, (Beese, 1972; Eklund, 1933; Hill, 1950) have all proposed various formulas for calculating spread coefficient under hot rolling conditions but the ones by Sparling (1961) and El-Kalay and Sparling (1968) gave most accurate values.

$$\ln w_2/w_1 = A \ln \frac{H_2}{H_1} . e^{-BZ} \qquad (4)$$

$$Z = \left({}^{w_1}\!/\!_{H_1} \right)^C x \left({}^{H_1}\!/\!_{R^1} \right)^D x\, r^E \qquad (5)$$

where,

w_1, w_2 – initial and final width (mm)

H_1, H_2 – initial and final thickness (mm)

R^1 – deformed roll radius (mm)

Z – Geometrical dimensionless variable

And A,B,C,D,E are constants.

A comparison of the constants as obtained by El-Kalay and Sparling (1968) is shown in Table 1.

$$Y = \ln \left\{ \frac{\ln\left({}^{H_1}\!/\!_{H_2} \right)}{\ln\left({}^{w_2}\!/\!_{w_1} \right)} \right\} \text{ can be plotted against Z}$$

i.e. logarithm of Draft strain to spreading strain ratio vs geometrical dimensionless variable, Z (see Fig. 4).

According to Sparling,

$$w_2/w_1 = \left({}^{H_1}\!/\!_{H_2} \right)^m \qquad (6)$$

Where,

$$m = 0.981 e^{-0.6735\left\{2.395 \frac{w_1^{0.9}}{R^{0.55} H^{0.1} ((\Delta h))^{0.25}}\right\} abfgj}$$

where, a,b,f,g,j are constants

a = 1.0 for smooth ground rolls

< 1.0 for rough rolls

b = 1.0 for scale free bar metal surface

> 1.0 for scaled metal surface

by Sparling (1961) have been used with experimental data of Aiyedun (1984) to obtain the spread coefficient for stainless steel at reductions, r = 8-25%; low strain rates, $\bar{\varepsilon}$ = 0.08-2.5s^{-1} on a mill of diameter 254mm.

Defining SPECO 1, SPECO 2 and SPECO 3 as spread coefficients obtained for: rolling with smooth rolls, light scale using El-Kalay and Sparling theory; rolling with rough rolls, light scale using El-Kalay and Sparling theory; and rolling with smooth rolls, light scale using Sparling theory respectively, the effects of reduction, square root of thickness, and spread constant on spread coefficient were studied for hot flat rolled stainless steel (HC SS316).

According to Al-Alawi and Sparling (1982), lubrication of rolls reduces roll force and torque while it gives a decrease in roll wear and spread of specimen. In addition to the general observation that for $w_1 >> (R\delta)^{1/2}$ where $(R\delta)^{1/2}$ = Arc Length = Square Root of (Deformed Redius x Reduction in Thickness), lubricated test pieces spread less than dry test pieces, lubrication affects the amount of spread, being lower for lubricated bars with light scale but it has almost no effect with more heavily scaled bars. Less spread occurred with smooth rolls than with rough rolls and in general, well scaled specimens spread less than specimens without scale.

SPREAD DURING HOT ROLLING AND SPREAD FORMULAE

Magnitude of spread is judged using either spread ratio w_2/w_1 or absolute spread w_2-w_1. Defining spread coefficient as the ratio of the natural strain in the width direction to the natural (compressive) strain in the thickness direction,

$$S_w = \frac{\ln\left(w_2/w_1\right)}{\ln\left(h_1/h_2\right)} \qquad (1)$$

The strong effect of friction on spread, due to the following mechanisms: effect of friction on inhomogeneity coupled with strain hardening affecting spread; scales effect on rolls and stock thus affecting friction and consequently spread; variation in friction due to variation of relative velocity between rolls and stock; effects of water and steam from coolants affecting friction and consequently spread, have been highlighted in an earlier paper, (Aiyedun, 2002).

According to Sellars et al (1976), in plane strain compression, if $w_1 < 4w$, the spread is significant.

$$w_2/w_1 = 1 + S - S\left(h_2/h_1\right)^{1/2} \qquad (2)$$

f = 1.0 for 0.13%C steel, 0..55% Mn
< 1.0 for M.C. steel and stainless steel

g ≥ 1.0 for temperature ≥ 1100°C
< 1.0 for temperature < 1100°C

j ≤ 1.0 for strain rate ≤ $5.0s^{-1}$
< 1.0 for higher strain rates.

abfgj = 1.0 for completely isotropic material
< 1.0 for anisotropic material.

