



Technical Working Area 21
Mechanical Tests for Hardmetals

**Bend Strength Measurements for Hardmetals
International Prestandardisation Collaborative Activity**

Part 1 - Rationale and Results

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Bend Strength Measurements for Hardmetals International Prestandardisation Collaborative Activity (VAMAS)

Part 1 - Rationale and Results

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ABSTRACT

This report is a compendium of results for a VAMAS international collaborative activity on bend strength measurements for hardmetals. The interlaboratory tests involved fourteen laboratories, mostly industrial, in eight countries testing seven materials to eleven testpiece geometries. The report provides the rationale for the activity as well as the results. It does not include detailed analysis of the data. A further report is planned within the next year giving recommendations for testing based on these results and will present a full analysis of the data. Preliminary examination of the data indicated that a very good agreement was obtained between tests at different laboratories. However, considerable differences in strength were observed for the different geometries. Also testpiece preparation method was an important factor. These issues will be discussed in more detail in the forthcoming analysis report.

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Approved on behalf of Managing Director, NPL, by Dr M K Hossain,
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APPENDIX B BEND TEST SCHEDULE

1 INTRODUCTION

There is a need to re-evaluate the current standard for Transverse Rupture Tests (bend tests) for Hardmetals, ISO 3327, to take account of developments in the understanding of strength measurements, the increasing desire for data more relevant to material quality and design, and not least, to work towards a test which can give results comparable to test data obtained on competing materials, such as ceramics and cermets. Following an initial assessment an agreement was reached to perform an international interlaboratory exercise, (Appendix A). The purpose of the exercise was to examine a number of alternative methods of bend tests for hardmetals to that specified in ISO 3327, to include geometries which compare with standards for ceramics (3 and 4 pt), to include tests on small specimens, to include unconventional geometries (round and notched) and possibly to include methods of specimen preparation.

Background

In North America a military standard MIL-STD-1942A for flexure tests on ceramics has been adopted by the ASTM. In Europe a new CEN standard for bend tests on ceramics has been prepared. In Japan there is a relevant standard JIS R 1601. None of these geometries are compatible with ISO 3227.

In addition some companies have expressed views regarding the usefulness of testing round specimens. Also, work at NPL has indicated that notched bend tests can give useful data. Furthermore, communication with colleagues in Japan, where they test different geometries again, has indicated puzzling data obtained in bend tests on ultra-fine grained hardmetals. Clearly there is considerable scope for examining these issues on an international basis, in order to generate a widely agreed test procedure. This harmonised approach will provide the basis for validated and improved recommended methods of testing. Following preliminary discussions questionnaires were sent to various organisations around the world for comments on the suitability of an international prestandardisation collaborative activity.

Outline plan

The outline plan consisted of three parts:

- comparison of relevant standards (Appendix A)
- a matrix of testing options (Appendix C)
- materials and sources (Table 1).

A large series of tests were envisaged to take account of the widespread interest in participation. Some of the tests involved jigs being circulated between several organisations.

Testpieces and procedure

All rectangular testpieces were horizontally ground to ISO 3327, 0.2 mm chamfer (45°), out of squareness $\nless 2^\circ$, ± 0.01 mm tolerance, cylindrical load supports and load points with loading rate of $\nless 1500$ N s⁻¹. Load measured to $\pm 1\%$. Round testpieces were circumferentially ground to similar tolerances. Notched testpieces were annealed at 800 °C for 1h in vacuum to relieve residual stresses. Also a selected number of rectangular and round testpieces were annealed before testing.

Standards

3 pt testing, rectangular testpieces

Background information was taken from four standards documents which contain information of relevance: EN843 pt 1 (flexure testing of ceramics), ISO 3327 (TRS of hardmetals), ASTM B406 (TRS of cemented carbides) and CIS 026-1983 (TRS of cemented carbides - CCTMAS, Japan).

4 pt testing, rectangular testpieces

The standards for testing hardmetals do not include the option of 4 pt tests. However, the ASTM conducted a comparative exercise in the 1980s and the EN standard for ceramics will allow 4 pt tests. Testpiece preparation was essentially the same as that given for 3 pt test comparisons.

Additional comments

The following comments taken from the ASTM B09.06 exercise (courtesy of J J Oakes, Teledyne Advanced Materials and ASTM) on 3 pt vs 4 pt tests, and additional notes from the Japanese standards document CIS 026-1983 must be taken into account.

ASTM B09.06: (a) 4 pt TRS results are significantly lower than those measured by 3 pt tests; (b) the use of 4 pt test gave no improvement in test data scatter compared with 3 pt tests; (c) no significant difference was noted between 3 pt tests using a 10 mm diameter cemented carbide ball or a 6.35 mm diameter cemented carbide roll for the central loading point.

CIS 026-1983: The document indicates that preliminary tests were conducted to compare the Japanese testpiece design (24 x 8 x 4) with the ISO type A design (35 x 5 x 5) and type B design (20 x 6.5 x 5.25). The following comments have been selected (the full document can be obtained on request): (a) the ISO type B is recommended to be excluded because the data scatter was larger and bigger loads were required (and hence more damage to jigs); (b) the use of balls as load points was excluded; (c) no difference was noted between tests on ground compared with as-sintered testpieces, therefore both are allowed.

Non-standard testpieces

The proposed interlaboratory exercise included tests on both round and notched testpieces. The justification for this was as follows:

Round testpieces

A number of organisations are currently using tests on round testpieces because it is an important product form. Their preliminary data indicate that there is a reduction in scatter associated with this form of testpiece. Accordingly, it is important to include a number of tests in the current exercise.

Notched testpieces

Previous work at NPL [1] has shown that the bend strength of hardmetals is determined by two factors:

- the distribution of large defects (pores etc), greater in size than approximately 20 μm
- the intrinsic strength of the average microstructure, termed limiting strength.

Further work [2,3] has shown that the limiting strength can be measured using a notched bend testpiece. This test method has several advantages; as follows:

- the scatter is considerably reduced
- much lower loads are required to break testpieces, ie less damage to jigs and perhaps less expensive test machines
- the strength values obtained are more representative of the intrinsic material strength (because failures from large defects are excluded).

The notched tests performed to date have been on modified ISO 3327 testpieces (type B), ie 14.5 mm span x 2 mm wide x 5 mm high (3 pt) with a 1 mm deep notch with a 0.5 mm notch radius. The tests planned in this current exercise examined 4 pt notched tests and 3 pt tests on different geometry specimens, Figs 1 and 2.

2 MATERIALS

Seven materials were provided for test by industry (Table 1). All testpieces were diamond ground in line with the recommendations in ISO 3327 (Bend Tests for Hardmetals). All the notched testpieces were annealed at 800 °C for 1h in a vacuum to remove residual stresses at the notch root. Some of the unnotched testpieces were also annealed before testing. These are appropriately indicated in the data tables in the Results Set (Part 6).

3 TESTING AND SCHEDULE

The bend test geometries used in the testing schedules are shown in Figs 1 and 2. They included

- Current 3 pt ISO standards
(R3a, R3b)
- 4 pt equivalent of ISO Type A - R3b
(R4b)
- 3 and 4 pt ceramic testing equivalents
(R3c and R4c)
- Notch tests on rectangular testpieces, 3 and 4 pt
(RN3a, RN3b and RN4b)
- Round testpieces, 3 and 4 pt
(C3 and C4)
- Notched round testpieces, 4 pt
(CN4)

The detailed testing schedules are given in APPENDIX B.

- Standard (ISO Type B) tests were generally carried out at industry laboratories
- NPL tested all other geometries for all materials
- The testing of other geometries was spread across participating organisations - as shown in APPENDIX B.

- The data tables give loading rates, either directly in N s^{-1} or in mm min^{-1} for crosshead speed.

4 RESULTS AND PRELIMINARY CONCLUSIONS

Notes for Results Sets

The data for the tests are given, with supplementary comments, in the accompanying sets of tables at the end of the report in section 7, before the appendices.

The formulae used to calculate the failure stresses are given in Table 2.

The results are plotted as a set of data ranked against strength. The rank value (R) is calculated from

$$R = \frac{n_i - 0.5}{N}$$

where n_i is the i^{th} value of strength and N is the total number of tests.

It is necessary to be careful in comparing plots because different symbols have been used in different plots. Consistent sets of symbols would have required the widespread use of colour which would have increased the cost considerably since over 100 sets of data have to be reproduced.

Also different axis limits have been chosen for the X co-ordinates to enable the data to be fully discriminated in each plot.

The plots are numbered A, Aa and 1, 1a to 10, 10a etc where A and Aa are full plots of all the data, with Aa containing plots in which results from different laboratories on the same geometry have been combined. Similarly for each number a second plot, subnumbered Na, contains the data for combined sets.

Combining Data

The criteria for combining data sets from different laboratories is purely visual at this stage. It is not supported by statistical analysis as yet.

The only data sets which appeared to be out of line in this respect were some of the test results returned from Teledyne Advanced Materials where the values were about 5-10% greater than expected from examination of the results from other laboratories. For the purpose of comparing results from different geometries these data were corrected and the correction factors are given on each appropriate results comment sheet for the Boart (fine WC/Co) and Sandvik Hard Materials (fine WC/Co) testpieces. Also one or two sets of data returned from K-Hertel on the Sandvik Med/Coarse material (Category 5 - Set 6) were high and were not used for combining data sets.

Preliminary Conclusions

A further report is planned in 1997 which will analyse the data in more detail. However, a number of preliminary conclusions are fairly obvious even at this stage and are listed here for convenience.

1. There is good agreement between laboratories testing a given geometry and material.

2. Surface preparation has a very significant effect on strength for some of the materials tested. In particular, annealing reduces strength by relieving compressive residual stresses introduced during grinding.
3. Nominal strengths can differ by a factor of up to two depending on the geometry used.
4. Notched testpieces give less scatter except in material processed to contain few macroscopic internal defects.

5 REFERENCES

1. E A Almond and B Roebuck, Defect initiated fracture and the bend strength of WC/Co hardmetals. *Met. Sci.*, **11** (1977) 458-61.
2. B Roebuck, Notched bend tests on WC/Co hardmetals. *J. Mater. Sci.*, **23** (1988) 281-7.
3. B Roebuck and W Coles, Mechanical test discriminability for WC hardmetals. *Int. J. Refractory Met. and Hard Mat.*, **11** (1992) 127-36.

6 ACKNOWLEDGEMENTS

Thanks are due to the organisations listed in Appendices A and B for their extensive contribution to the testing schedule. The NPL contribution was supported by the MTS Programme on Advanced Materials, a programme of underpinning materials measurement research financed by the EAM Directorate, UK Department of Trade and Industry.

TABLE 1 - MATERIALS

Data supplied by Manufacturers

Organisation	Type	Supply Code	NPL Code	Cobalt Content wt%	Other carbides? wt%	Hardness	Density Mg m ⁻³	Coercivity	Magnetic moment (or saturation)	HIPped, As-sintered or Sinter HIPped (SH)	Condition supplied to NPL As ground (G), As sintered (S)
Teledyne Advanced Materials (USA)	UFine, WC/Co	HU-6	(1)	6	VC	92.7 (HRA)	14.87	276 Oersteds	116 emu/g = 4 π [σ =160 for pure Co]	Sinter plus conventional HIP	(S)
Boart Longyear (S Africa)	Fine, WC/Co	56	(2)	6	None	1520 \pm 30 HV	14.97 \pm 0.03	170 \pm 15 Oersteds	170 emu/g \pm 6	++	As Sinter HIPped
Sandvik Hard Materials (UK)	Fine, WC/Co	H10F	(3)	10	0.5 Cr ₃ C ₂	1600 HV30	14.50	20.5 kA/m	8.5% magnetic cobalt	As-sintered	(S)
Kennametal (USA)	WC/Cubic/Co	-	(4)	8.5	TaC 10.2 TiC 5.9	91.2 (HRA)	12.62	123 Oersteds	94%	As-sintered	(S)
Sandvik Coromant (Sweden)	Ti(C,N) Cermet	CT515	(5)	13.7*	VC, Mo ₂ C WC	1660 (HV10)	6.9	-	-	As-sintered	(S)
Sandvik Coromant (Sweden)	Med/Coarse, WC/Co	+	(6)	10.0	No	1200 (HV3)	14.48	6.7 kA/m	0.16 Tesla (saturation)		(S)
Boart (S Africa)	Coarse, WC/Co	B25N	(7)	9.5	No	1050 HV10 85.8 HRA	14.55	46-58 Oersteds	14.0 g cm ³ g ⁻¹	++	As sinter HIPped

* Co plus Ni

+ Grade discontinued

++ Sinter HIPped; 1390 °C and 45 bar argon

TABLE 2 Failure Stress Formulae (Bend Tests)

Geometry	Stress, σ	Dimensions
R3a	$\frac{3PL}{2BW^2}$	L = 14.5 mm (nominal)
R3b	$\frac{3PL}{2BW^2}$	L = 30 mm (nominal)
R3c	$\frac{3PL}{2BW^2}$	L = 40 mm (nominal)
RN3a	$\frac{3PL}{B(W-d)^2}$	L = 14.5 mm (nominal) d = notch depth, nominally 1 mm (radius, 0.5 mm)
RN3b	$\frac{3.26 PL}{B(W-d)^2}$	L = 30 mm (nominal) d = notch depth, nominally 1 mm (radius, 0.5 mm)
R4b	$\frac{3PL}{BW^2}$	L = 10 mm (nominal)
R4c	$\frac{3PL}{BW^2}$	L = 10 mm (nominal)
RN4b	$\frac{6.31 PL}{B(W-d)^2}$	L = 10 mm (nominal) d - notch depth, nominally 1 mm (radius, 0.5 mm)
C3	$\frac{8PL}{\pi D^3}$	L = 30 mm (nominal)
C4	$\frac{16PL}{\pi D^3}$	L = 10 mm (nominal)
CN4	$\frac{16 k PL}{\pi D^3}$	L = 10 mm (nominal) k = 3.55 for notch depth = 0.5 mm and notch radius = 0.5 mm

Hardmetal Bend Tests

Three Point Tests

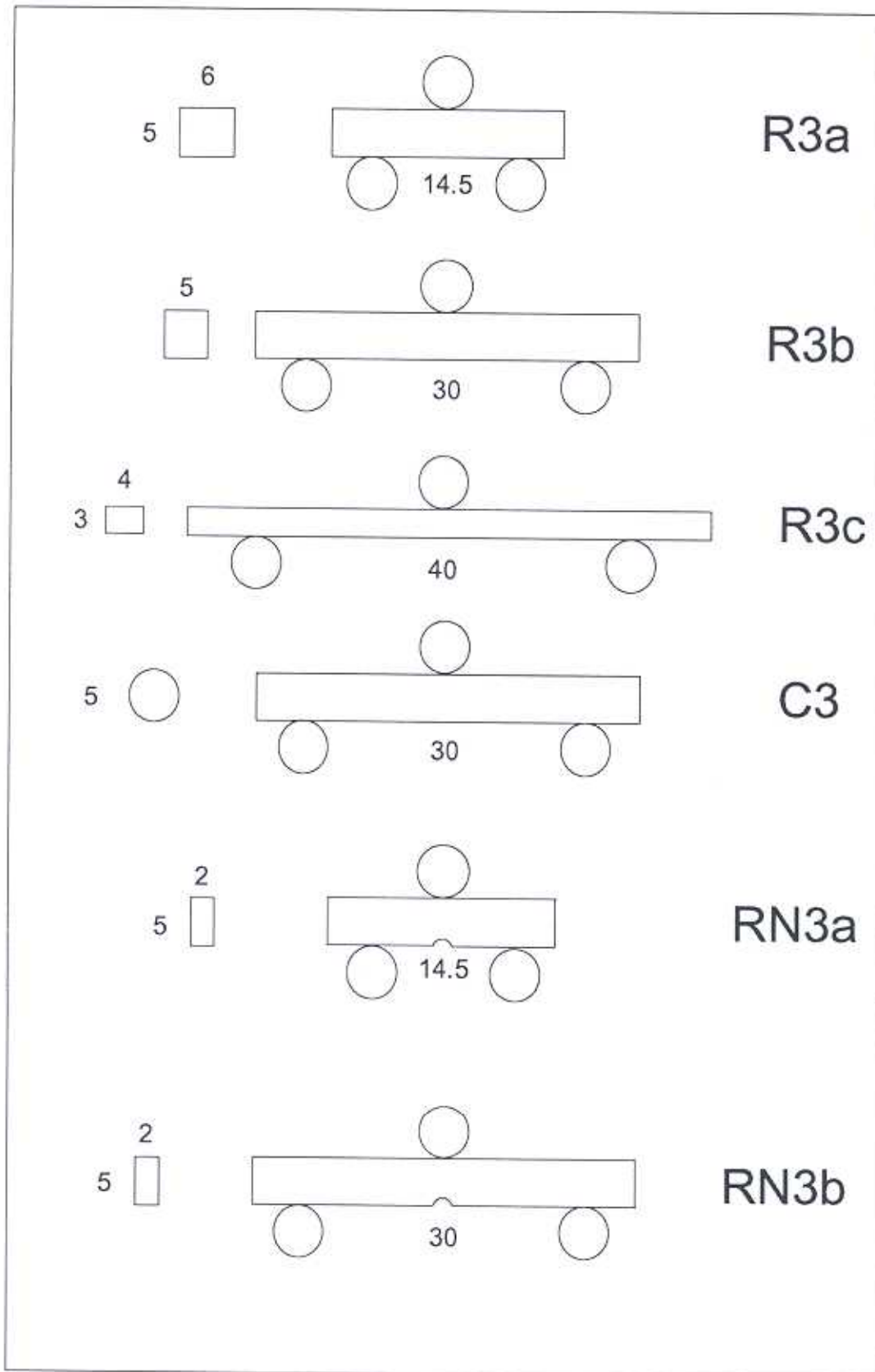


Fig 1 Schematic Design of 3 pt Geometries

Hardmetal Bend Tests

Four Point Tests

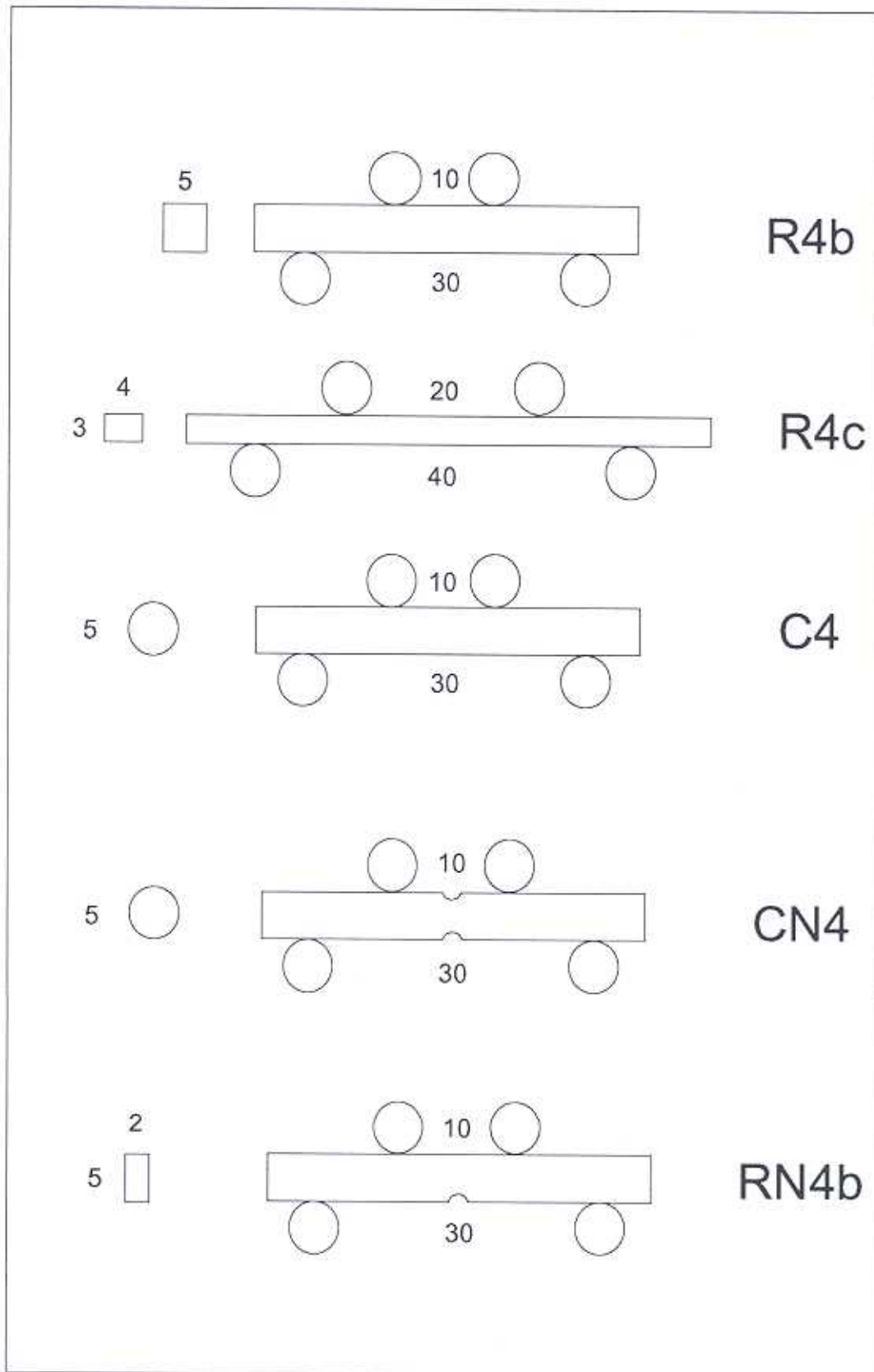


Fig 2 Schematic Design of 4 pt Geometries

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Part 1 - Rationale and Results