RESULTS AND DISCUSSION

Results for spread coefficients (SPECO 1 and SPECO 2) obtained using El-Kalay and Sparling (1968) equation with smooth and rough rolls on materials with light scales, and spread coefficient (SPECO 3) obtained using Sparling's equation (Sparling, 1961) with smooth rolls on materials with light scales will be looked at under the following headings:

1. **Effect of varying reduction (r) at varying speeds**

For varying reductions of 8 – 25% and varying strain rates ($\bar{\varepsilon}$) of 0.06 – $1.7s^{-1}$, the spread coefficient, SPECO 1, 2 and 3 were observed at low and high speeds of 9.32mm/s and 133mm/s respectively.

From Table 2 and Fig. 1, spread coefficient increased gradually for SPECO 1 (0.056-0.073), SPECO 2 (0.048-0.066) and SPECO 3 (0.023-0.055) respectively while their respective average values were 0.0650, 0.057 and 0.0390 for a reduction of 8% to 25%. This agrees with earlier result obtained by Aiyedun (2002).

2. **Effect of varying the square root of thicknesses $(H_1/H_2)^{1/2}$ at low and high rolling speeds.**

From Table 2 and Fig. 2, spread coefficient SPECO 1, SPECO 2 and SPECO 3 increased gradually with increase in square root of thicknesses (SRTHS) with SPECO 1 having the highest value and SPECO 3 the least.

For SRTHS (i.e. $(H_1/H_2)^{1/2}$) varying between 1.04 and 1.16, SPECO 1 was (0.057-0.076), SPECO 2 (0.048-0.069) and SPECO 3 (0.025-0.056) respectively for low and high speeds of 9.32mm/s and 133mm/s.

A plot of spread coefficient or w_2/w_1 against SRTHS giving straight lines as shown in Fig. 2 agree with results obtained by Sellars et al (1976) who compressed aluminum, lead and steel at elevated temperatures.

3. **Effect of varying spread constant (Z1) at low and high rolling speeds**

From Table 2 and Fig. 3, the effect of spread constant Z1 on spread coefficient (SPECO 1,