PART 7 RESULTS SETS

RESULTS SET

(1) TELEDYNE ADVANCED MATERIALS

Ultrafine, WC/Co

Data Tables

Supplementary Comments

Data Plots

HARDMETAL BEND TESTS INTERNATIONAL INTERCOMPARISON

TABLES OF RESULTS

SET 1

WC/Co (Ultra fine grained) - Source: Teledyne Advanced Materials

<i>Geometry</i>		<i>Organisation</i>
3 pt TRS	R3a	Standard Tests (Boart/Sandvik)
3,4 pt Rectangular	R3, R4	NPL
3,4 pt Rectangular	R3, R4	CERMeP
3,4 pt Rectangular	R3, R4	Kennametal
3,4 pt Rectangular Notched	RN3, RN4	NPL
3,4 pt Rectangular Notched	RN3, RN4	CERMeP
3,4 pt Rectangular Notched	RN3	Kennametal
Round	C3, C4, CN4	NPL
Round	C4, CN4	CERMeP
Round	C3, CN4	Kennametal

**TELEDYNE WC/Co(1) - UFINE
STANDARD TRS TESTS - R3a**

Boart				Span 14.5 mm			Rate	130 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.39	5.07	31232	4136	2	4365	1	96.7
2	6.39	5.08	33096	4365	5	4330	2	90.0
3	6.39	5.07	29459	3901	13	4304	3	83.3
4	6.39	5.12	29102	3779	6	4300	4	76.7
5	6.39	5.07	32700	4330	10	4270	5	70.0
6	6.39	5.08	32599	4300	11	4214	6	63.3
7	6.39	5.07	30048	3979	12	4161	7	56.7
8	6.39	5.15	27500	3529	1	4136	8	50.0
9	6.39	5.12	28800	3739	14	4038	9	43.3
10	6.39	5.12	32888	4270	15	4018	10	36.7
11	6.39	5.07	31827	4214	7	3979	11	30.0
12	6.38	5.06	31247	4161	3	3901	12	23.3
13	6.39	5.07	32501	4304	4	3779	13	16.7
14	6.39	5.12	31096	4038	9	3739	14	10.0
15	6.39	5.07	30340	4018	8	3529	15	3.3

Sandvik				Span 15 mm			Rate	250 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
16	6.39	5.07	29603	4055	13	4533	1	96.7
17	6.39	5.08	31163	4252	5	4504	2	90.0
18	6.39	5.11	31157	4201	11	4500	3	83.3
19	6.39	5.12	30427	4087	8	4385	4	76.7
20	6.39	5.07	32878	4504	2	4252	5	70.0
21	6.38	5.11	27225	3677	3	4201	6	63.3
22	6.38	5.11	24647	3329	15	4178	7	56.7
23	6.39	5.06	31886	4385	4	4087	8	50.0
24	6.39	5.07	28419	3893	1	4055	9	43.3
25	6.39	5.11	29495	3977	10	3977	10	36.7
26	6.39	5.06	32721	4500	12	3913	11	30.0
27	6.39	5.12	29130	3913	9	3893	12	23.3
28	6.39	5.06	32959	4533	14	3760	13	16.7
29	6.38	5.11	27838	3760	6	3677	14	10.0
30	6.38	5.06	30333	4178	7	3329	15	3.3

**TELEDYNE WC/Co(1) - UFINE
NPL BEND TESTS (R3b, R3c, R4b, R4c)**

R3b				Span 30 mm		Rate	200 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	5.00	5.18	10650	3572	8	3690	1	94.4
2	5.00	5.18	10590	3552	6	3687	2	83.3
3	5.00	5.18	5737	1924	9	3653	3	72.2
4	5.00	5.18	7767	2605	1	3572	4	61.1
5	4.98	5.16	8713	2957	2	3552	5	50.0
6	5.00	5.17	10950	3687	7	3103	6	38.9
7	5.00	5.16	9179	3103	5	2957	7	27.8
8	5.00	5.17	10960	3690	4	2605	8	16.7
9	5.00	5.18	10890	3653	3	1924	9	5.6
10*	5.00	5.16	8027	2713	3*	2817	1	87.5
11*	5.00	5.17	6894	2321	1*	2713	2	62.5
12*	4.99	5.18	8382	2817	4*	2565	3	37.5
13*	4.98	5.16	7559	2565	2*	2321	4	12.5

*annealed 800 °C 1h in vacuum

R3c				Span 40 mm		Rate	35 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	3.00	2153	3588	7	3935	1	94.4
2	4.00	3.00	1526	2543	1	3588	2	83.3
3	4.00	3.00	1423	2372	5	3325	3	72.2
4	4.00	3.02	1726	2839	8	2857	4	61.1
5	4.00	3.00	1995	3325	4	2839	5	50.0
6	4.00	3.00	769	1282	2	2543	6	38.9
7	3.98	2.96	2287	3935	9	2415	7	27.8
8	4.00	3.00	1714	2857	3	2372	8	16.7
9	4.00	3.00	1449	2415	6	1282	9	5.6
10								

R4b				Outer Span 10 mm			Rate	200 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	5.00	5.18	11130	2489	5	3351	1	91.7
2	5.00	5.18	12330	2757	3	3253	2	75.0
3	5.00	5.17	14490	3253	6	3250	3	58.3
4	5.00	5.16	8430	1900	2	2757	4	41.7
5	5.00	5.17	14930	3351	1	2489	5	25.0
6	5.00	5.17	14480	3250	4	1900	6	8.3
7								
8								
9								
10								

R4c				Outer Span 10 mm			Rate	100 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	3.00	2961	2468	2	3170	1	95
2	3.98	3.00	3785	3170	7	3148	2	85
3	4.00	3.00	3339	2783	5	2853	3	75
4	4.00	3.00	3415	2846	4	2846	4	65
5	4.00	3.00	3424	2853	3	2783	5	55
6	3.98	3.00	2190	1834	9	2684	6	45
7	4.00	3.01	3803	3148	10	2607	7	35
8	3.98	3.00	1315	1101	1	2468	8	25
9	4.00	3.00	3221	2684	6	1834	9	15
10	4.00	3.00	3128	2607	8	1101	10	5

**TELEDYNE WC/Co(1) - UFINE
CERMeP BEND TESTS (R3b, R4b)**

R3b					Span 30 mm		Rate 5 mm min ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	5.02	5.20	10775	3572	3	3929	1	95
2	5.00	5.18	10581	3549	9	3802	2	85
3	5.01	5.16	11648	3929	10	3712	3	75
4	5.00	5.18	10484	3516	7	3595	4	65
5	5.00	5.18	9902	3321	1	3572	5	55
6	5.01	5.17	9805	3295	8	3563	6	45
7	5.00	5.17	10678	3595	2	3549	7	35
8	5.00	5.17	10581	3563	4	3516	8	25
9	5.01	5.18	11357	3802	5	3321	9	15
10	5.00	5.18	11066	3712	6	3295	10	5

R4b					Outer Span 10 mm		Rate 5 mm min ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	5.01	5.18	15528	3465	1	3465	1	95
2	5.01	5.17	13000	2912	3	3399	2	85
3	5.00	5.17	15140	3399	6	3399	3	75
4	5.01	5.17	13200	2957	5	3333	4	65
5	5.02	5.18	14966	3333	9	3311	5	55
6	5.00	5.17	15140	3399	10	3252	6	45
7	5.00	5.17	13782	3094	7	3094	7	35
8	5.01	5.17	11648	2609	4	2957	8	25
9	5.00	5.17	14752	3311	2	2912	9	15
10	5.01	5.16	14461	3252	8	2609	10	5

**TELEDYNE WC/Co(1) - UFINE
KENNAMETAL BEND TESTS (R3c, R4c)**

R3c				Span 30 mm		Rate	22 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.01	3.00	2308	3837	1	3837	1	95
2	4.00	3.00	1838	3063	4	3674	2	85
3	4.00	3.00	1658	2763	9	3473	3	75
4	4.00	3.01	2219	3674	10	3472	4	65
5	4.00	3.00	1883	3138	5	3138	5	55
6	4.00	3.00	1569	2615	2	3063	6	45
7	4.00	3.00	1233	2055	3	2763	7	35
8	4.00	3.00	1546	2577	6	2615	8	25
9	4.00	3.00	2084	3473	8	2577	9	15
10	4.00	3.00	2083	3472	7	2055	10	5

R4c				Outer Span 10 mm		Rate	22 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	3.01	3608	2987	3	3332	1	95
2	4.00	3.00	3160	2633	5	3268	2	85
3	3.99	3.00	3989	3332	9	3193	3	75
4	4.00	3.00	3586	2988	4	2988	4	65
5	4.00	3.00	3922	3268	1	2987	5	55
6	4.00	2.99	3138	2633	7	2665	6	45
7	4.01	3.01	3227	2665	2	2633	7	35
8	4.00	3.00	2622	2185	10	2633	8	25
9	4.00	3.00	3832	3193	6	2633	9	15
10	4.00	3.00	3160	2633	8	2185	10	5

**TELEDYNE WC/Co(1) - UFINE
NPL BEND TESTS (RN3a, RN3b, RN4b)**

RN3a (Annealed 800 °C 1h in vacuum)					Span 13.8 mm		Rate	250 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.55	5.07	2611	2559	5	2909	1	91.7
2	2.55	5.07	2927	2869	2	2873	2	75.0
3	2.55	5.07	2968	2909	6	2869	3	58.3
4	2.55	5.12	3004	2873	3	2559	4	41.7
5	2.55	5.07	2438	2389	4	2389	5	25.0
6	2.55	5.12	2433	2327	1	2327	6	8.3

RN3b (Annealed 800 °C 1h in vacuum)					Span 30 mm		Rate	80 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.90	5.00	779	2506	6	2897	1	91.7
2	1.87	4.98	815	2691	3	2764	2	75.0
3	1.90	4.99	855	2764	5	2726	3	58.3
4	1.90	4.99	777	2512	2	2691	4	41.7
5	1.89	5.00	843	2726	4	2512	5	25.0
6	1.90	4.99	896	2897	1	2506	6	8.3

RN4b (Annealed 800 °C 1h in vacuum)					Outer Span 10 mm		Rate	100 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.90	4.98	1181	2476	6	2649	1	91.7
2	1.90	5.00	1254	2603	3	2628	2	75.0
3	1.90	5.00	1266	2628	5	2605	3	58.3
4	1.90	5.00	1198	2487	2	2603	4	41.7
5	1.90	5.00	1255	2605	4	2487	5	25.0
6	1.90	5.00	1276	2649	1	2476	6	8.3

**TELEDYNE WC/Co(1) - UFINE
CERMeP BEND TESTS (RN3a, RN4b)**

RN3a (Annealed 800 °C 1h in vacuum)					Span 15 mm		Rate	0.5 mm min ⁻¹
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.54	5.07	2433	2394	4	2680	1	91.7
2	2.53	5.08	2627	2582	3	2678	2	75.0
3	2.53	5.08	2724	2678	6	2667	3	58.3
4	2.54	5.07	2724	2680	5	2654	4	41.7
5	2.54	5.09	2724	2654	2	2582	5	25.0
6	2.54	5.08	2724	2667	1	2394	6	8.3

RN4b (Annealed 800 °C 1h in vacuum)					Span 10 mm		Rate	0.5 mm min ⁻¹
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.87	5.00	1269	2676	4	2866	1	91.7
2	1.87	5.00	1269	2676	1	2676	2	75.0
3	1.88	5.00	1171	2456	2	2676	3	58.3
4	1.88	5.00	1366	2866	3	2456	4	41.7
5	1.88	5.00	978	2052	6	2256	5	25.0
6	1.87	5.01	1075	2256	5	2052	6	8.3

**TELEDYNE WC/Co(1) - UFINE
KENNAMETAL BEND TESTS (RN3b)**

RN3b (Annealed 800 °C 1h in vacuum)					Span 30 mm		Rate	22 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.90	5.00	717	2307	4	2680	1	91.7
2	1.90	5.00	762	2451	3	2623	2	75.0
3	1.89	4.99	807	2623	6	2596	3	58.3
4	1.90	4.99	829	2680	2	2451	4	41.7
5	1.89	5.00	695	2248	1	2307	5	25.0
6	1.91	4.99	807	2596	5	2248	6	8.3

**TELEDYNE WC/Co(1) - UFINE
NPL BEND TESTS (C3, C4, CN4)**

C3				Span 30 mm		Rate	100 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	5425	3296	6	3734	1	91.7
2	5.01	5922	3598	5	3603	2	75.0
3	5.01	5929	3602	3	3602	3	58.3
4	5.01	5888	3577	2	3598	4	41.7
5	5.01	5931	3603	4	3577	5	25.0
6	5.01	6147	3734	1	3296	6	8.3
7*	5.01	3237	1966	3*	2038	1	83.3
8*	5.01	3123	1897	1*	1966	2	50.0
9*	5.01	3355	2038	2*	1897	3	16.7

*annealed 800 °C 1h in vacuum

C4				Outer Span 10 mm		Rate	100 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	7797	3158	6	3422	1	91.7
2	5.01	7589	3074	3	3420	2	75.0
3	5.01	8445	3420	4	3399	3	58.3
4	5.01	8392	3399	5	3286	4	41.7
5	5.01	8114	3286	1	3158	5	25.0
6	5.01	8450	3422	2	3074	6	8.3
7*	5.01	5028	2036	1*	2036	1	83.3
8*	5.01	4845	1962	2*	1962	2	50.0
9*	5.01	4459	1806	3*	1806	3	16.7

*annealed 800 °C 1h in vacuum

CN4 (annealed 800 °C 1h in vacuum)				Outer Span 10 mm		Rate	100 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	1386	1995	2	2159	1	87.5
2	5.01	1500	2159	4	2137	2	62.5
3	5.01	1445	2080	3	2080	3	37.5
4	5.01	1485	2137	1	1995	4	12.5

**TELEDYNE WC/Co(1) - UFINE
CERMeP BEND TESTS (C4, CN4)**

C4				Outer Span 10 mm		Rate	0.5 mm min ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	7962	3225	4	3264	1	94.4
2	5.02	7865	3166	1	3225	2	83.3
3	5.01	7671	3107	2	3166	3	72.2
4	5.01	8059	3264	3	3107	4	61.1
5	5.00	5828	2375	10	3067	5	50.0
6	5.01	5634	2282	8	2967	6	38.9
7	5.00	7283	2967	5	2375	7	27.8
8	5.01	4955	2007	6	2282	8	16.7
9	5.01	7574	3067	9	2007	9	5.6

CN4 (annealed 800 °C 1h in vacuum)				Outer Span 10 mm		Rate	0.5 mm min ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	1560	2245	1	2245	1	87.5
2	5.02	1560	2232	2	2232	2	62.5
3	5.01	932	1341	3	1341	3	37.5
4	5.01	835	1202	4	1202	4	12.5

TELEDYNE WC/Co(1) - FINE
KENNAMETAL BEND TESTS - (C3, CN4)

C3				Span 30 mm		Rate	22 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	4774	2900	3	3717	1	95
2	5.01	4549	2764	5	3717	2	85
3	5.01	6118	3717	6	3621	3	75
4	5.01	5939	3608	4	3608	4	65
5	5.01	6118	3717	9	3581	5	55
6	5.01	5961	3621	7	3553	6	45
7	5.01	5849	3553	10	3336	7	35
8	5.01	5199	3158	8	3158	8	25
9	5.01	5894	3581	1	2900	9	15
10	5.01	5491	3336	2	2764	10	5

CN4 (annealed 800 °C 1h in vacuum)				Outer Span 10 mm		Rate	22 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	1345	1936	3	2258	1	87.5
2	5.01	1434	2064	2	2064	2	62.5
3	5.01	1569	2258	1	1936	3	37.5
4	5.01	1345	1936	4	1936	4	12.5