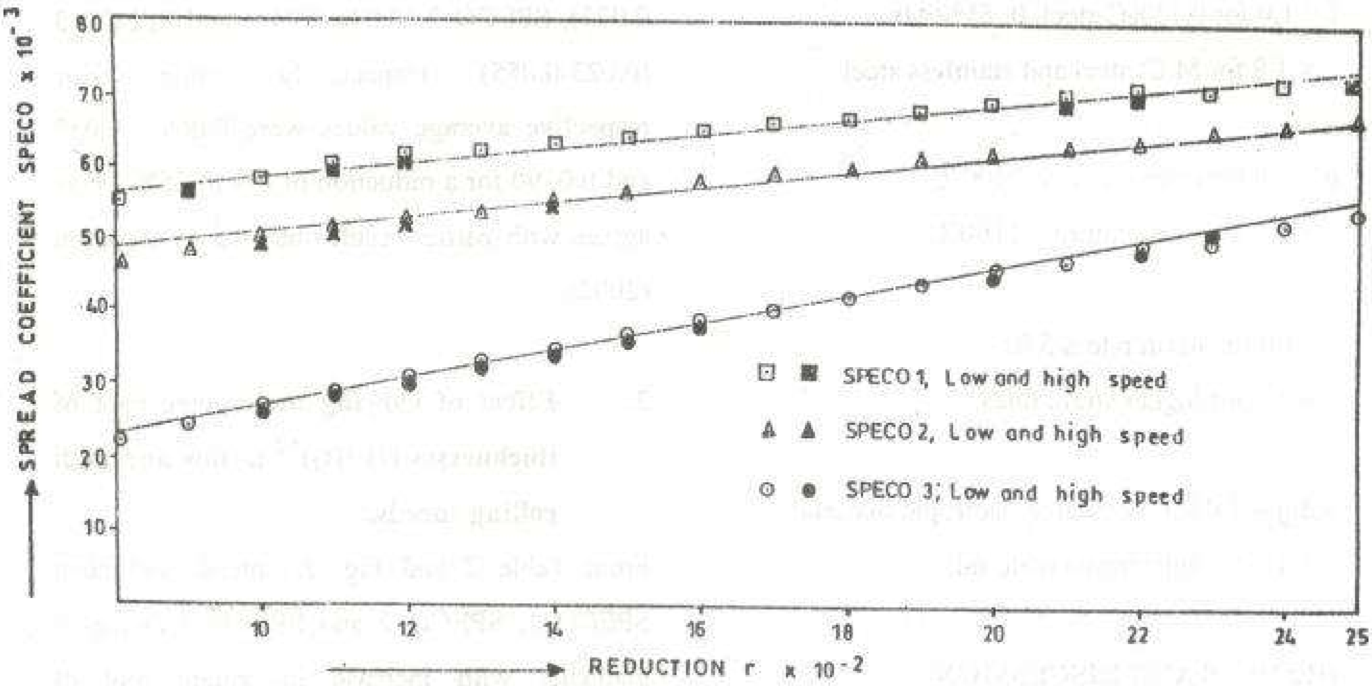

Fig.1: Spread Coefficient, SPECO against Reduction, r for low and high speeds of 9.32 and 133 mm/s

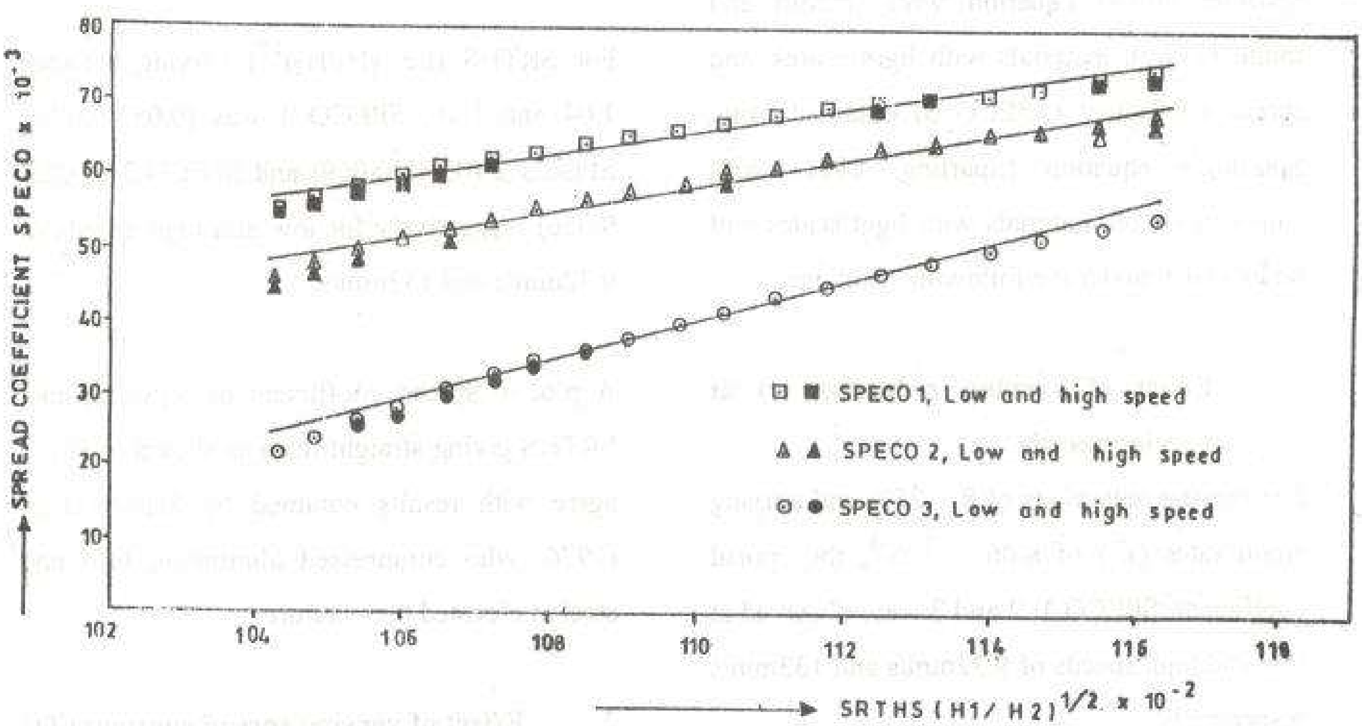

Fig. 2: Spread Coefficient, SPECO against square root of ratio of Thicknesses [SRTHS i.e $(H1/H2)^{1/2}$] for low and high speeds of 9.32 and 133 mm/s