HARDMETAL BEND TESTS

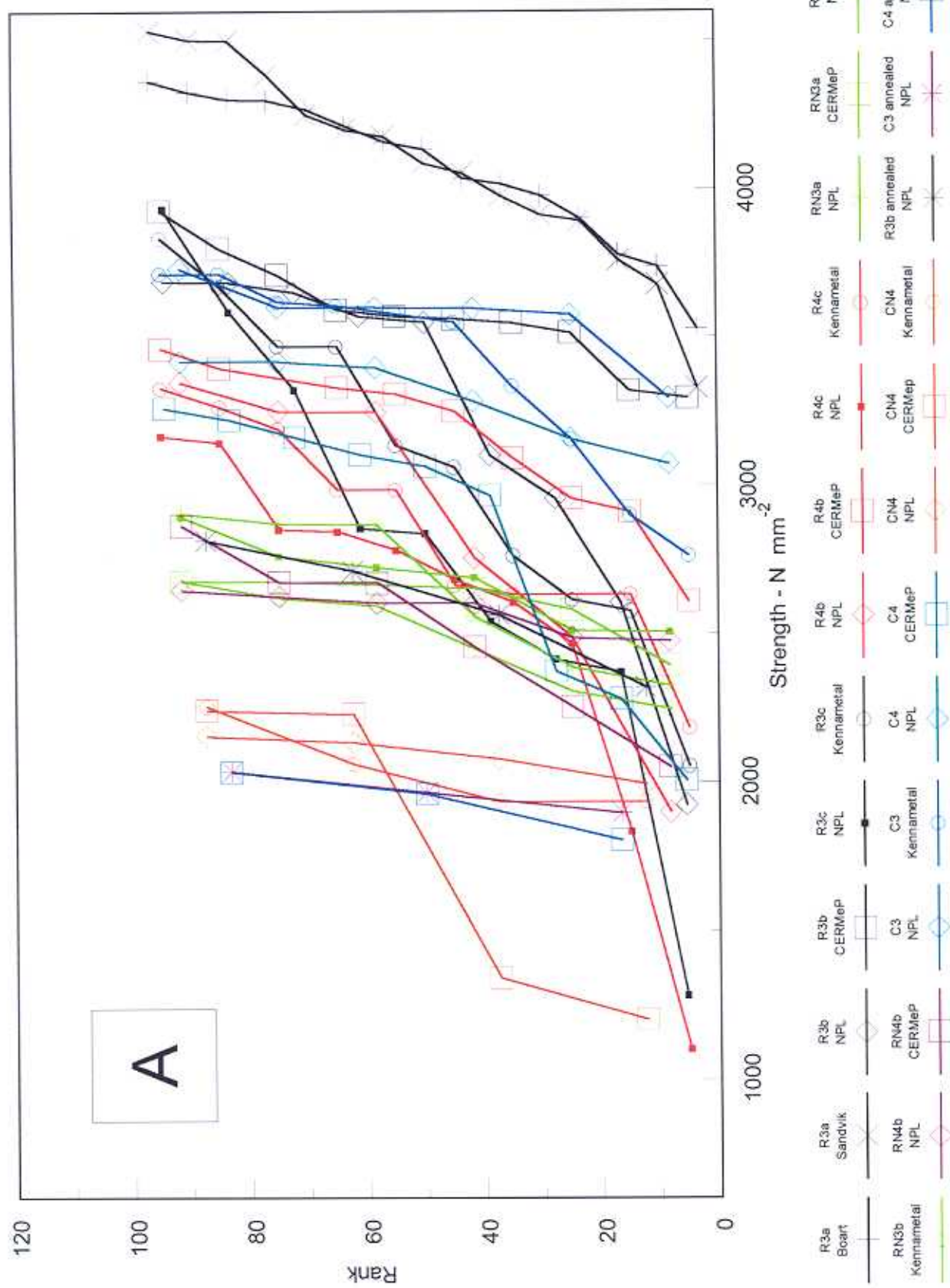
Results Comment Sheet

Teledyne - Category (1) UltraFine WC/Co Hardmetal

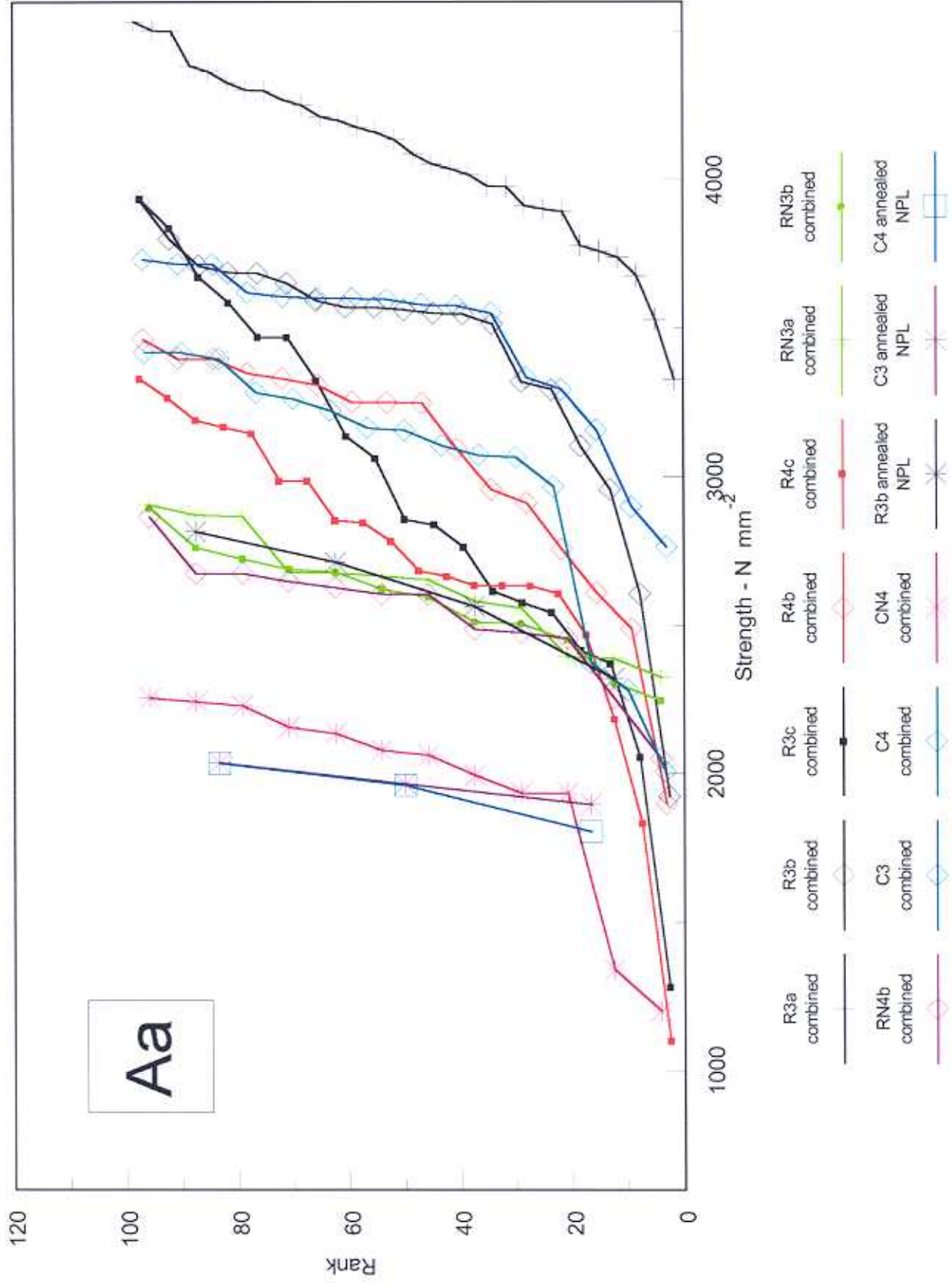
PLOT SEQUENCE

- A - Complete set of all strength values.
- Aa - Complete set, different laboratories combined.
- 1 - Standard tests, ISO type B (R3a).
- 1a - Combined R3a.
- 2 - 3 pt rectangular tests; (R3a, R3b, R3c).
- 2a - Combined R3a, R3b and R3c.
- 3 - 4 pt rectangular tests, compared with standard ISO type B; (R3a, R4b, R4c).
- 3a - Combined R3a, R4b and R4c.
- 4 - 3 pt vs 4 pt tests; R3b, R3c, R4b, R4c; not including R3a.
- 4a - Combined R3b, R3c, R4b and R4c.
- 5 - Round testpieces, compared with standard R3a; C3, C4 and R3a.
- 5a - Combined C3, C4 and R3a.
- 6 - 3 pt rectangular and round; R3b, R3c and C3; not including R3a.
- 6a - Combined C3 compared with R3b and R3c combined.
- 7 - 4 pt rectangular and round; R4b, R4c and C4.
- 7a - Combined C4 compared with R4b and R4c.
- 8 - Notched rectangular testpieces; RN3a, RN3b and RN4b.
- 8a - Combined notched testpieces; RN3a, RN3b and RN4b.
- 9 - Notched round compared with combined notched rectangular; CN4 and RN3a, RB3b and RN4b.
- 9a - Combined notched round compared with combined notched rectangular; CN4 and RN3a, RN3b and RN4b.
- 10 - Annealed NPL R3b, C3 and C4 testpieces compared with as-ground testpieces.

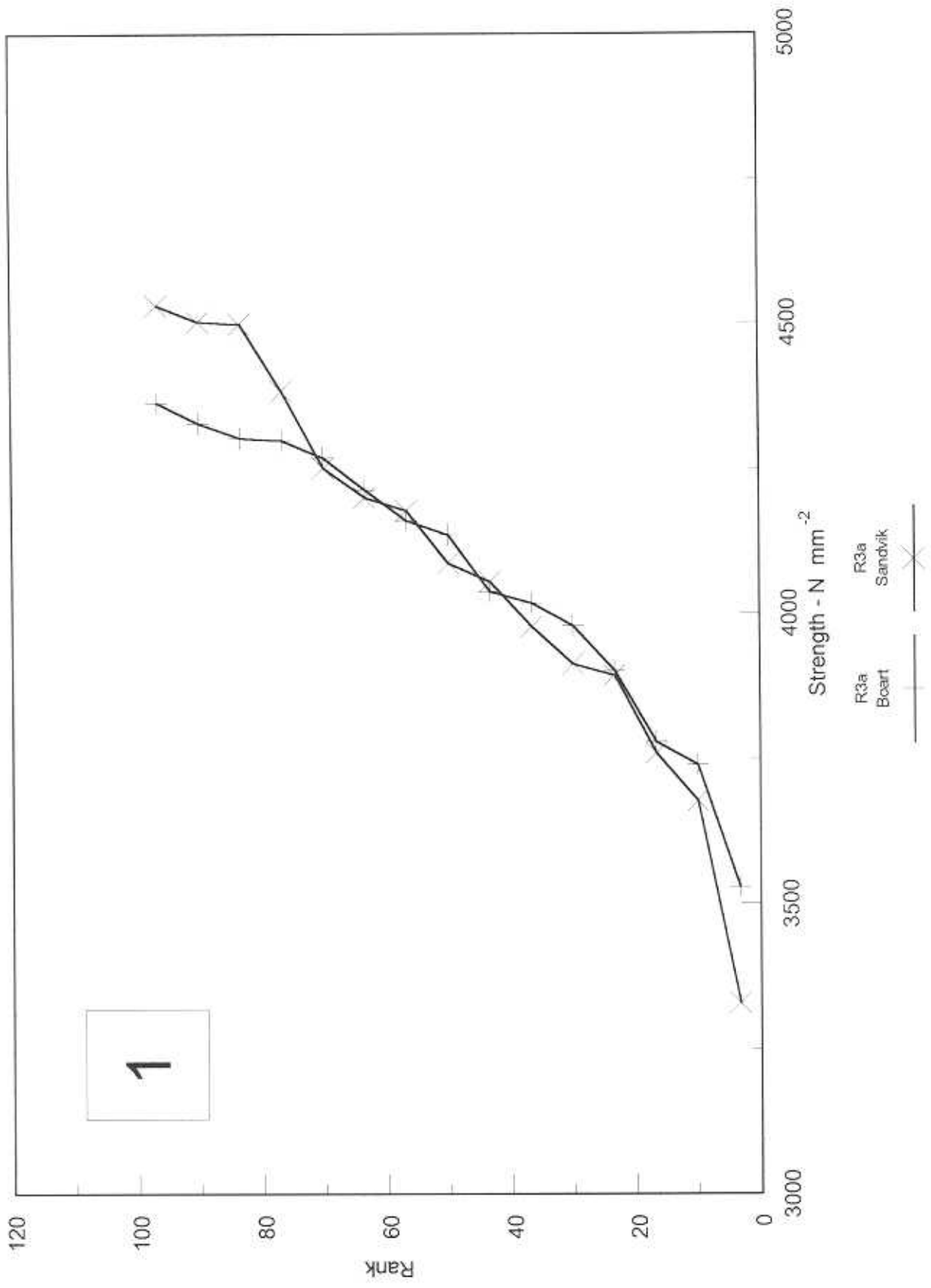
Bend Tests - Teledyne WC/Co (1)



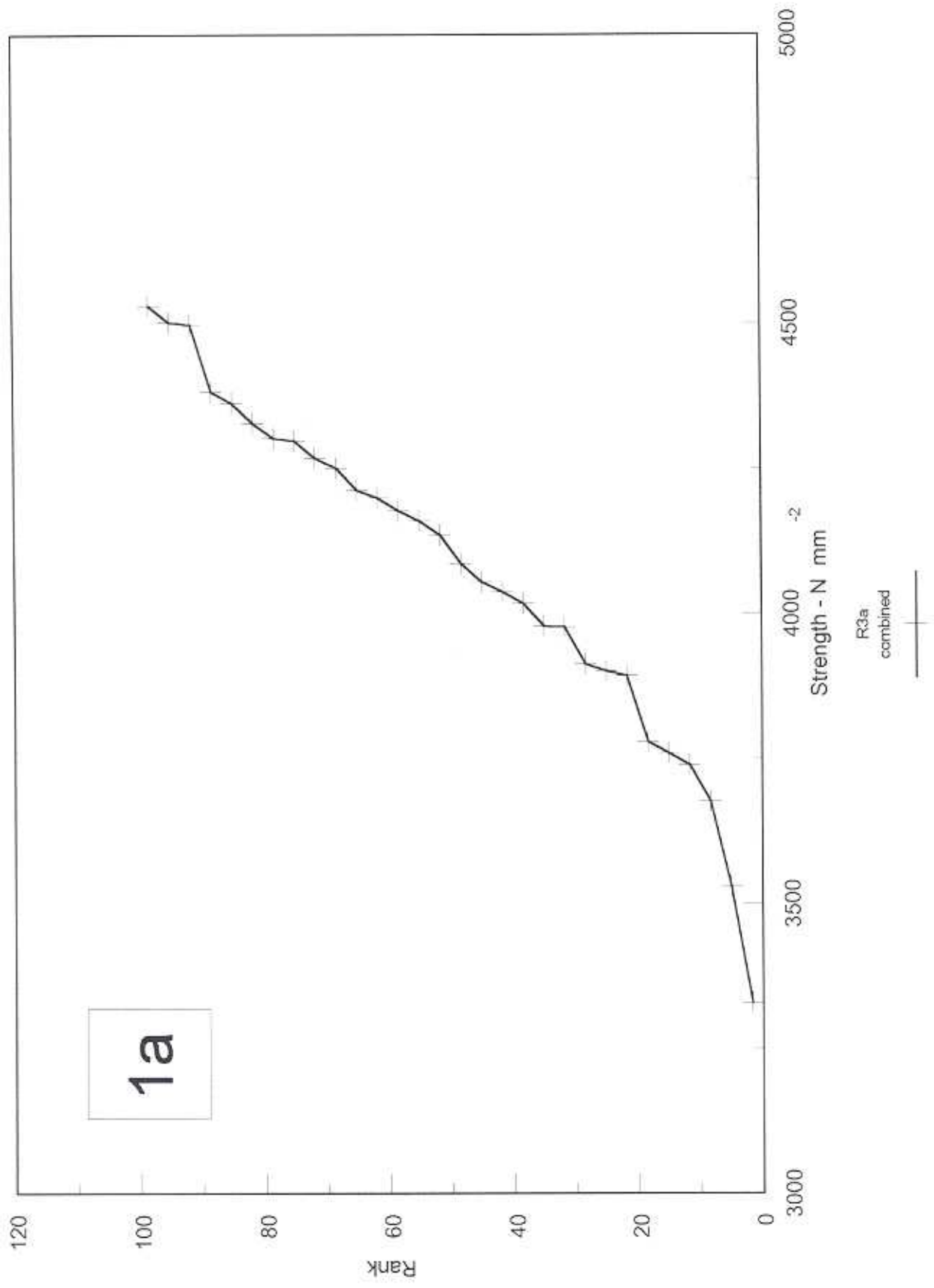
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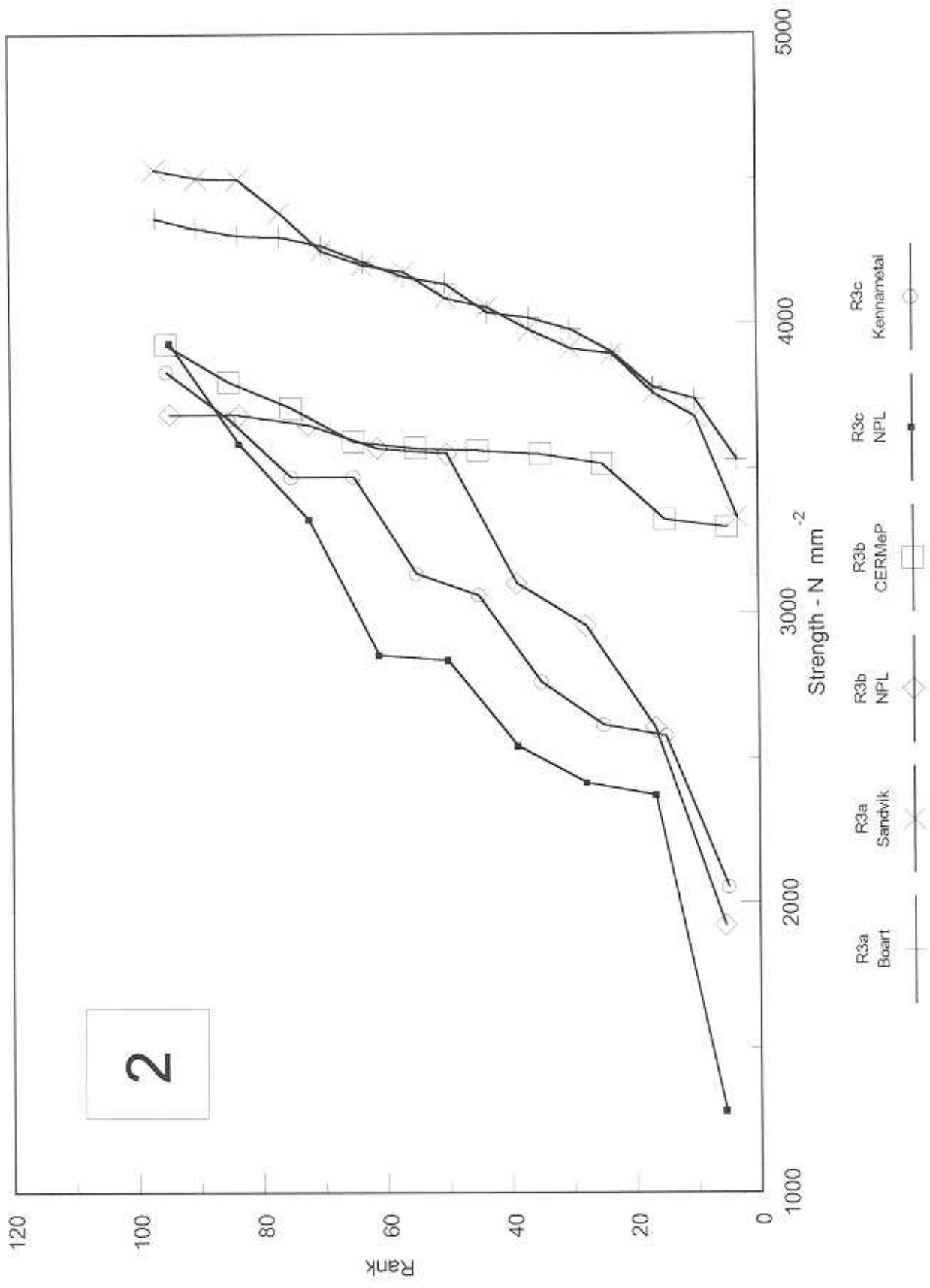
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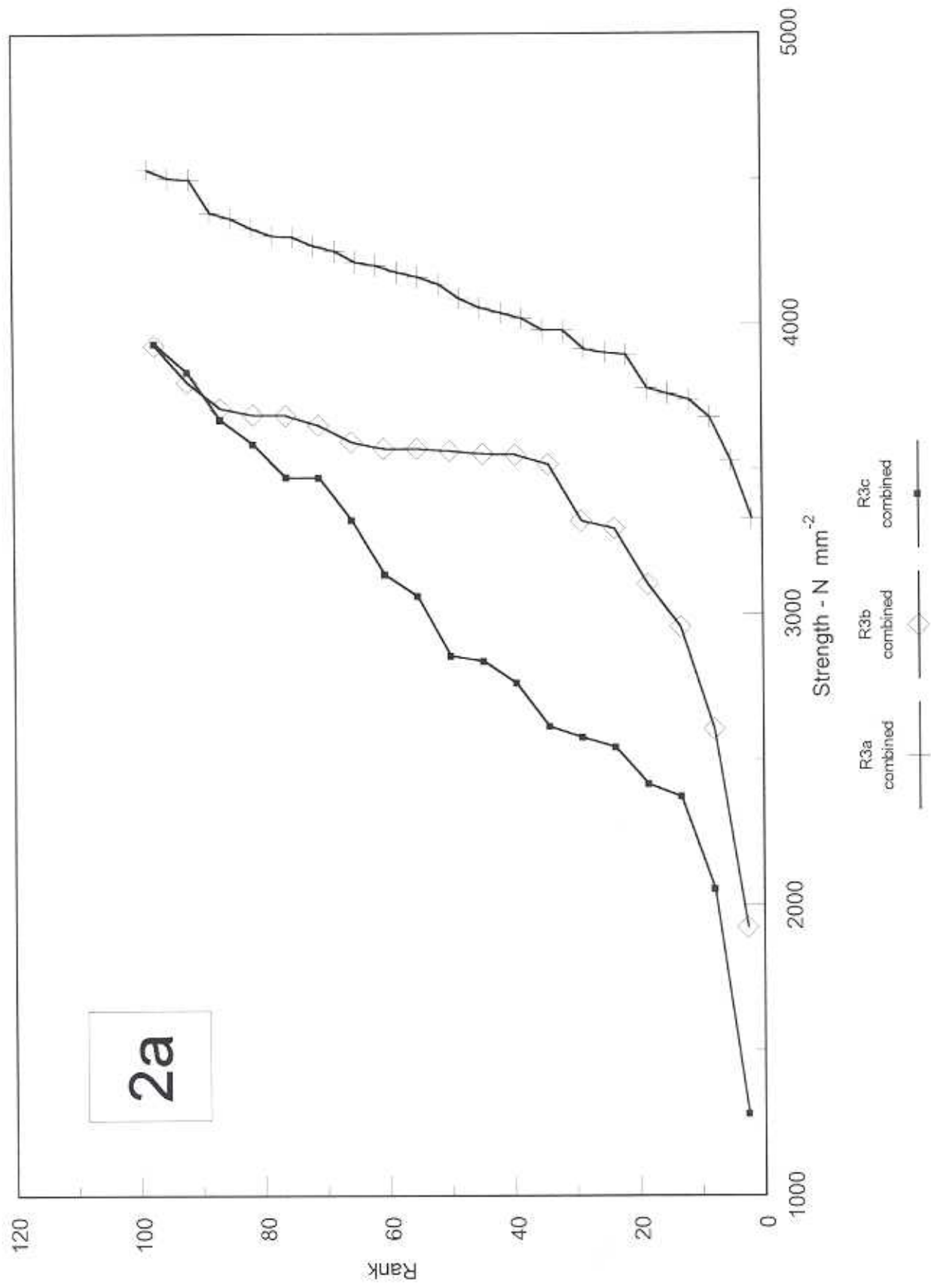
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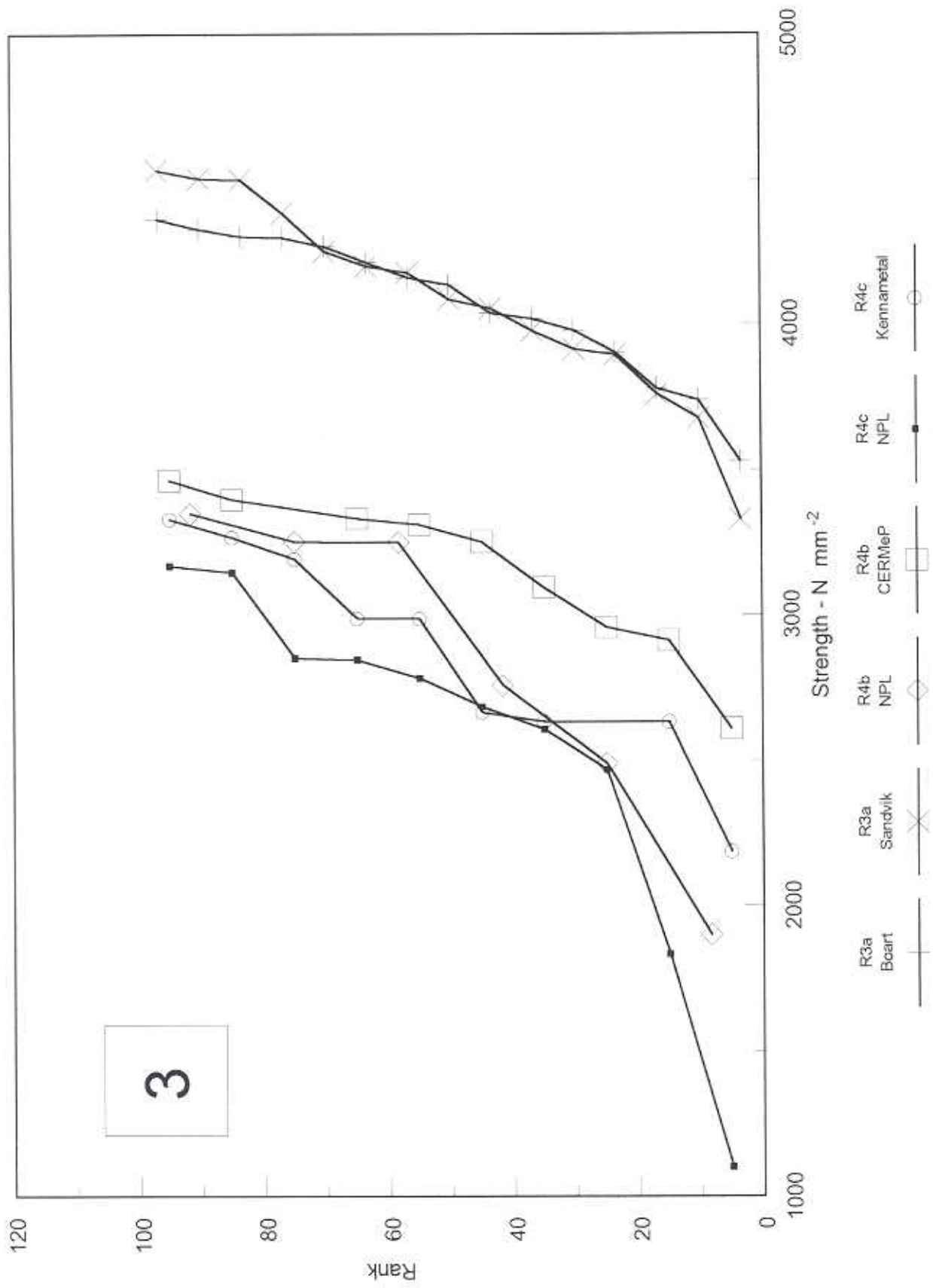
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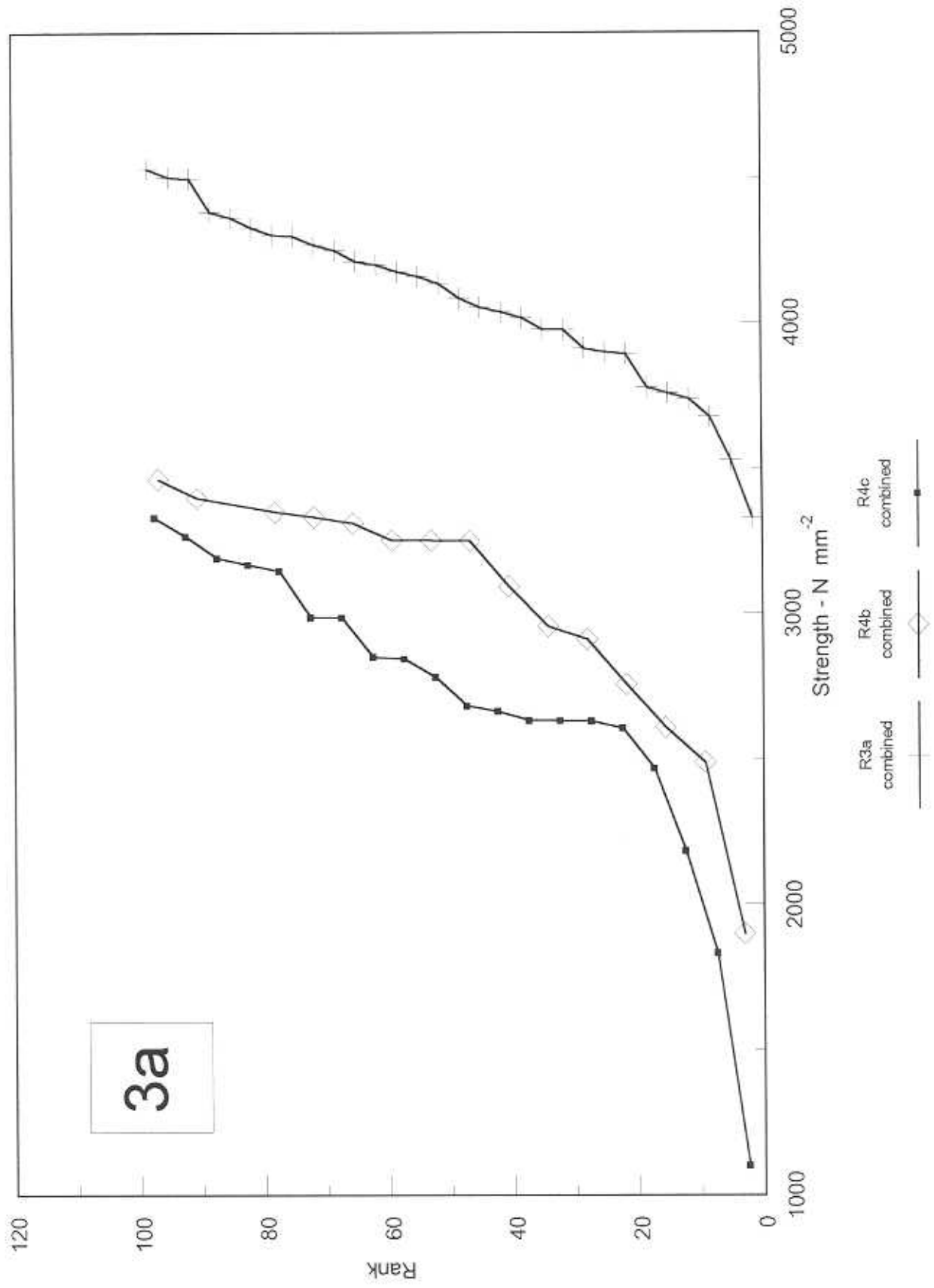
Bend Tests - Teledyne WC/Co (1)