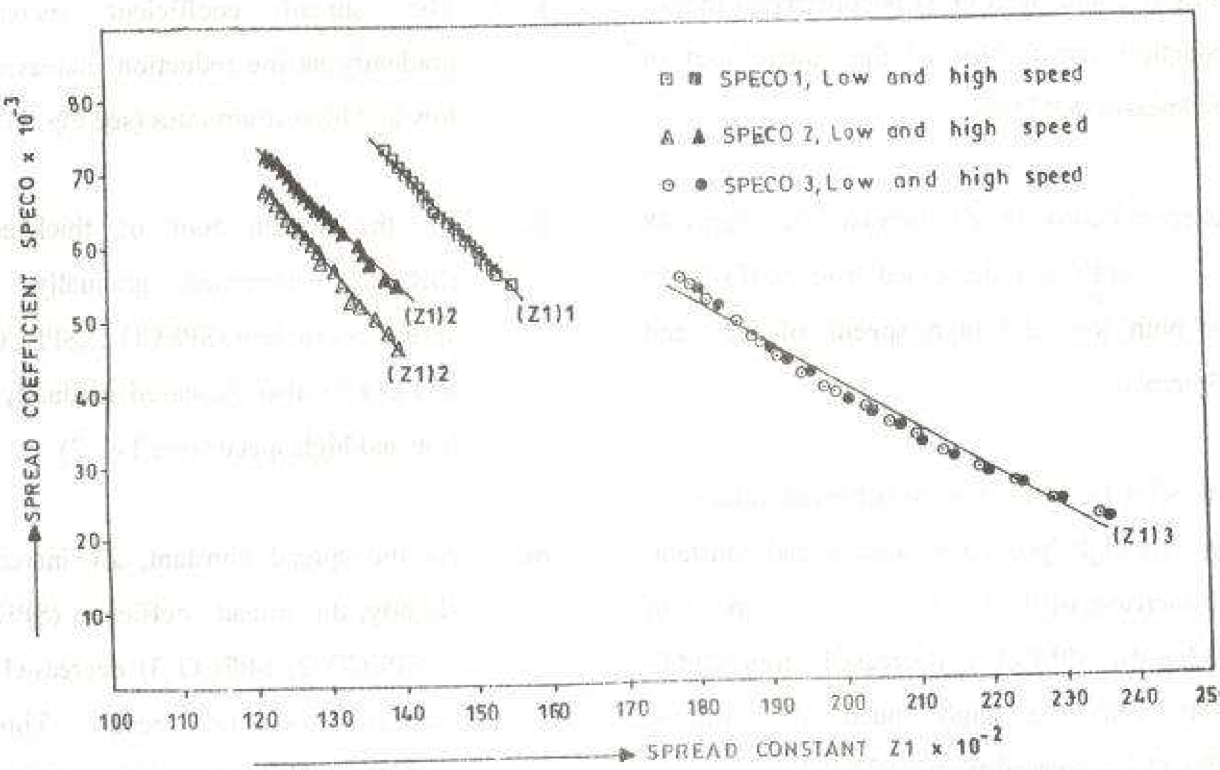

Fig. 3: Spread Coefficient, SPECO against Spread Constant, Z1 for low and high speeds of 9.32 and 133 mm/s

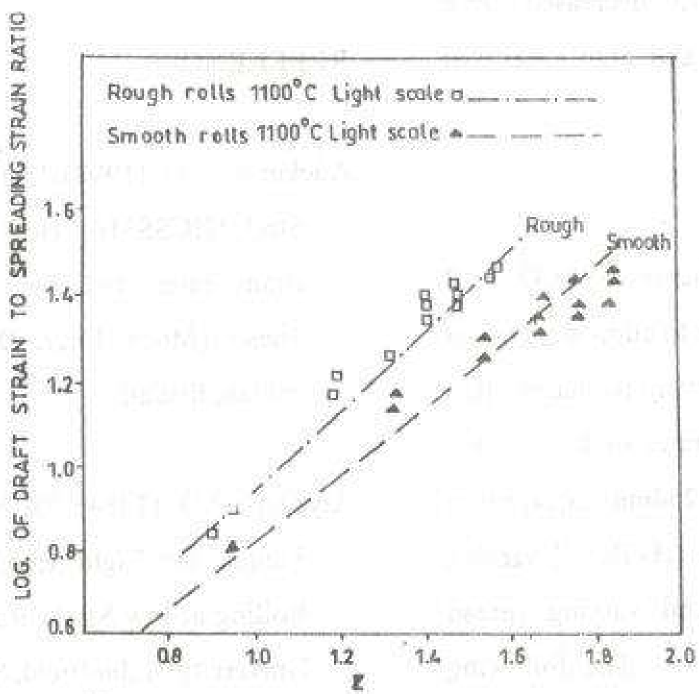

Fig. 4: Log strain ratio v geometrical dimensionless variable, z (after El-kalay and Sparling, 1968).

SPECO 2 and SPECO 3) is contrary to that of reduction and to that of the square root of thicknesses (SRTHS).

As spread constant, Z1 increased between 1.38 – 1.55, SPECO 1 decreased from 0.073-0.055 for both low and high speeds of 9.32 and 133mm/s.

For SPECO 2, there were different values for low and high speeds for same spread constant, Z1 increase of 1.23-1.40. For low speed of 9.32mm/s, SPECO 2 decreased from 0.068-0.046 while for high speed of 133mm/s, SPECO 2 decreased from 0.073-0.055.

For SPECO 3, as spread constant, Z1 increased from 1.70-2.36, SPECO 3 decreased from 0.054-0.020 for both low and high speeds of 9.32 and 133mm/s.

CONCLUSIONS

The spread coefficients (SPECO 1, 2 and 3) obtained in this investigation were based on rolling conditions of varying reductions (r = 8% - 25%), varying strain rates of $\bar{\varepsilon}$ = 0.06 – 1.75s^{-1} on mill of diameter 254mm, square root of thicknesses SRTHS [i.e. $(H_1/H_2)^{1/2}$] varying between 1.04 and 1.16 and varying spread constant (Z1) of 1.2 to 2.4. The following conclusions were obtained from this work.

i. The spread coefficient increased gradually as the reduction increased at low and high strain rates (see Fig. 1).

ii. As the square root of thicknesses (SRTHS) increased gradually, the spread coefficient (SPECO 1, SPECO 2, SPECO 3) also increased gradually for low and high speeds (see Fig. 2).

iii. As the spread constant, Z1 increased slightly, the spread coefficient (SPECO 1, SPECO 2, SPECO 3) decreased for both low and high speeds. This is contrary to the effect of reduction and square root of thicknesses on spread coefficient (see Fig. 3).

REFERENCES

Adekunle, N.O. (1998). "Spread Calculation for Steel (HCSS316) Hot Flat rolled at low strain rates and low reduction." M.Sc. Thesis (Mech. Engr. Dept.) University of Ibadan, Ibadan.

Aiyedun, P.O. (1984). "A Study of Loads and Torque for Light Reduction in Hot Flat Rolling at low Strain Rates". Ph.D Thesis, University of Sheffield, Sheffield, UK.

Aiyedun, P.O. (2002). "Spread Calculation for Steel (HC SS316) Hot Flat Rolled at Low strain Rates". Paper presented at Nigerian Materials Congress 2002 (NIMACON 2002) – Theme: Engineering Materials and National Development, Nov. 11-13, 2002, EMDI, Akure, Nigeria.

Al-Alawi, A.M.S. and Sparling, L.G.M. (1982). "Use of Lubricants in Hot Steel Rolling". Ironmaking and Steel-making, vol. 9, No. 2., pp. 77-88.

Beese, J.G. (1972). "Ratio of Lateral Strain to Thickness Strain During Hot Rolling of Steel Slabs". J.I.S.I. No. 210, (6) pp. 433 – 436.

Eklund, S. (1933), "The Analysis of Factors Influencing Rolling Pressure and Power Consumption in Hot Rolling of Steel". Steel 93 Nos. 8-14 (translated from Jernkontorets Ann. Feb. 1927 by B.Blonquist).

El-Kalay, A.K.E.H.A and Sparling, L.G.M. (1968) "Factors Affecting Friction and their Effect upon Load, Torque, and Spread in Hot Flat Rolling". J.I.S.I. Vol. 206, Feb. 1968, pp. 152 - 163.

Helmi, A. and Alexander, J.M. (1969). "Geometric Factors Affecting Roll Force and Torque in the Hot Flat Rolling of Steel". J.I.S.I. Sept. 1969, pp. 1219 - 1231.