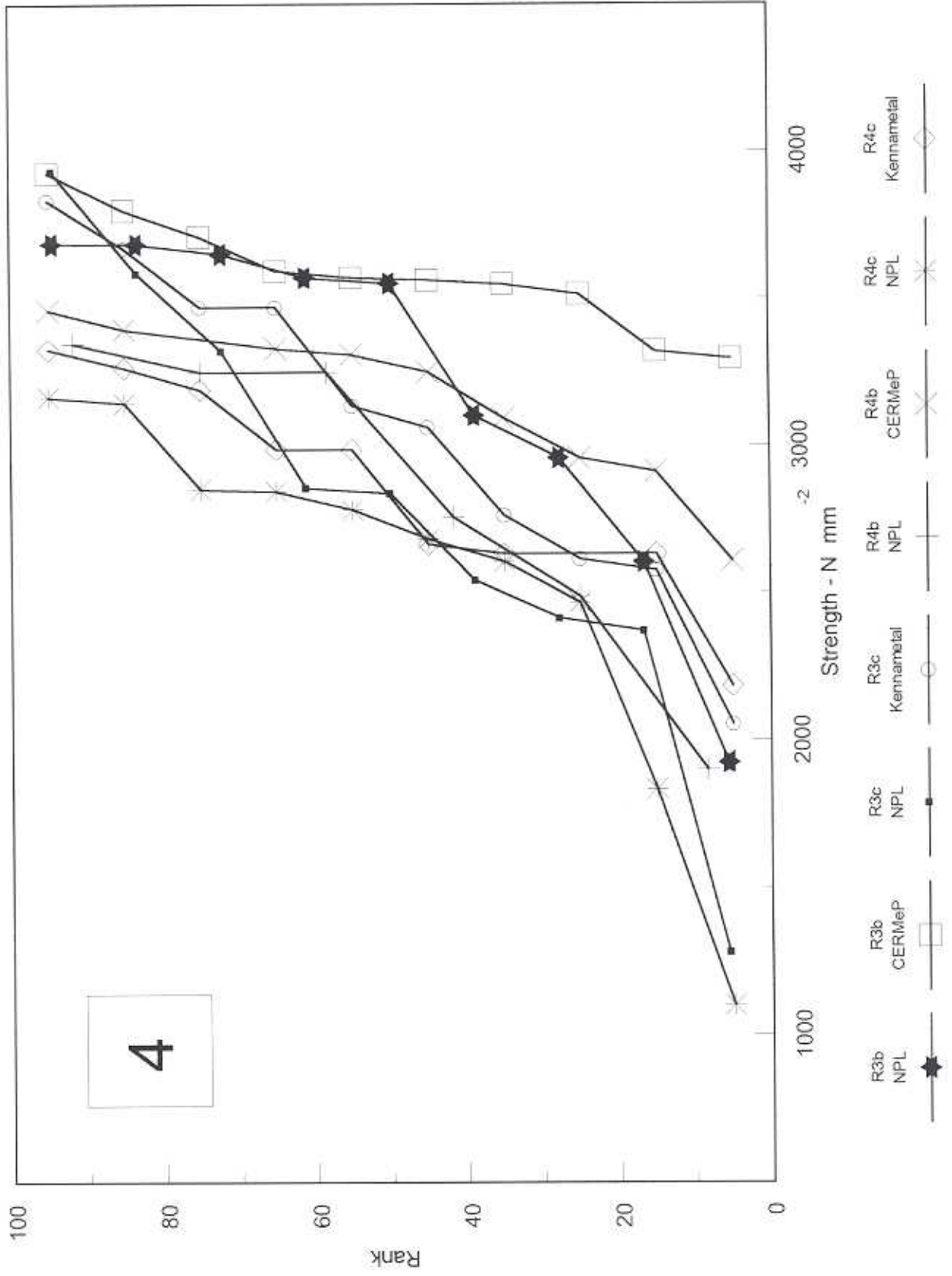
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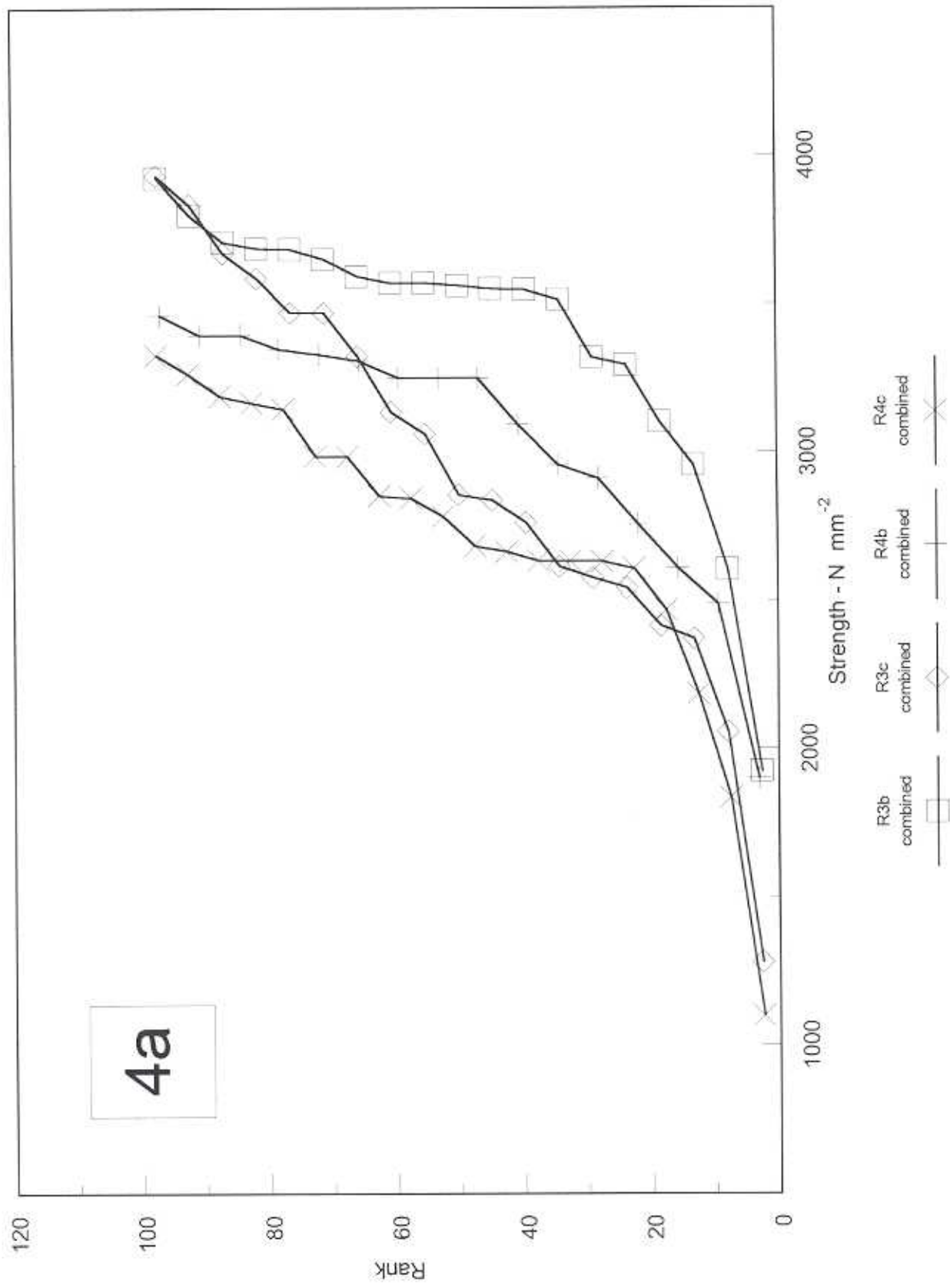
Bend Tests - Teledyne WC/Co (1)



Bend Tests - Teledyne WC/Co (1)

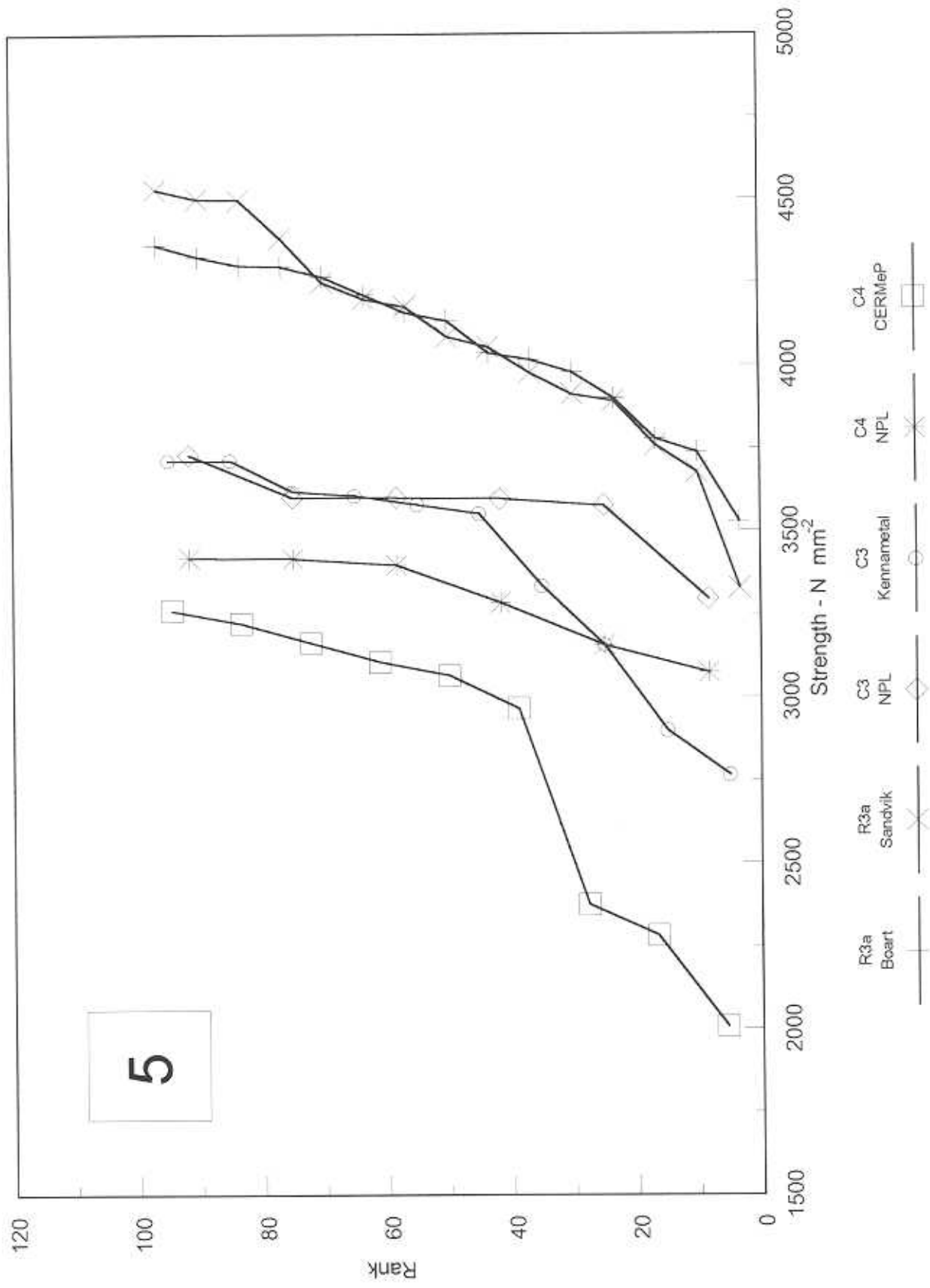


Bend Tests - Teledyne WC/Co (1)



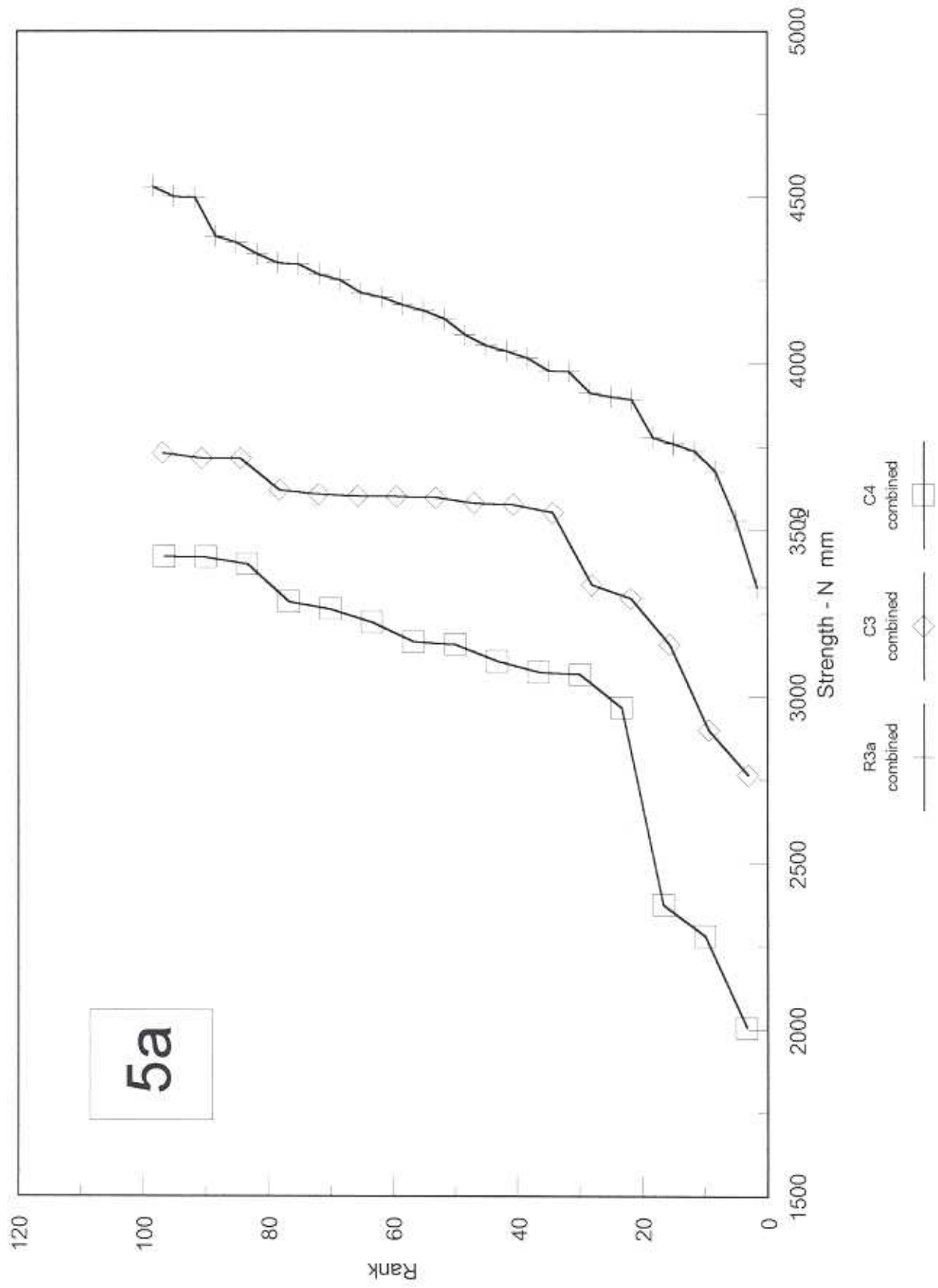
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Bend Tests - Teledyne WC/Co (1)