Hill, R. (1950). "The Mathematical Theory of Plasticity". Clarendon – Oxford – Publishers.

Sellars, C.M., Sah, J.P., Beynon, J.H. and Foster, S.R. (1976). "Plane Strain Compression Testing at Elevated Temperatures". Report on Research Work Supported by SRC Grant No. B/R6/1481.

Sparling, L. G. M. (1961) "Formula for Spread in Hot Flat Rolling". Proc. I. Mech. E. Vol. 175, (II), pp. 604 – 617.

Table 1: Conditions and constants A,B,C,D,E for El-Kalay and Sparling equation and Sparling equation for spread constant

	Conditions El-Kalay and Sparling	A	B	C	D	E
1.	Smooth rolls, light scale	0.851	1.766	0.643	0.386	-0.104
2.	Rough rolls, light scale	0.993	2.186	0.569	0.402	-.0123
	Sparling					
3.	Smooth rolls, light scale	0.981	1.615	0.900	0.55	-0.25

Table 2 (a-d): Calculated values of Spread Constant, Z1, square root of ratio of thicknesses (SRTHS), and Spread Coefficient, (SPECO 1,2,3) against reductions for various rolling speeds

SPEED RPM	RED	SPREAD CONSTANT, Z1			SRTHS	SPREAD COEFFICIENT		
		(Z1)1	(Z1)2	(Z1)3	$(H1/H2)^{1/2}$	SPECO1	SPECO2	SPECO3
9.32 (a)	0.08	1.548	1.400	2.351	1.043	0.0552	0.0465	0.0220
	0.09	1.532	1.383	2.290	1.048	0.0568	0.0483	0.0243
	0.10	1.518	1.368	2.235	1.054	0.0583	0.0499	0.0265
	0.11	1.505	1.354	2.187	1.060	0.0596	0.0515	0.0287
	0.12	1.494	1.341	2.144	1.066	0.0609	0.0529	0.0308
	0.13	1.483	1.329	2.104	1.072	0.0621	0.0543	0.0328
	0.14	1.473	1.318	2.068	1.078	0.0632	0.0556	0.0348
	0.15	1.463	1.308	2.035	1.085	0.0642	0.0569	0.0367
	0.16	1.454	1.299	2.004	1.091	0.0653	0.0581	0.0386
	0.17	1.446	1.290	1.976	1.098	0.0662	0.0592	0.0404
	0.18	1.438	1.282	1.949	1.104	0.0671	0.0603	0.0421
	0.19	1.431	1.274	1.924	1.111	0.0689	0.0613	0.0439
	0.20	1.424	1.266	1.901	1.118	0.0689	0.0624	0.0456
	0.21	1.417	1.259	1.879	1.125	0.0697	0.0633	0.0472
	0.22	1.411	1.252	1.858	1.132	0.0705	0.0643	0.0488
	0.23	1.405	1.246	1.838	1.140	0.0712	0.0652	0.0504
	0.24	1.399	1.240	1.819	1.147	0.0720	0.0661	0.0520
	0.25	1.393	1.234	1.802	1.155	0.0727	0.0669	0.0535
	0.26	1.388	1.228	1.785	1.163	0.0734	0.0677	0.0550
19.95 (b)	0.08	1.545	1.398	2.345	1.043	0.0556	0.0468	0.0222
	0.09	1.530	1.381	2.284	1.048	0.0571	0.0485	0.0245
	0.10	1.516	1.366	2.231	1.054	0.0585	0.0502	0.0267
	0.11	1.503	1.352	2.183	1.060	0.0598	0.0517	0.0289
	0.12	1.492	1.339	2.140	1.066	0.0611	0.0532	0.0310
	0.13	1.481	1.328	2.101	1.072	0.0622	0.0545	0.0330
	0.14	1.471	1.317	2.065	1.078	0.0634	0.0558	0.0350
	0.15	1.462	1.307	2.032	1.085	0.0644	0.0571	0.0369
	0.16	1.453	1.298	2.001	1.091	0.0654	0.0582	0.0387
	-0.17	1.445	1.289	1.973	1.098	0.0664	0.0594	0.0405
	0.18	1.439	1.280	1.947	1.104	0.0673	0.0605	0.0423
	0.19	1.430	1.278	1.922	1.111	0.0682	0.0615	0.0440
	0.20	1.423	1.265	1.899	1.118	0.0690	0.0625	0.0457
	-0.21	1.416	1.258	1.877	1.125	0.0698	0.0635	0.0474
	0.22	1.410	1.252	1.856	1.132	0.0706	0.0644	0.0490
	0.23	1.404	1.245	1.836	1.140	0.0714	0.0653	0.0506
	0.24	1.398	1.239	1.818	1.147	0.0721	0.0662	0.0521
	0.25	1.392	1.233	1.800	1.155	0.0728	0.0670	0.0536
	0.26	1.387	1.228	1.783	1.163	0.0735	0.0679	0.0551

Table 2(a-d): Contd.

SPEED RPM	RED	SPREAD CONSTANT, Z1			SRTHS	SPREAD COEFFICIENT		
		(Z1)1	(Z1)2	(Z1)3	$(H1/H2)^{1/2}$	SPECO1	SPECO2	SPECO3
	0.08	1.551	1.403	2.357	1.043	0.0550	0.0462	0.0218
33.0	0.09	1.535	1.386	2.295	1.048	0.0566	0.0480	0.0241
(c)	0.10	1.521	1.370	2.240	1.054	0.0580	0.0497	0.0263
	0.11	1.508	1.356	2.192	1.060	0.0594	0.0513	0.0285
	0.12	1.496	1.343	2.148	1.066	0.0607	0.0527	0.0306
	0.13	1.484	1.331	2.108	1.072	0.0619	0.0541	0.0326
	0.14	1.474	1.320	2.071	1.078	0.0630	0.0554	0.0346
	0.15	1.465	1.310	2.038	1.085	0.0641	0.0567	0.0365
	0.16	1.456	1.300	2.007	1.091	0.0651	0.0579	0.0384
	0.17	1.447	1.291	1.978	1.098	0.0661	0.0590	0.0402
	0.18	1.439	1.283	1.951	1.104	0.0670	0.0601	0.0420
	0.19	1.432	1.275	1.926	1.111	0.0679	0.0612	0.0437
	0.20	1.425	1.267	1.903	1.118	0.0687	0.0622	0.0454
	0.21	1.418	1.260	1.881	1.125	0.0696	0.0632	0.0471
	0.22	1.412	1.253	1.860	1.132	0.0704	0.0641	0.0487
	0.23	1.406	1.247	1.840	1.140	0.0711	0.0651	0.0503
	0.24	1.400	1.241	1.821	1.147	0.0719	0.0659	0.0518
	0.25	1.394	1.235	1.803	1.155	0.0726	0.0668	0.0533
	0.26	1.389	1.229	1.786	1.163	0.0733	0.0676	0.0548
133.0	0.08	1.555	1.407	2.370	1.043	0.0546	0.0458	0.0215
(d)	0.09	1.539	1.389	2.304	1.048	0.0562	0.0476	0.0238
	0.10	1.524	1.373	2.248	1.054	0.0577	0.0493	0.0260
	0.11	1.511	1.359	2.198	1.060	0.0591	0.0509	0.0282
	0.12	1.498	1.346	2.154	1.066	0.0604	0.0524	0.0303
	0.13	1.487	1.333	2.113	1.072	0.0616	0.0538	0.0323
	0.14	1.477	1.322	2.076	1.078	0.0627	0.0552	0.0343
	0.15	1.467	1.312	2.042	1.085	0.0638	0.0564	0.0362
	0.16	1.458	1.302	2.011	1.091	0.0648	0.0577	0.0381
	-0.17	1.449	1.293	1.982	1.098	0.0658	0.0588	0.0400
	0.18	1.441	1.285	1.955	1.104	0.0668	0.0599	0.0417
	0.19	1.434	1.276	1.930	1.111	0.0677	0.0610	0.0435
	0.20	1.427	1.269	1.906	1.118	0.0685	0.0620	0.0452
	-0.21	1.420	1.262	1.884	1.125	0.0694	0.0630	0.0468
	0.22	1.413	1.255	1.862	1.132	0.0702	0.0639	0.0485
	0.23	1.407	1.248	1.843	1.140	0.0709	0.0649	0.0505
	0.24	1.401	1.242	1.824	1.147	0.0717	0.0658	0.0516
	0.25	1.395	1.236	1.806	1.155	0.0724	0.0666	0.0531
	0.26	1.390	1.230	1.788	1.163	0.0731	0.0675	0.0546