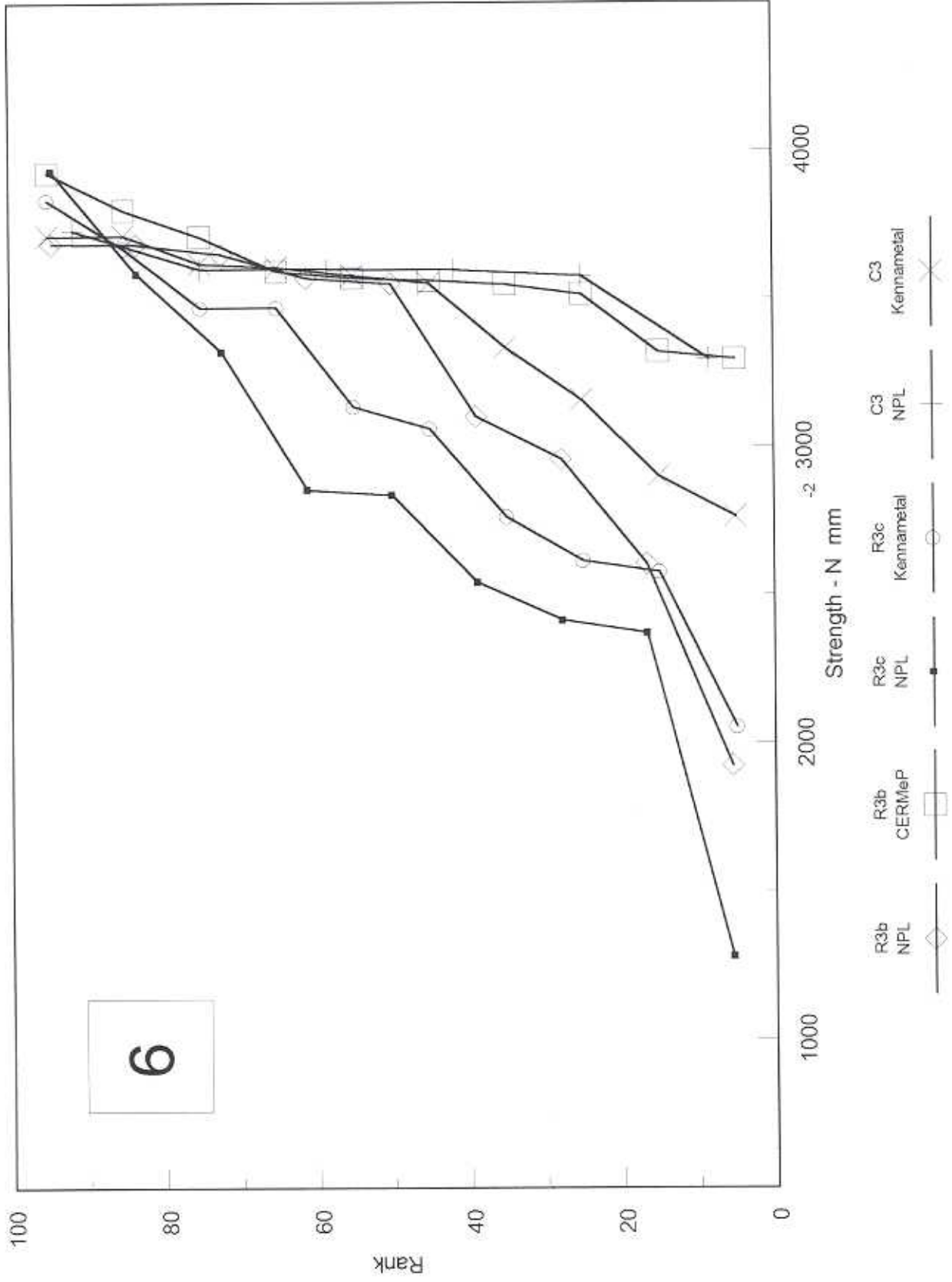


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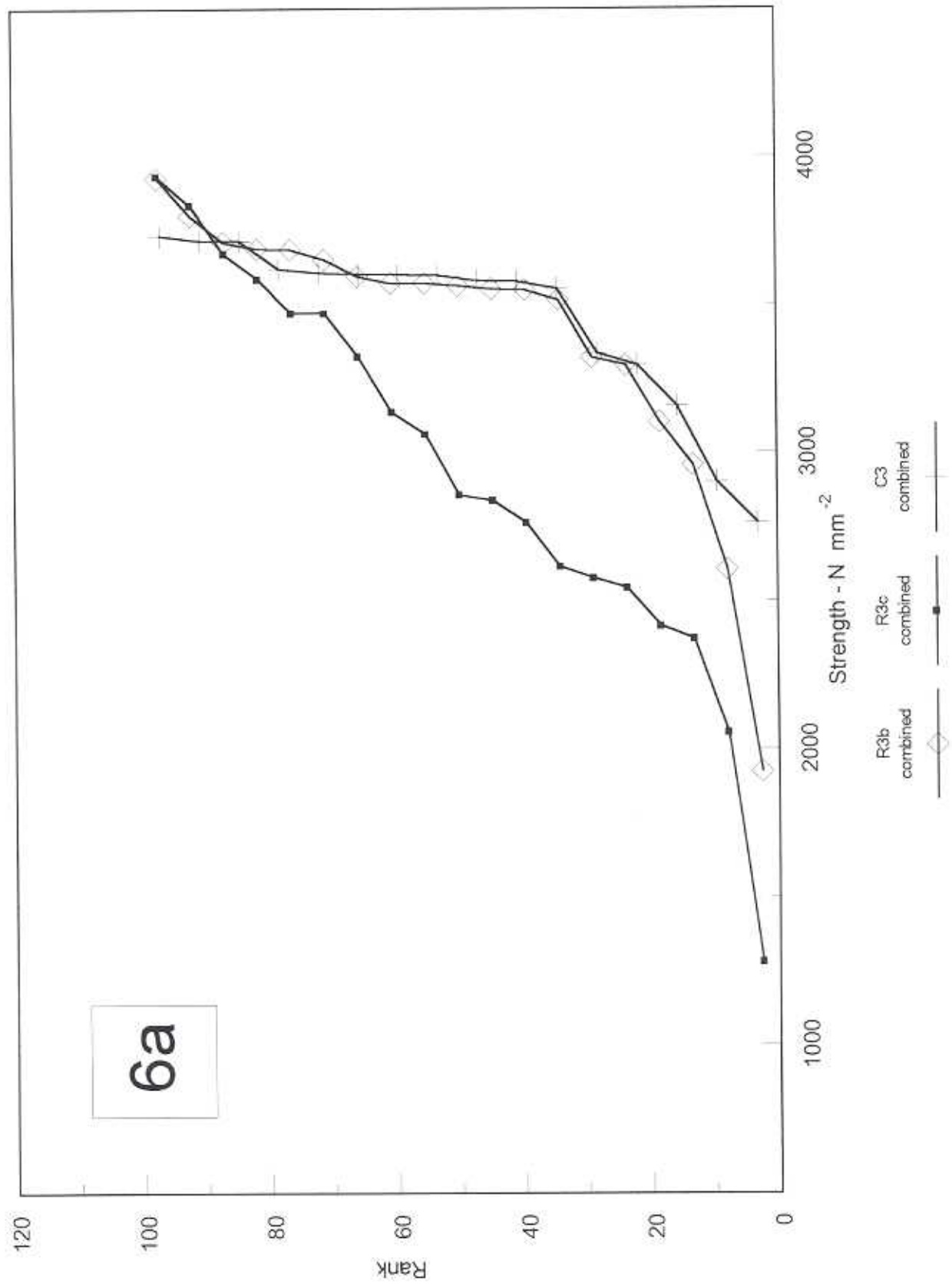
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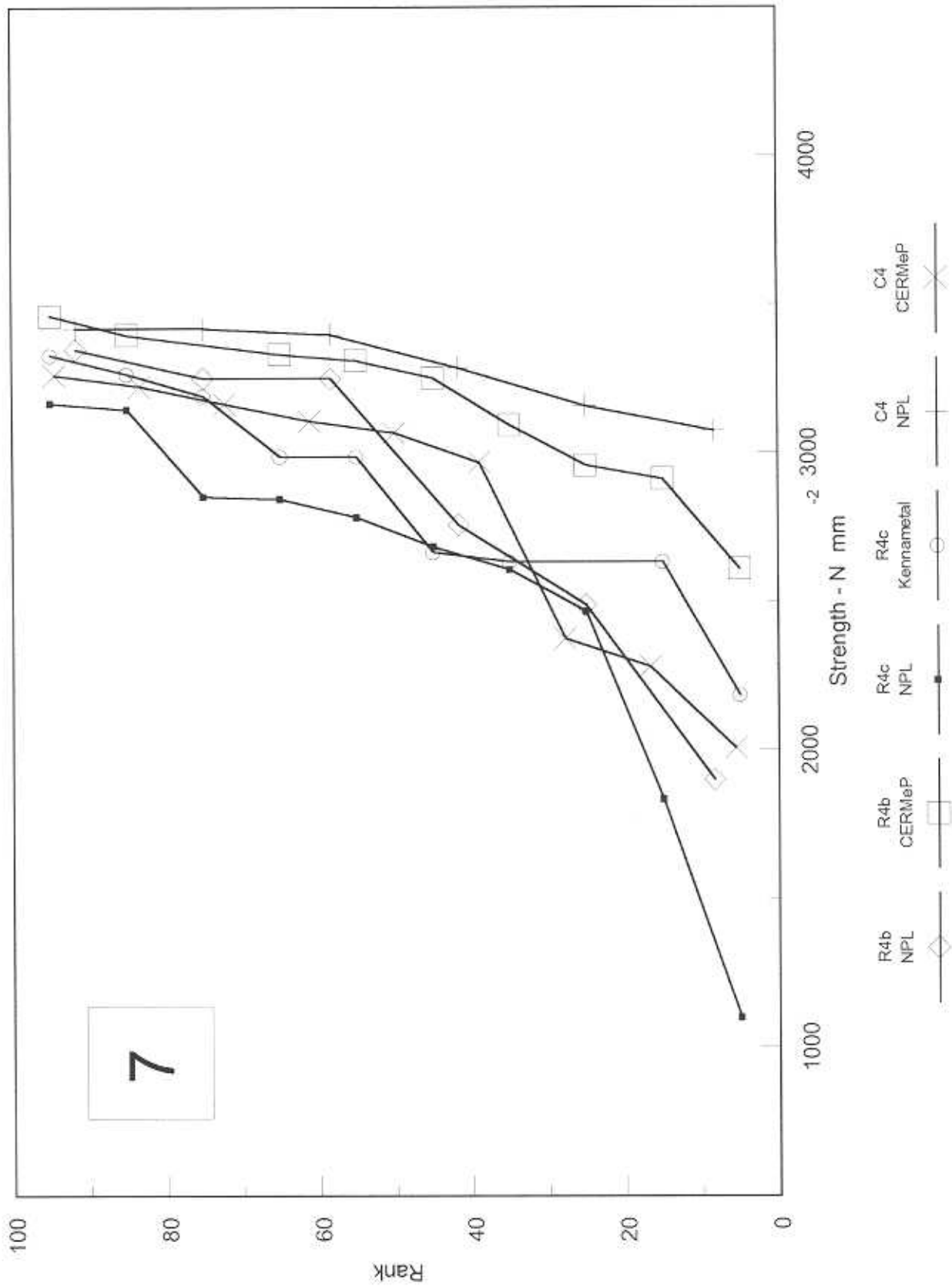
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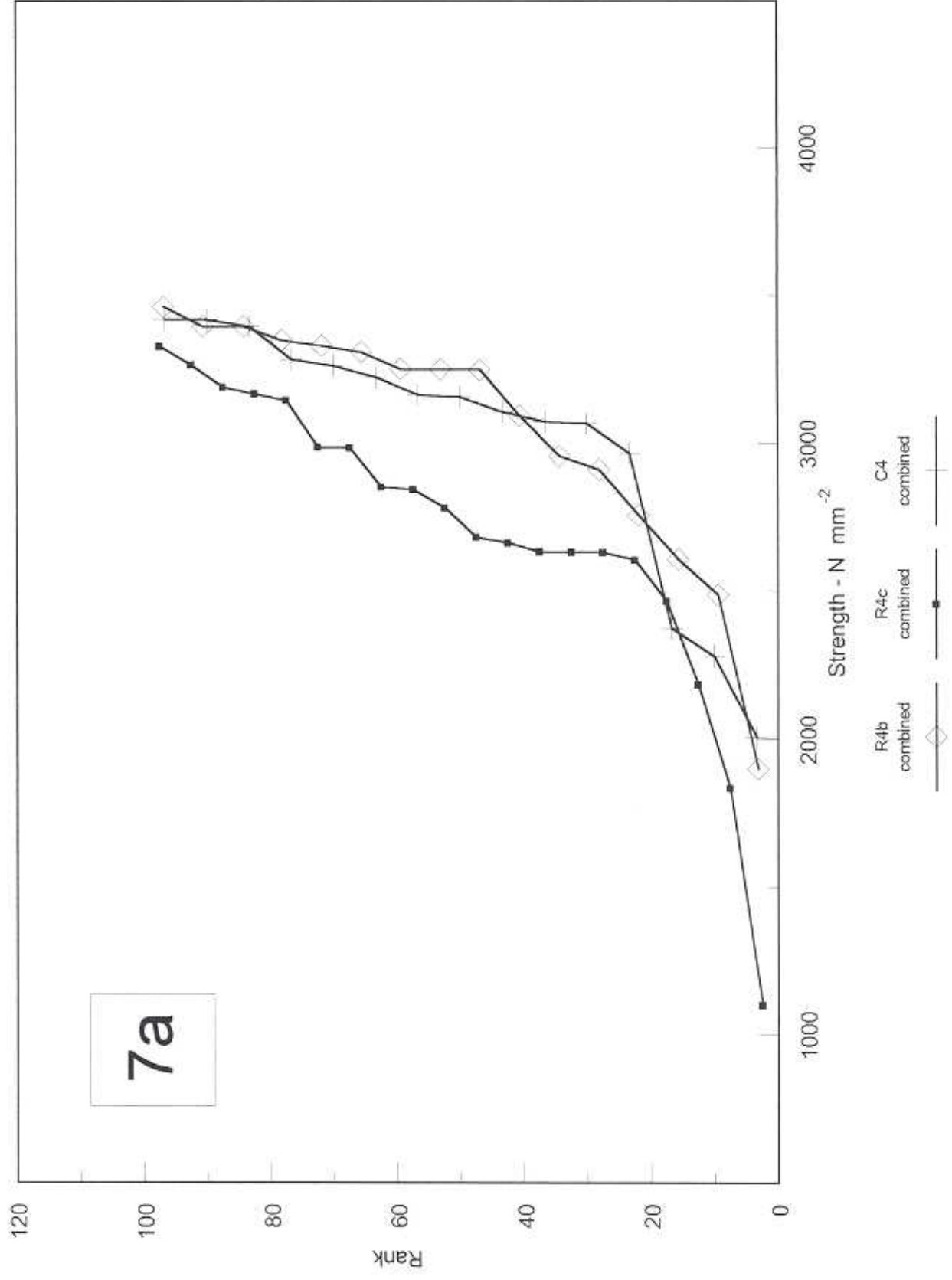
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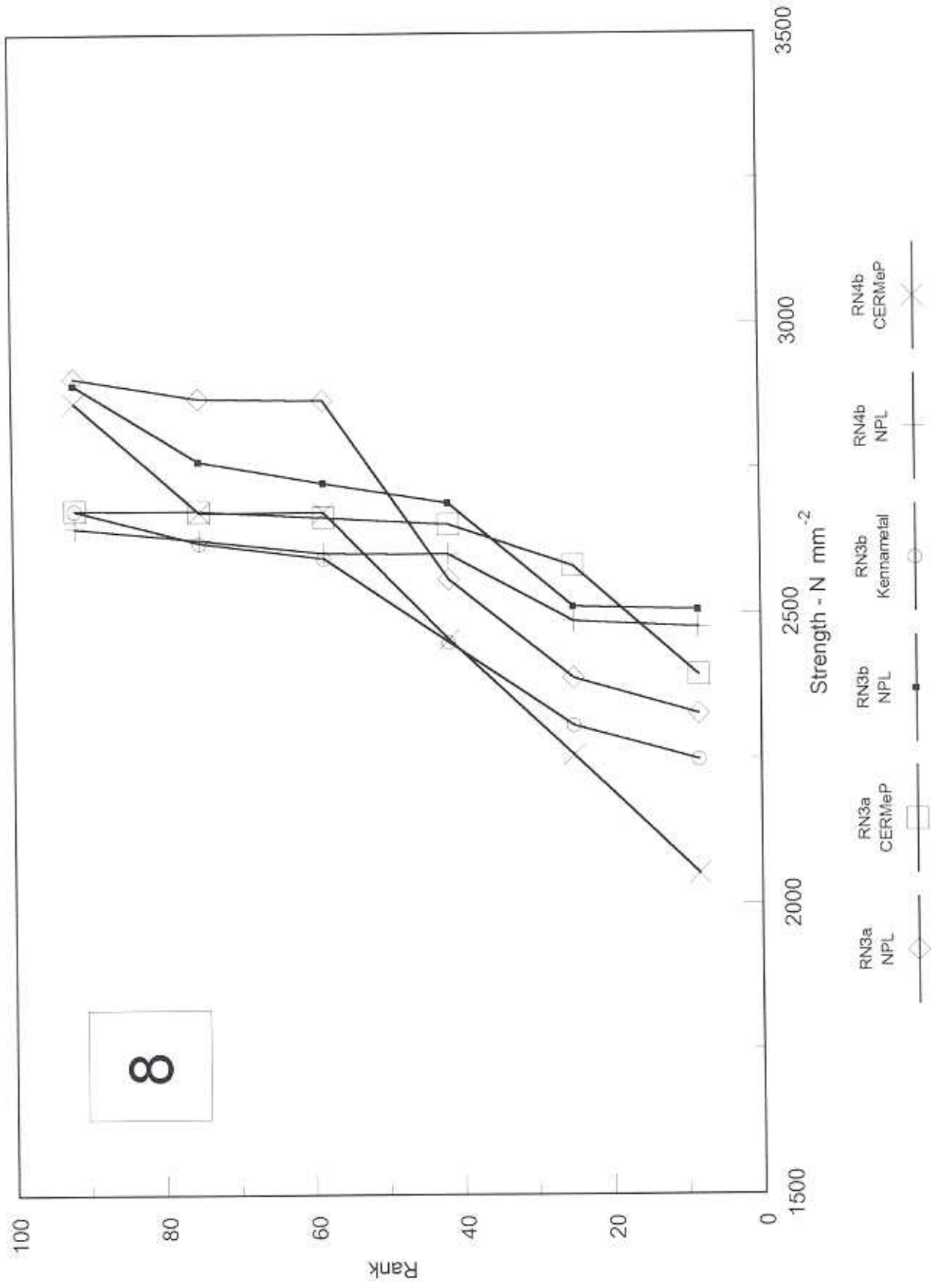
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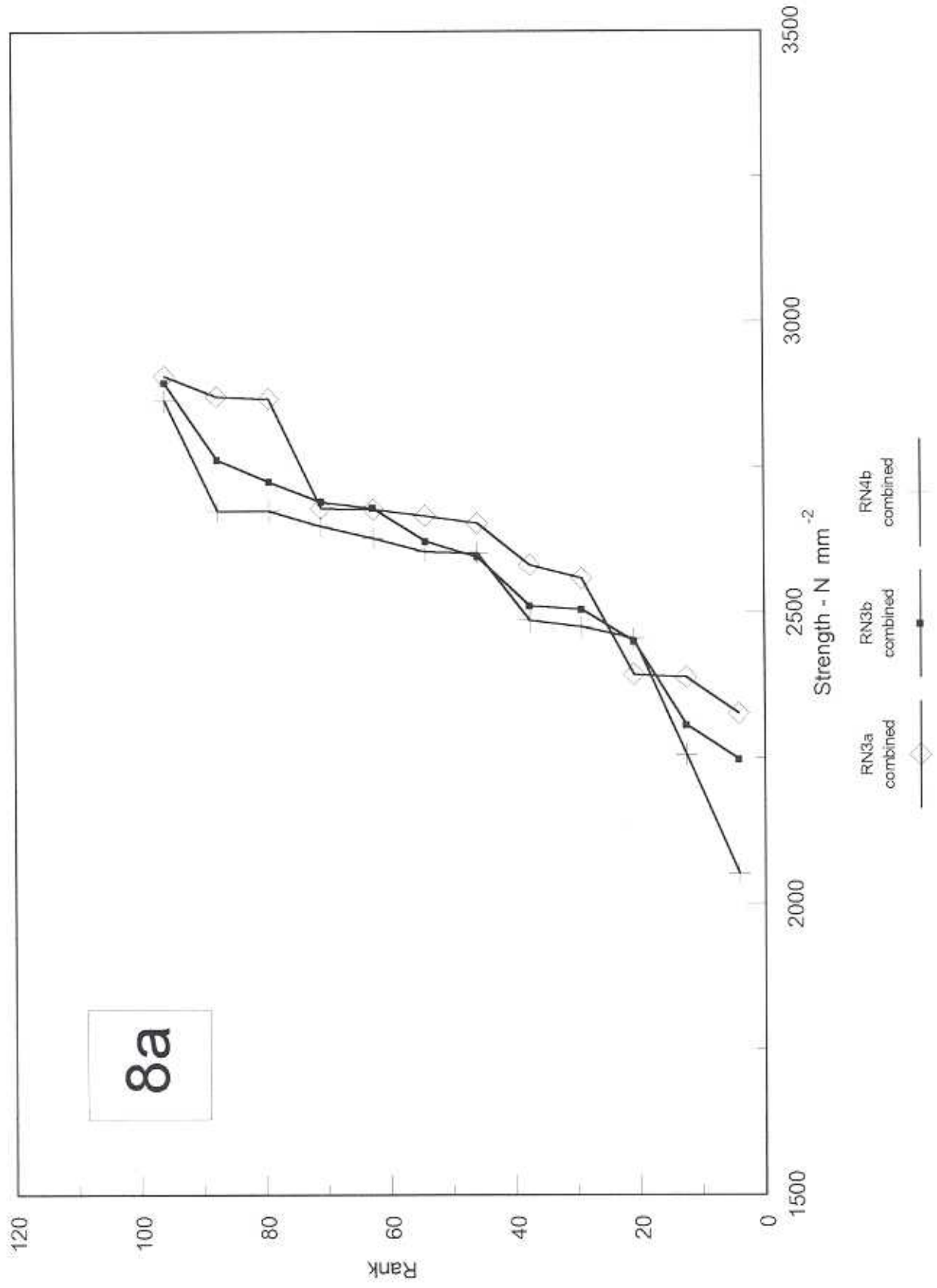
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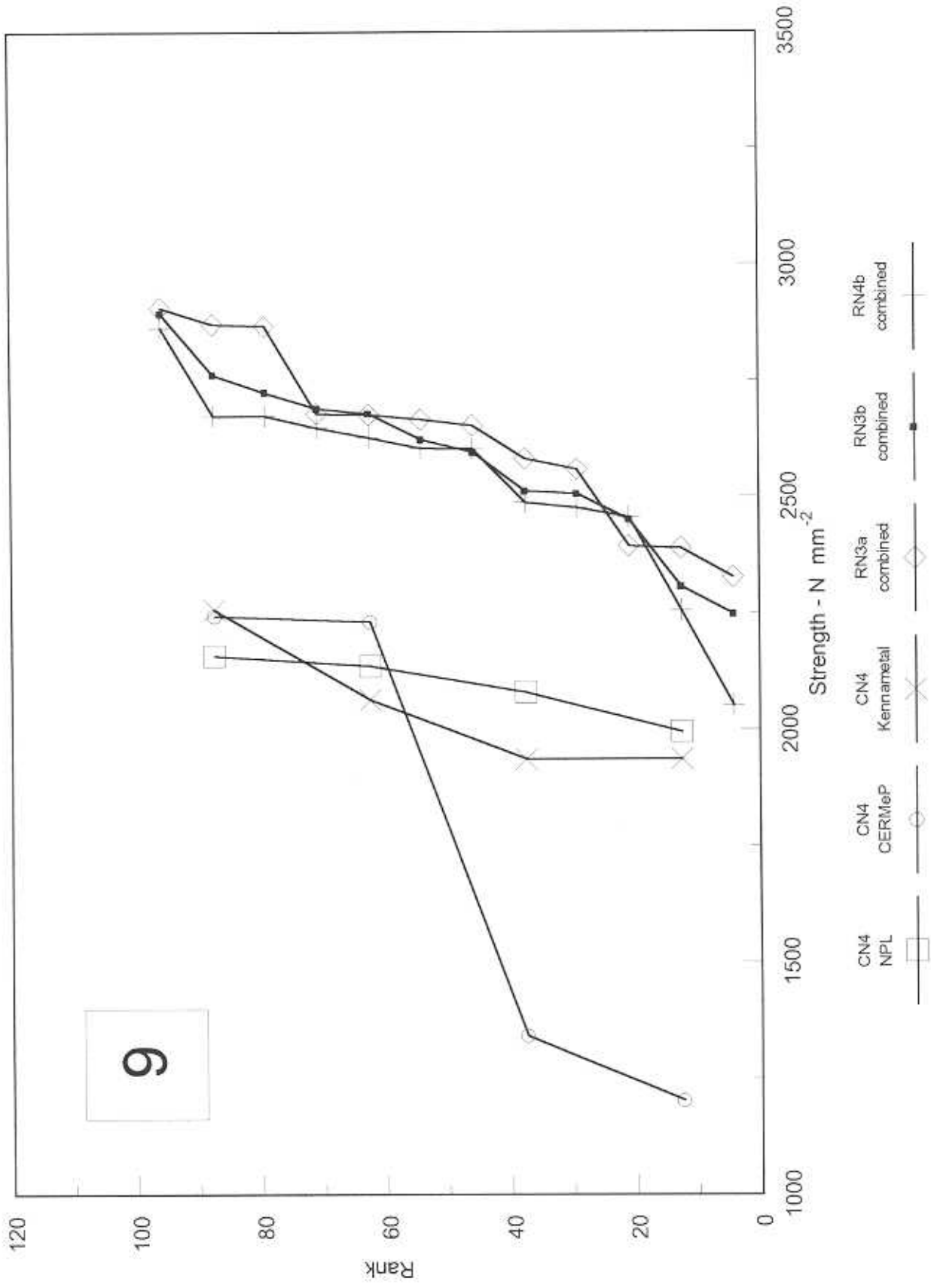
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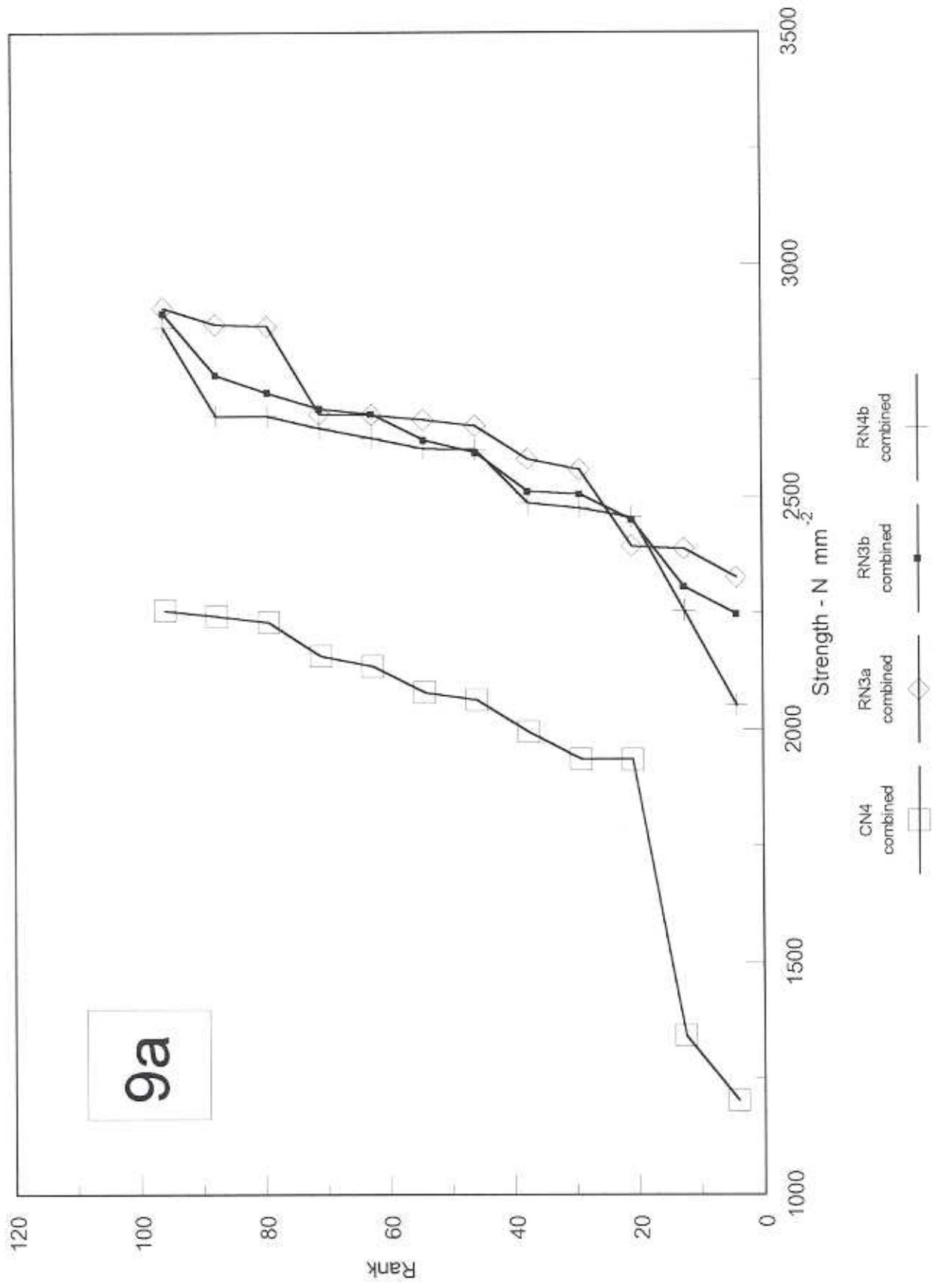
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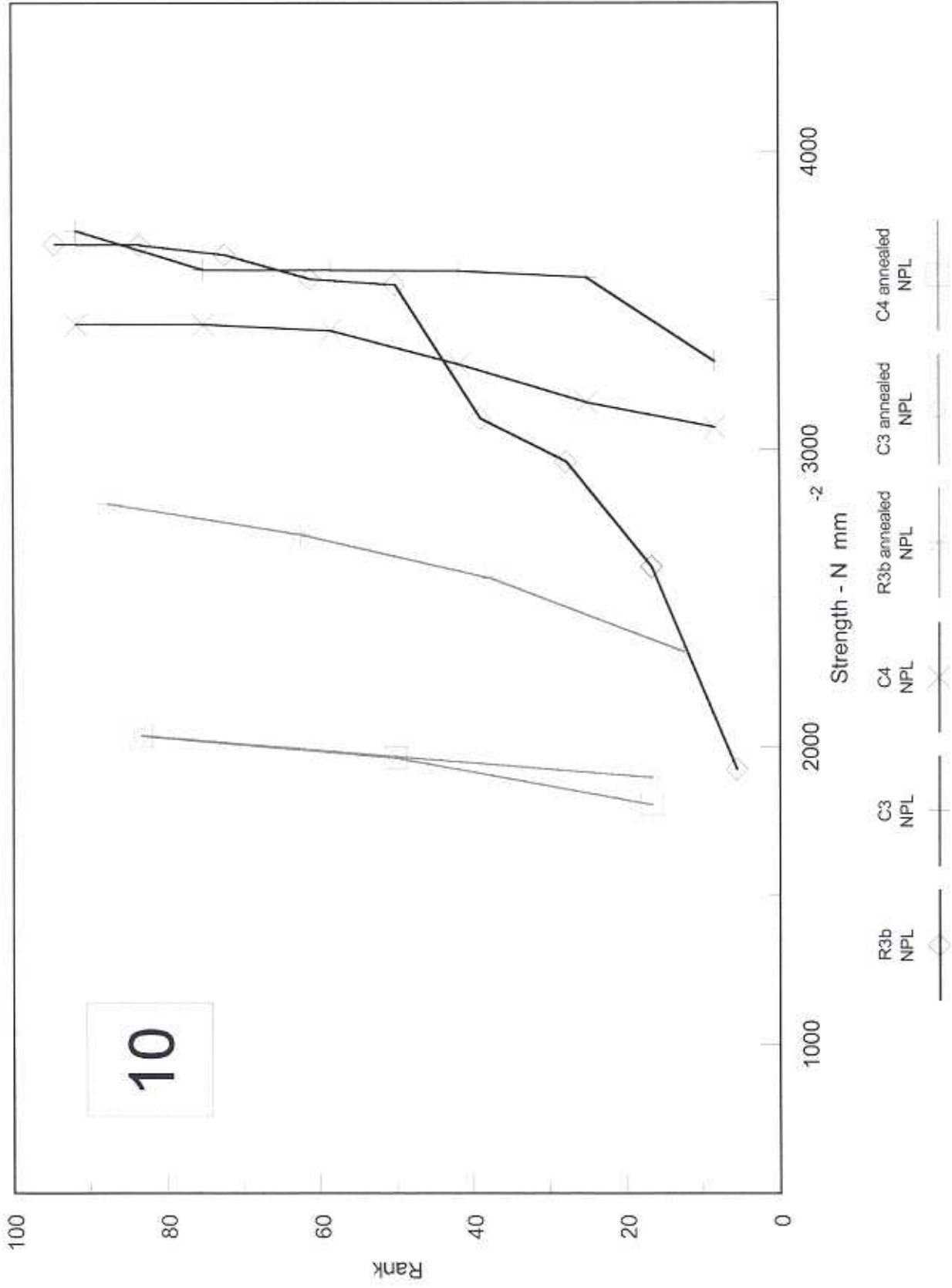
Bend Tests - Teledyne WC/Co (1)



Bend Tests - Teledyne WC/Co (1)



Bend Tests - Teledyne WC/Co (1)



RESULTS SET

(2) BOART LONGYEAR

Fine, WC/Co

Data Tables

Supplementary Comments

Data Plots

HARDMETAL BEND TESTS INTERNATIONAL INTERCOMPARISON

TABLES OF RESULTS

SET 2

WC/Co (Fine grained) - Source: Boart Longyear RC

<i>Geometry</i>		<i>Organisation</i>
3 pt TRS	R3a	Standard Tests (Teledyne/Sandvik)
3,4 pt Rectangular	R3, R4	NPL
3,4 pt Rectangular	R3, R4	Sandvik
3,4 pt Rectangular	R3, R4	Teledyne
3,4 pt Rectangular Notched	RN3, RN4	NPL
3,4 pt Rectangular Notched	RN3, RN4	Sandvik
3,4 pt Rectangular Notched	RN3	Teledyne
Round	C3, C4, CN4	NPL
Round	C4, CN4	Sandvik
Round	C3, CN4	Teledyne

**BOART WC/Co(2) - FINE
STANDARD TRS TESTS - R3a**

Teledyne				Span 14.3 mm		Rate 900 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.37	5.10	24910	3225	15	3349	1	96.7
2	6.35	5.10	24287	3154	9	3348	2	90
3	6.36	5.10	24287	3149	10	3343	3	83.3
4	6.35	5.08	24465	3202	14	3343	4	76.7
5	6.36	5.08	23798	3110	13	3319	5	70
6	6.36	5.08	24668	3224	11	3261	6	63.3
7	6.36	5.08	24243	3168	8	3243	7	56.7
8	6.35	5.08	24777	3243	1	3225	8	50
9	6.35	5.08	25577	3348	6	3224	9	43.3
10	6.36	5.08	25577	3343	4	3202	10	36.7
11	6.35	5.08	24910	3261	7	3168	11	30
12	6.35	5.08	22130	2897	2	3154	12	23.3
13	6.35	5.08	25355	3319	3	3149	13	16.7
14	6.36	5.08	25577	3343	5	3110	14	10
15	6.36	5.08	25622	3349	12	2897	15	3.3

Sandvik				Span 15 mm		Rate 250 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.36	5.08	21971	3012	15	3296	1	96.7
2	6.35	5.07	23431	3230	10	3230	2	90
3	6.35	5.08	22394	3075	2	3230	3	83.3
4	6.35	5.07	21448	2957	6	3222	4	76.7
5	6.34	5.08	22356	3074	13	3183	5	70
6	6.34	5.08	23428	3222	9	3102	6	63.3
7	6.35	5.07	22391	3087	8	3089	7	56.7
8	6.34	5.07	22375	3089	12	3087	8	50
9	6.34	5.08	22558	3102	7	3087	9	43.3
10	6.34	5.07	23395	3230	3	3075	10	36.7
11	6.34	5.08	21805	2999	5	3074	11	30
12	6.34	5.08	22449	3087	1	3012	12	23.3
13	6.35	5.08	23183	3183	11	2999	13	16.7
14	6.34	5.07	18138	2504	4	2957	14	10
15	6.35	5.08	24002	3296	14	2504	15	3.3

BOART WC/Co(2) - FINE
NPL BEND TESTS (R3b, R3c, R4b, R4c)

R3b				Span 30 mm		Rate		200 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.77	4.76	5385	2242	8	2851	1	94.4
2	4.76	4.76	4763	1987	9	2738	2	83.3
3	4.77	4.77	5534	2295	4	2716	3	72.2
4	4.77	4.77	6551	2716	6	2632	4	61.1
5	4.75	4.76	5937	2482	7	2582	5	50
6	4.77	4.77	6348	2632	5	2482	6	38.9
7	4.77	4.77	6227	2582	3	2295	7	27.8
8	4.76	4.76	6834	2851	1	2242	8	16.7
9	4.77	4.76	6575	2738	2	1987	9	5.6
10								

R3c				Span 40 mm		Rate		35 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.70	2.78	1314	2757	10	2835	1	95
2	3.70	2.78	553	1160	1	2757	2	85
3	3.70	2.79	636	1325	7	2686	3	75
4	3.70	2.78	486	1020	5	2650	4	65
5	3.70	2.78	1263	2650	8	2316	5	55
6	3.70	2.78	525	1102	3	1325	6	45
7	3.70	2.78	1280	2686	2	1160	7	35
8	3.70	2.78	1104	2316	6	1102	8	25
9	3.70	2.78	503	1055	9	1055	9	15
10	3.70	2.78	1351	2835	4	1020	10	5

R4b			Outer Span 10 mm				Rate	200 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.77	4.77	9680	2676	1	2676	1	93.75
2	4.76	4.76	6782	1887	5	2592	2	81.25
3	4.76	4.76	7478	2080	8	2549	3	68.75
4	4.76	4.76	7543	2098	7	2394	4	56.25
5	4.76	4.76	9318	2592	4	2098	5	43.75
6	4.77	4.77	6715	1856	3	2080	6	31.25
7	4.77	4.77	8660	2394	2	1887	7	18.75
8	4.77	4.77	9220	2549	6	1856	8	6.25
9								
10								

R4c			Outer Span 10 mm				Rate	100 N s ⁻¹
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.70	2.78	2181	2288	6	2530	1	94.4
2	3.71	2.79	2404	2497	2	2497	2	83.3
3	3.71	2.78	2268	2373	5	2478	3	72.2
4	3.71	2.78	954	998	8	2429	4	61.1
5	3.72	2.79	2392	2478	3	2373	5	50
6	3.71	2.78	2418	2530	1	2288	6	38.9
7	3.70	2.78	969	1017	9	1600	7	27.8
8	3.70	2.78	2315	2429	7	1017	8	16.7
9	3.70	2.8	1547	1600	4	998	9	5.6
10								

**BOART WC/Co(2) - FINE
SANDVIK BEND TESTS (R3b, R4b)**

R3b					Span 30 mm		Rate 200 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.76	4.76	6173	2576	2	2987	1	95
2	4.76	4.76	7159	2987	4	2916	2	85
3	4.72	4.74	3746	1590	7	2745	3	75
4	4.76	4.76	6988	2916	10	2743	4	65
5	4.76	4.76	6305	2631	9	2683	5	55
6	4.75	4.75	5018	2107	8	2677	6	45
7	4.76	4.76	6578	2745	5	2631	7	35
8	4.76	4.77	6442	2677	1	2576	8	25
9	4.76	4.76	6430	2683	6	2107	9	15
10	4.76	4.76	6574	2743	3	1590	10	5

R4b					Outer Span 10 mm		Rate 200 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.76	4.76	9664	2688	10	2739	1	95
2	4.76	4.76	8225	2288	1	2688	2	85
3	4.76	4.76	7190	2000	8	2623	3	75
4	4.76	4.76	8415	2341	5	2529	4	65
5	4.77	4.77	9149	2529	9	2380	5	55
6	4.77	4.77	7736	2138	4	2341	6	45
7	4.77	4.76	7669	2129	2	2288	7	35
8	4.76	4.76	9429	2623	6	2138	8	25
9	4.76	4.76	8555	2380	7	2129	9	15
10	4.76	4.75	9804	2739	3	2000	10	5

**BOART WC/Co(2) - FINE
TELEDYNE BEND TESTS (R3c, R4c)**

R3c			Span 30 mm				Rate 445 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.71	2.79	401	833	8	3374	1	95
2	3.72	2.79	200	414	9	3237	2	85
3	3.71	2.79	668	1388	7	3052	3	75
4	3.71	2.79	334	694	10	2959	4	65
5	3.71	2.79	1246	2589	6	2607	5	55
6	3.71	2.78	1246	2607	5	2589	6	45
7	3.71	2.79	1469	3052	3	1388	7	35
8	3.71	2.79	1624	3374	1	833	8	25
9	3.71	2.79	1558	3237	4	694	9	15
10	3.71	2.79	1424	2959	2	414	10	5

R4c			Outer Span 10 mm				Rate 445 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.71	2.79	1046	1087	6	3051	1	95
2	3.71	2.79	1224	1272	10	2866	2	85
3	3.71	2.79	1469	1526	7	2820	3	75
4	3.71	2.79	979	1017	3	1526	4	65
5	3.71	2.79	1113	1156	8	1387	5	55
6	3.71	2.79	2937	3051	2	1272	6	45
7	3.71	2.79	2715	2820	5	1156	7	35
8	3.71	2.79	1335	1387	1	1087	8	25
9	3.71	2.78	1001	1047	9	1047	9	15
10	3.71	2.79	2759	2866	4	1017	10	5

BOART WC/Co(2) - FINE
NPL BEND TESTS (RN3a, RN3b, RN4b)

RN3a (annealed 800 °C 1h in vacuum)			Span 13.8 mm		Rate 200 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.52	5.08	2423	2391	5	2899	1	91.7
2	2.52	5.07	2866	2842	2	2842	2	75
3	2.52	5.08	2619	2585	6	2774	3	58.3
4	2.52	5.05	2536	2540	3	2585	4	41.7
5	2.52	5.08	2937	2899	4	2540	5	25
6	2.52	5.07	2797	2774	1	2391	6	8.3

RN3b (annealed 800 °C 1h in vacuum)			Span 30 mm		Rate 80 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.81	4.76	599	2289	6	2882	1	91.7
2	1.81	4.72	646	2522	5	2721	2	75
3	1.81	4.76	690	2637	4	2702	3	58.3
4	1.8	4.76	703	2702	3	2637	4	41.7
5	1.8	4.76	708	2721	2	2522	5	25
6	1.8	4.76	750	2882	1	2289	6	8.3

RN4b (annealed 800 °C 1h in vacuum)			Outer Span 10 mm		Rate 100 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.81	4.77	952	2335	4	2615	1	90
2	1.8	4.76	1037	2571	2	2571	2	70
3	1.82	4.76	964	2364	3	2364	3	50
4	1.82	4.77	1072	2615	1	2335	4	30
5	1.81	4.76	914	2254	5	2254	5	10
6								

**BOART WC/Co(2) - FINE
SANDVIK BEND TESTS (RN3a, RN4b)**

RN3a (annealed 800 °C 1h in vacuum)				Span 15 mm		Rate 100 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.52	5.08	2851	3058	1	3058	1	91.7
2	2.52	5.07	2701	2912	2	2912	2	75
3	2.52	5.07	2622	2827	5	2881	3	58.3
4	2.52	5.07	2635	2841	6	2848	4	41.7
5	2.52	5.08	2686	2881	4	2841	5	25
6	2.52	5.08	2655	2848	3	2827	6	8.3

RN4b (annealed 800 °C 1h in vacuum)				Span 10 mm		Rate 100 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.80	4.76	800	1984	2	2634	1	91.7
2	1.81	4.77	1074	2634	5	2521	2	75
3	1.80	4.76	1012	2509	3	2509	3	58.3
4	1.72	4.77	889	2295	6	2315	4	41.7
5	1.79	4.76	1011	2521	4	2295	5	25
6	1.81	4.77	944	2315	1	1984	6	8.3

**BOART WC/Co(2) - FINE
TELEDYNE BEND TESTS (RN3b)**

RN3b (annealed 800 °C 1h in vacuum)			Span 30 mm		Rate 445 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.82	4.77	668	2526	3	2570	1	91.7
2	1.8	4.77	668	2554	2	2554	2	75.0
3	1.81	4.77	676	2570	1	2526	3	58.3
4	1.82	4.76	445	1691	5	2381	4	41.7
5	1.81	4.76	623	2381	6	2259	5	25.0
6	1.73	4.73	556	2269	4	1691	6	8.3

**BOART WC/Co(2) - FINE
NPL BEND TESTS (C3, C4, CN4)**

C3				Span 30 mm		Rate 100 N s ⁻¹	
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	4376	2674	2	2891	1	94.4
2	5.00	4731	2891	4	2764	2	83.3
3	5.00	3948	2413	1	2674	3	72.2
4	5.00	4523	2764	7	2621	4	61.1
5	5.00	3966	2424	8	2606	5	50
6	5.00	4234	2588	6	2588	6	38.9
7	5.00	4288	2621	9	2467	7	27.8
8	5.00	4264	2606	5	2424	8	16.7
9	5.00	4037	2467	3	2413	9	5.6
10							

C4				Outer Span 10 mm		Rate 100 N s ⁻¹	
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	5629	2293	4	2750	1	94.4
2	5.00	5720	2331	9	2651	2	83.3
3	5.00	5849	2383	6	2615	3	72.2
4	5.00	6749	2750	5	2493	4	61.1
5	5.00	6119	2493	3	2383	5	50
6	5.00	6419	2615	2	2331	6	38.9
7	5.00	4000	1630	1	2293	7	27.8
8	5.00	5490	2237	8	2237	8	16.7
9	5.00	6506	2651	7	1630	9	5.6
10							

CN4 (annealed 800 °C 1h in vacuum)				Outer Span 10 mm		Rate 100 N s ⁻¹	
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	1564	2265	4	2547	1	87.5
2	5.00	1681	2434	2	2434	2	62.5
3	5.00	1488	2155	1	2265	3	37.5
4	5.00	1759	2547	3	2155	4	12.5

**BOART WC/Co(2) - FINE
SANDVIK BEND TESTS (C4, CN4)**

C4		Outer Span 10 mm				Rate	200 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	6251	2547	10	2619	1	95
2	5.00	5285	2153	7	2611	2	85
3	5.00	5179	2110	6	2569	3	75
4	5.00	5713	2328	1	2547	4	65
5	5.00	6243	2544	5	2544	5	55
6	5.00	6305	2569	4	2328	6	45
7	5.00	6408	2611	9	2284	7	35
8	5.00	5099	2078	2	2153	8	25
9	5.00	5607	2284	3	2110	9	15
10	5.00	6428	2619	8	2078	10	5

CN4 (annealed 800 °C 1h in vacuum)		Outer Span 10 mm				Rate	100 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	1800	2606	2	2683	1	87.5
2	5.00	1853	2683	1	2606	2	62.5
3	5.00	1654	2395	4	2502	3	37.5
4	5.00	1728	2502	3	2395	4	12.5

**BOART WC/Co(2) - FINE
TELEDYNE BEND TESTS - (C3, CN4)**

C3				Span 30 mm		Rate	445 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5	4561	2787	6	3073	1	94.4
2	5	4094	2502	4	3046	2	83.3
3	5	4228	2584	9	2965	3	72.2
4	5	4984	3046	5	2828	4	61.1
5	5	4628	2828	1	2787	5	50.0
6	5	5029	3073	7	2720	6	38.9
7	5	4450	2720	8	2665	7	27.8
8	5	4361	2665	3	2584	8	16.7
9	5	4851	2965	2	2502	9	5.6
10							

CN4 (annealed 800 °C 1h in vacuum)				Outer Span 10 mm		Rate	445 N s ⁻¹
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5	1700	2462	2	2674	1	87.5
2	5	1847	2674	3	2480	2	62.5
3	5	1713	2480	1	2462	3	37.5
4	5	1335	1933	4	1933	4	12.5

HARDMETAL BEND TESTS

Results Comment Sheet

Boart Longyear Category (2) Fine WC/Co Hardmetal

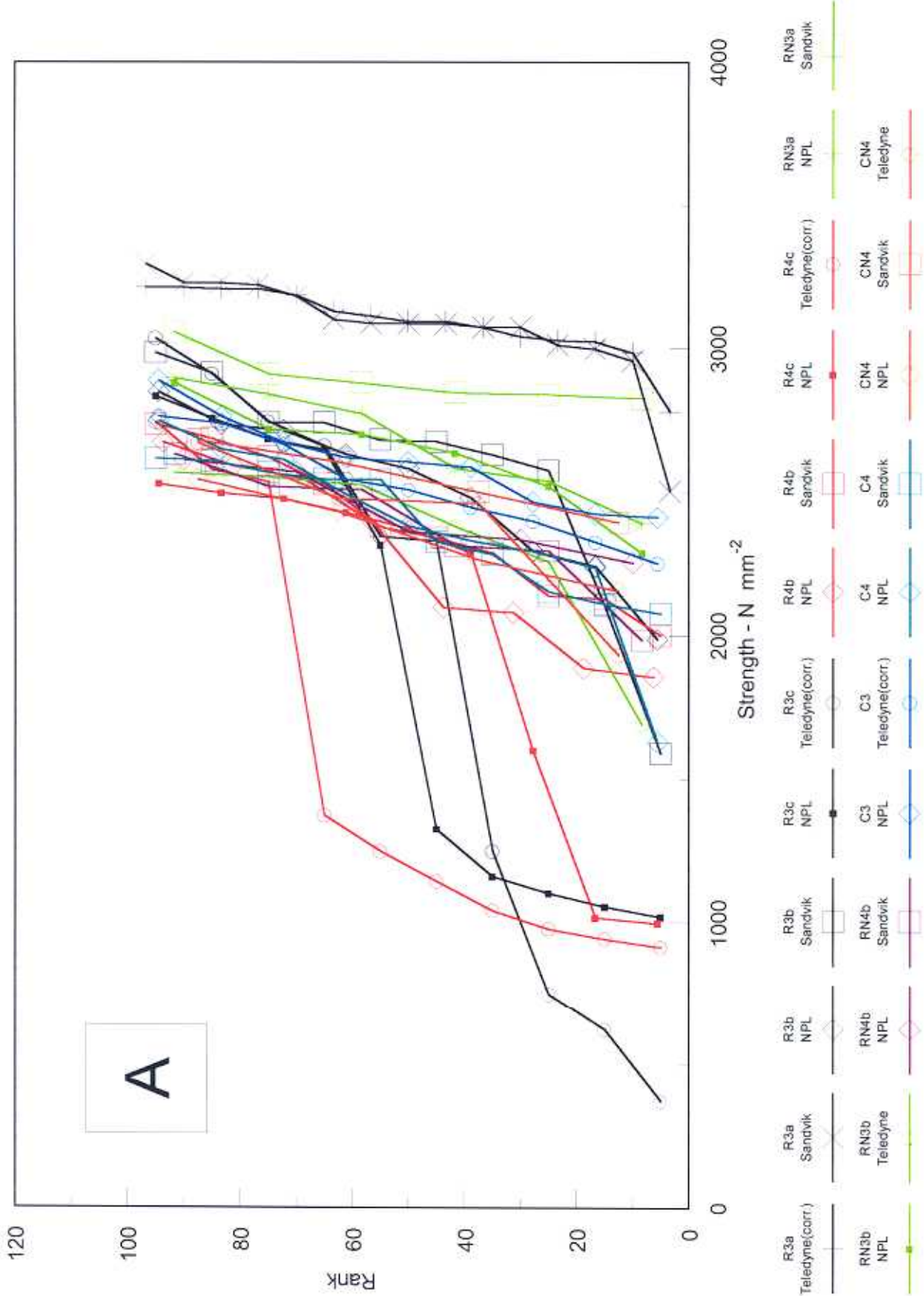
PLOT SEQUENCE

- A - Complete set of all strength values.
- Aa - Complete set, different laboratories combined.
- Aa expanded - As Aa but X ordinate expanded.
- 1 - Standard tests, ISO type B (R3a), including corrected Teledyne data*.
- 1a - Combined R3a.
- 2 - 3 pt rectangular tests; (R3a, R3b, R3c).
- 2a - Combined R3a, R3b and R3c.
- 3 - 4 pt rectangular tests, compared with Sandvik standard ISO type B; (R3a, R4b, R4c).
- 3a - Combined R3a, R4b and R4c.
- 4 - Individual 3 pt vs 4 pt tests; not including R3a; (R3b, R3c, R4b, R4c).
- 4a - Combined 3 pt vs 4 pt tests; R3b, R3c, R4b and R4c (not including R3a).
- 5 - Round testpieces, compared with standard R3a; (C3, C4 and R3a).
- 5a - Combined C3, C4 and R3a.
- 6 - 3 pt rectangular and round; (R3b, R3c and C3); not including R3a.
- 6a - Combined C3 compared with R3b combined and R3c combined.
- 7 - 4 pt rectangular and round (R4b, R4c and C4).
- 7a - Combined C4 compared with combined R4b and combined R4c.
- 8 - Notched rectangular testpieces, Teledyne not corrected; (RN3a, RN3b and RN4b).
- 8a - Combined notched testpieces except for RN3b; (RN3a and RN4b).
- 9 - Notched round compared with combined notched rectangular; (CN4, RN3a and RN4b).
- 9a - Combined notched round compared with combined notched rectangular; (CN4 and RN3a, RN3b and RN4b).

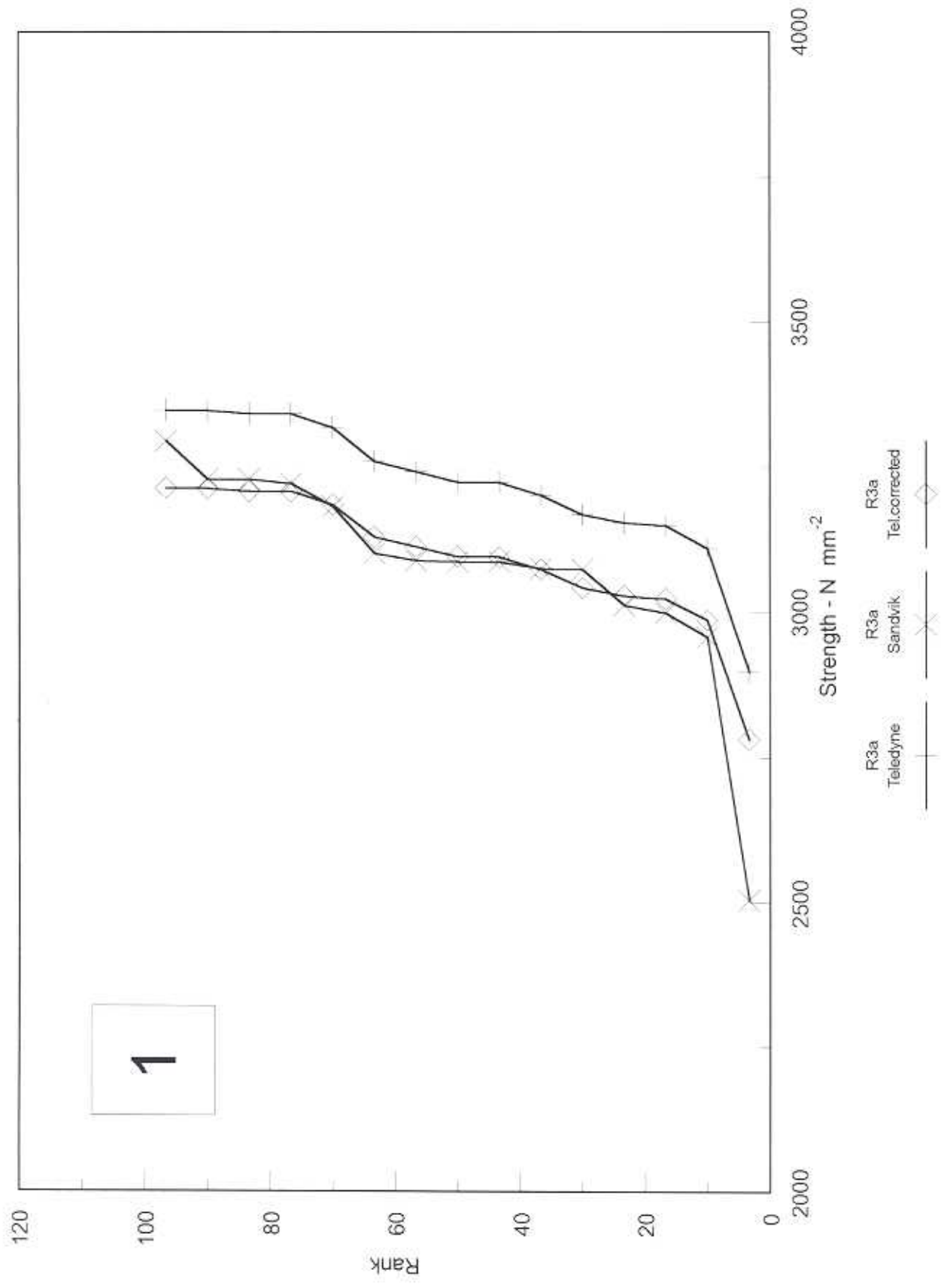
*NB *The R3a Teledyne data have been multiplied by 0.96 in the corrected data set.*

The other geometries for Teledyne data have been multiplied by 0.90 (except for the RN3b tests which have been plotted uncorrected).

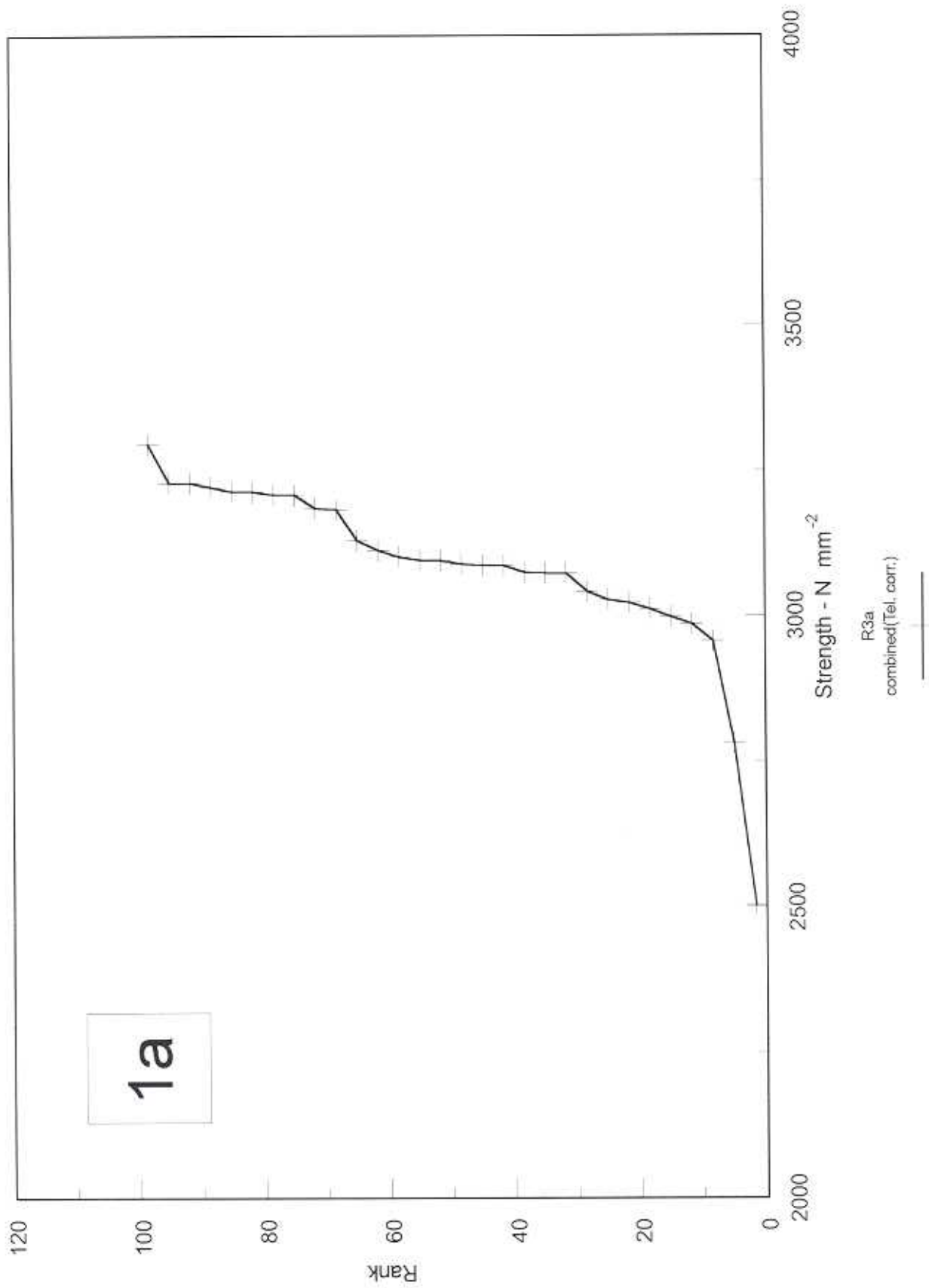
Bend Tests - Boart WC/Co (2)



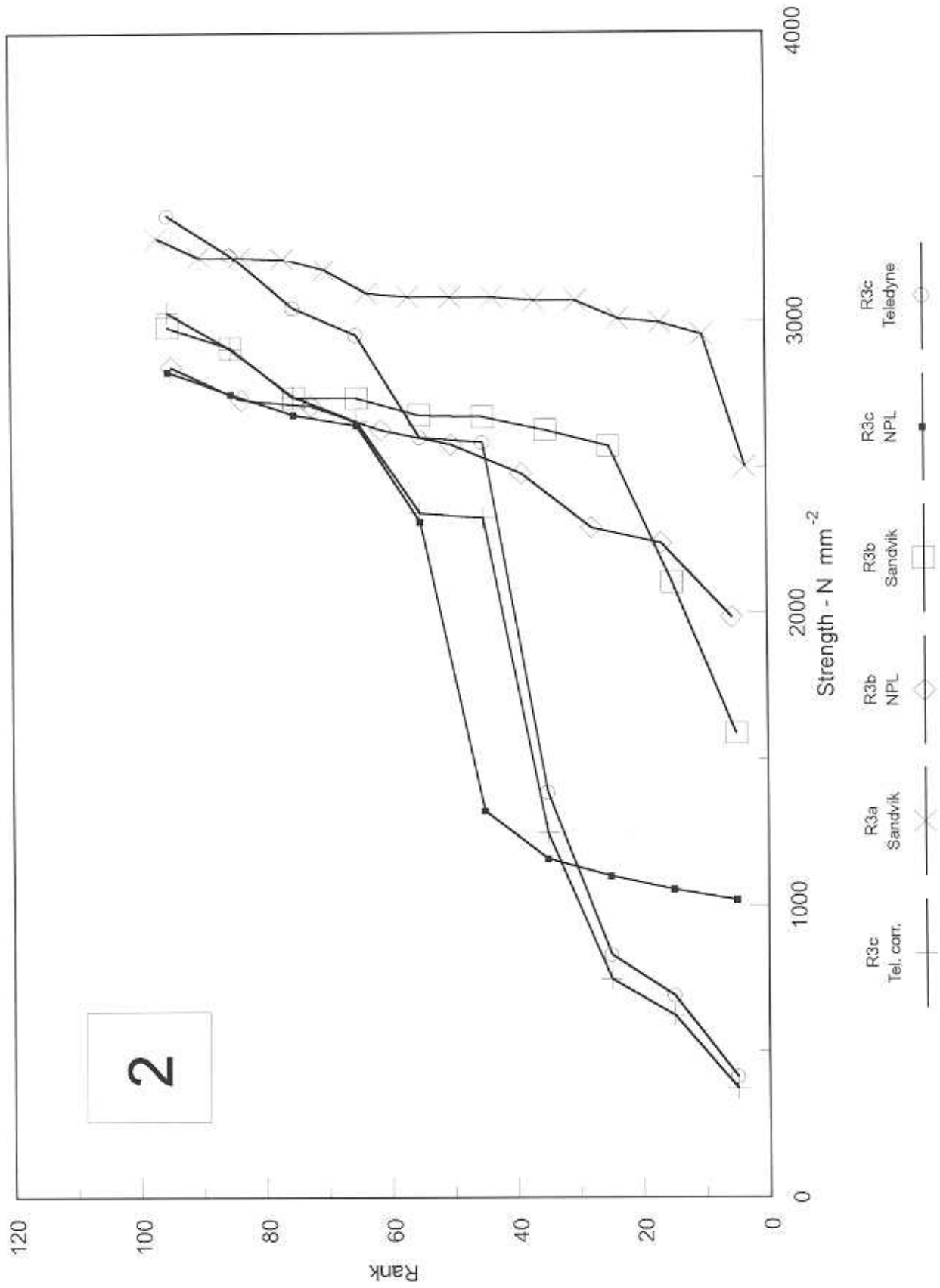
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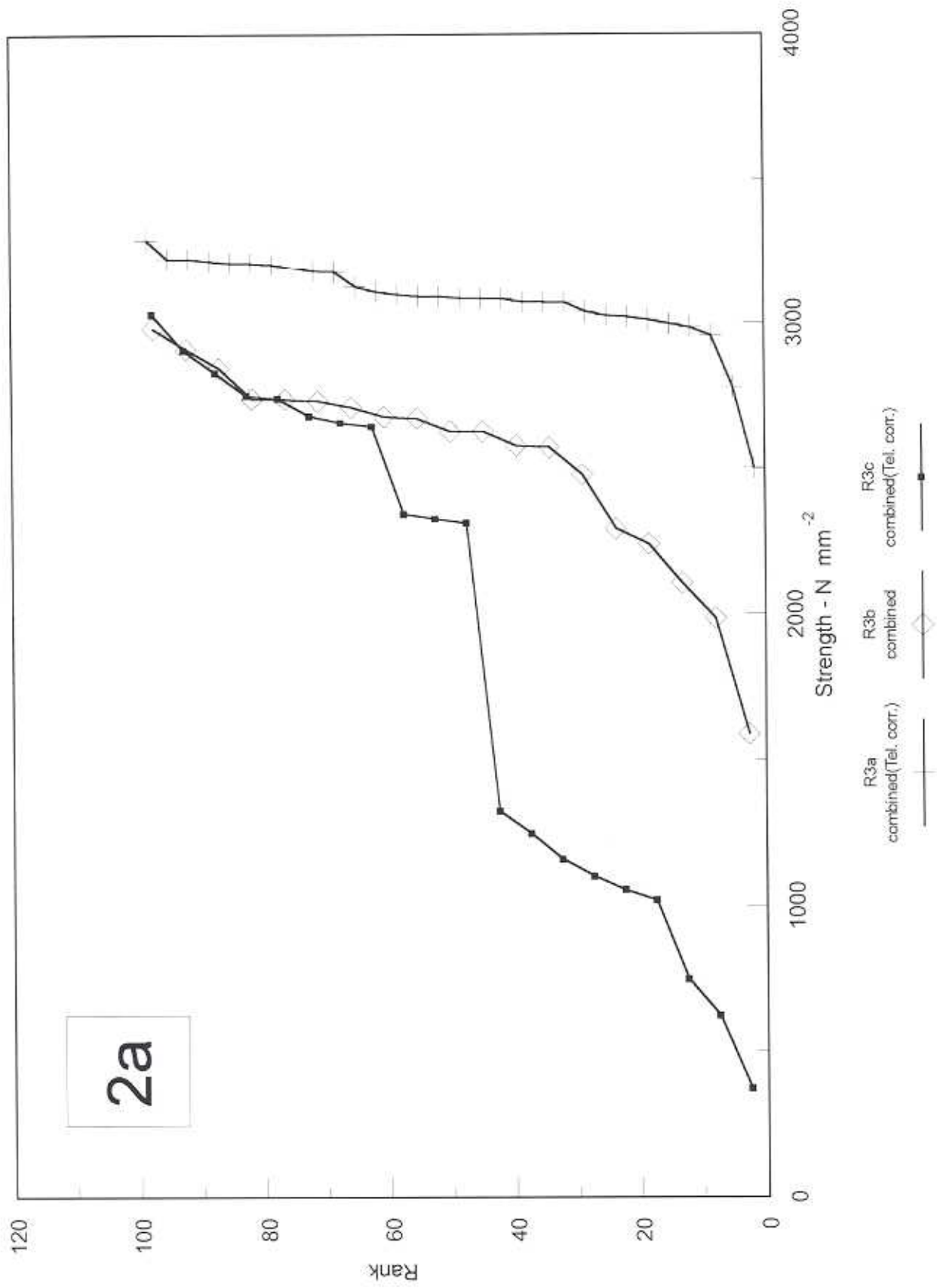
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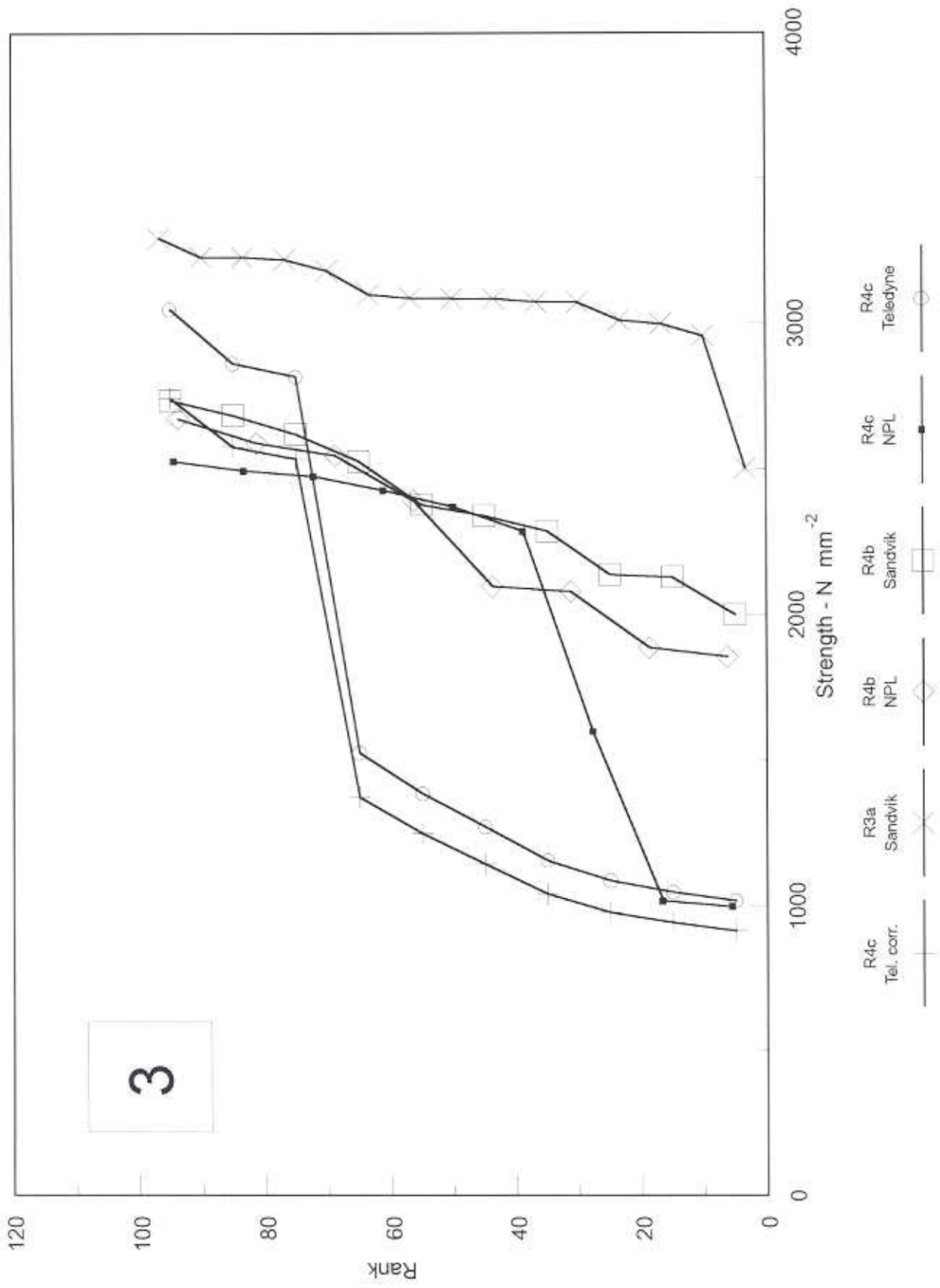
Bend Tests - Boart WC/Co (2)



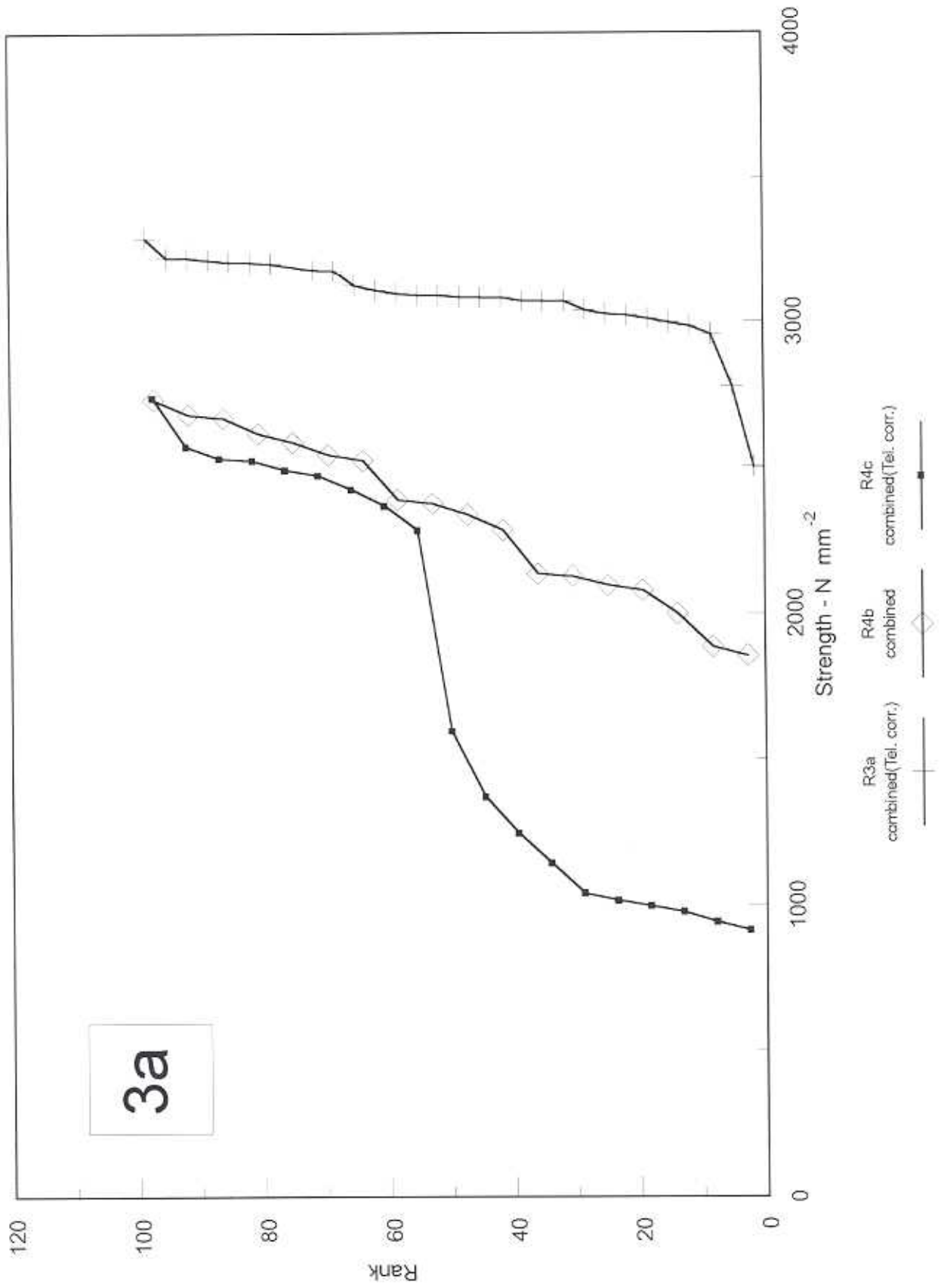
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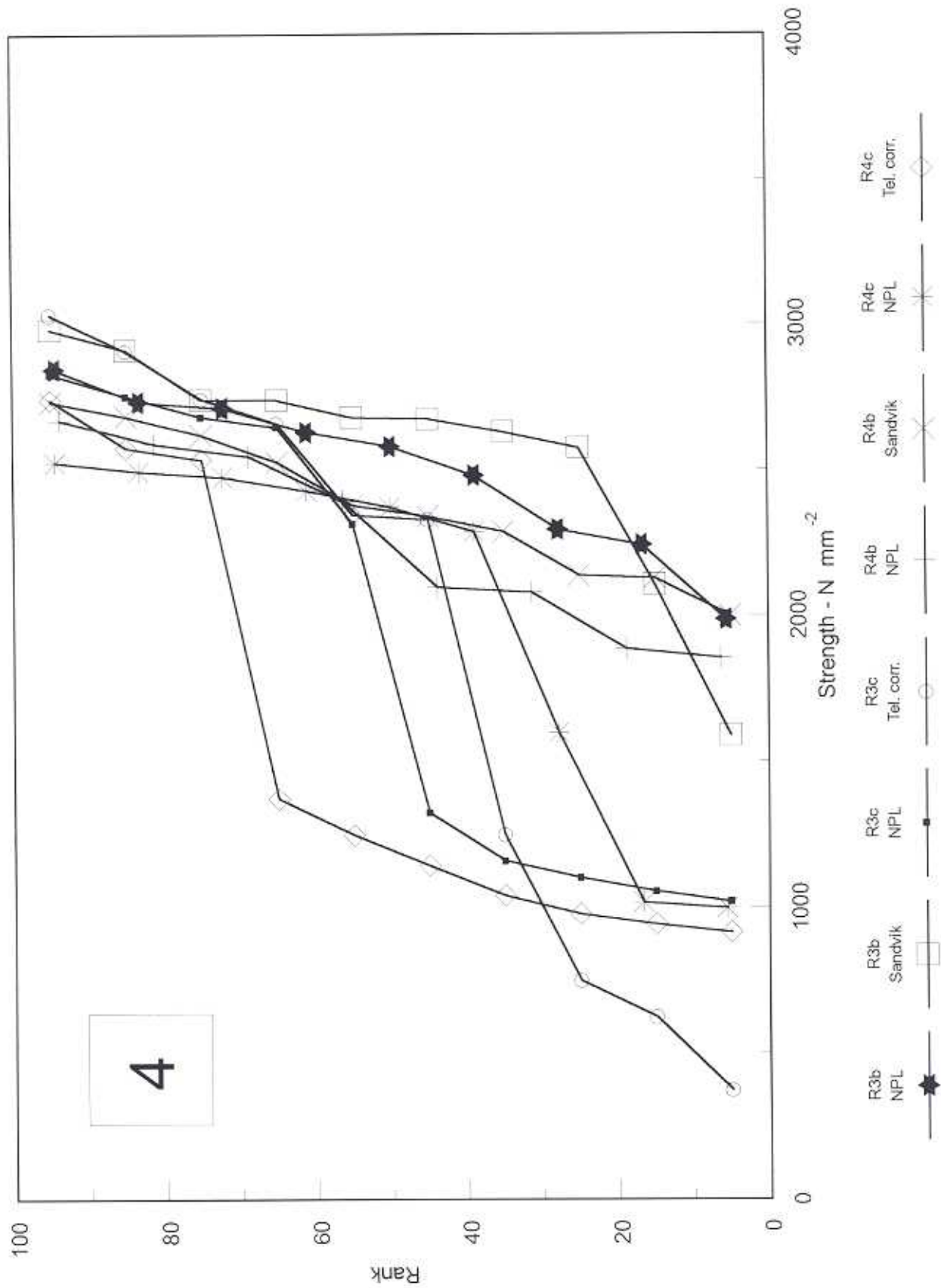
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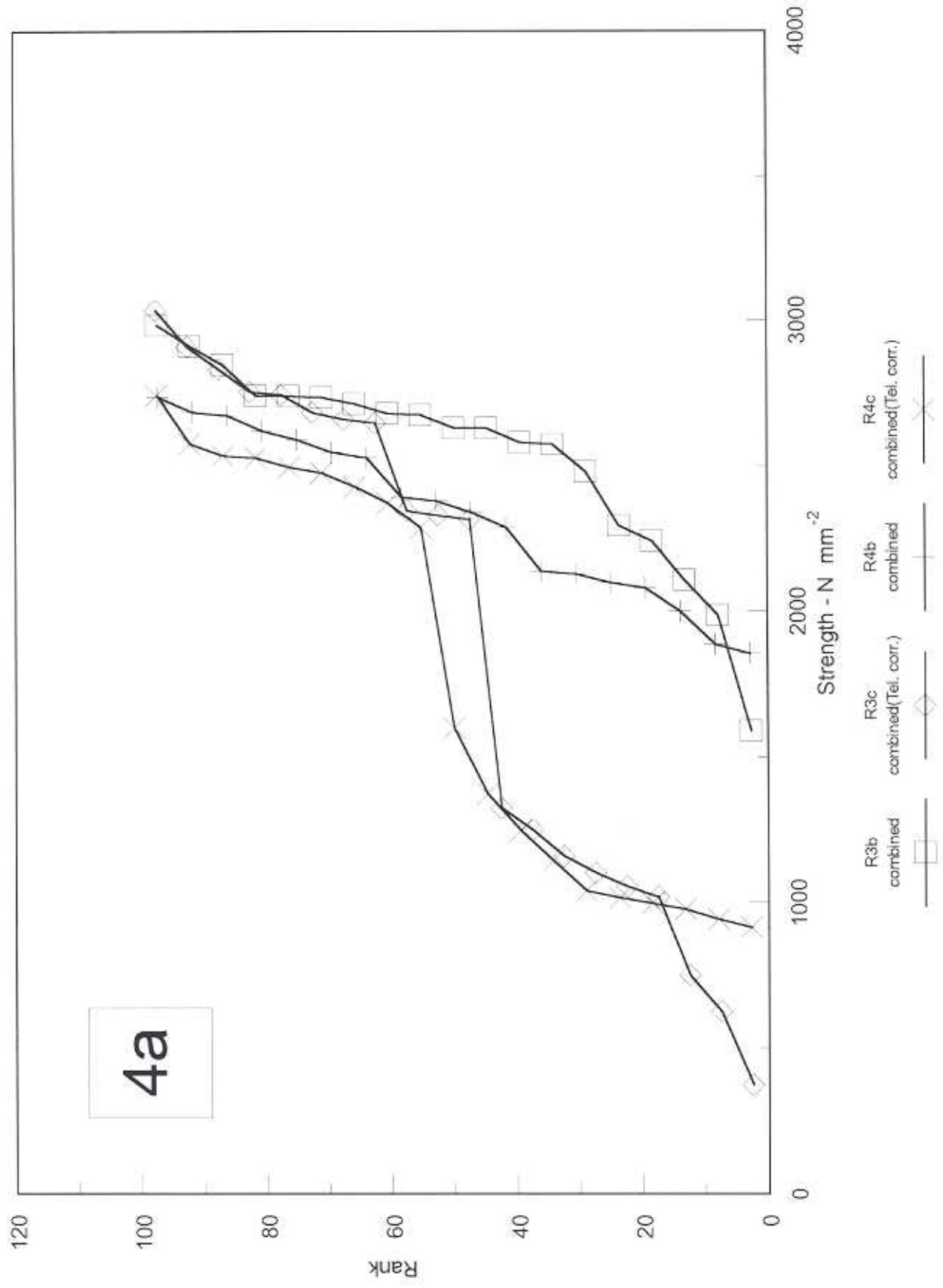
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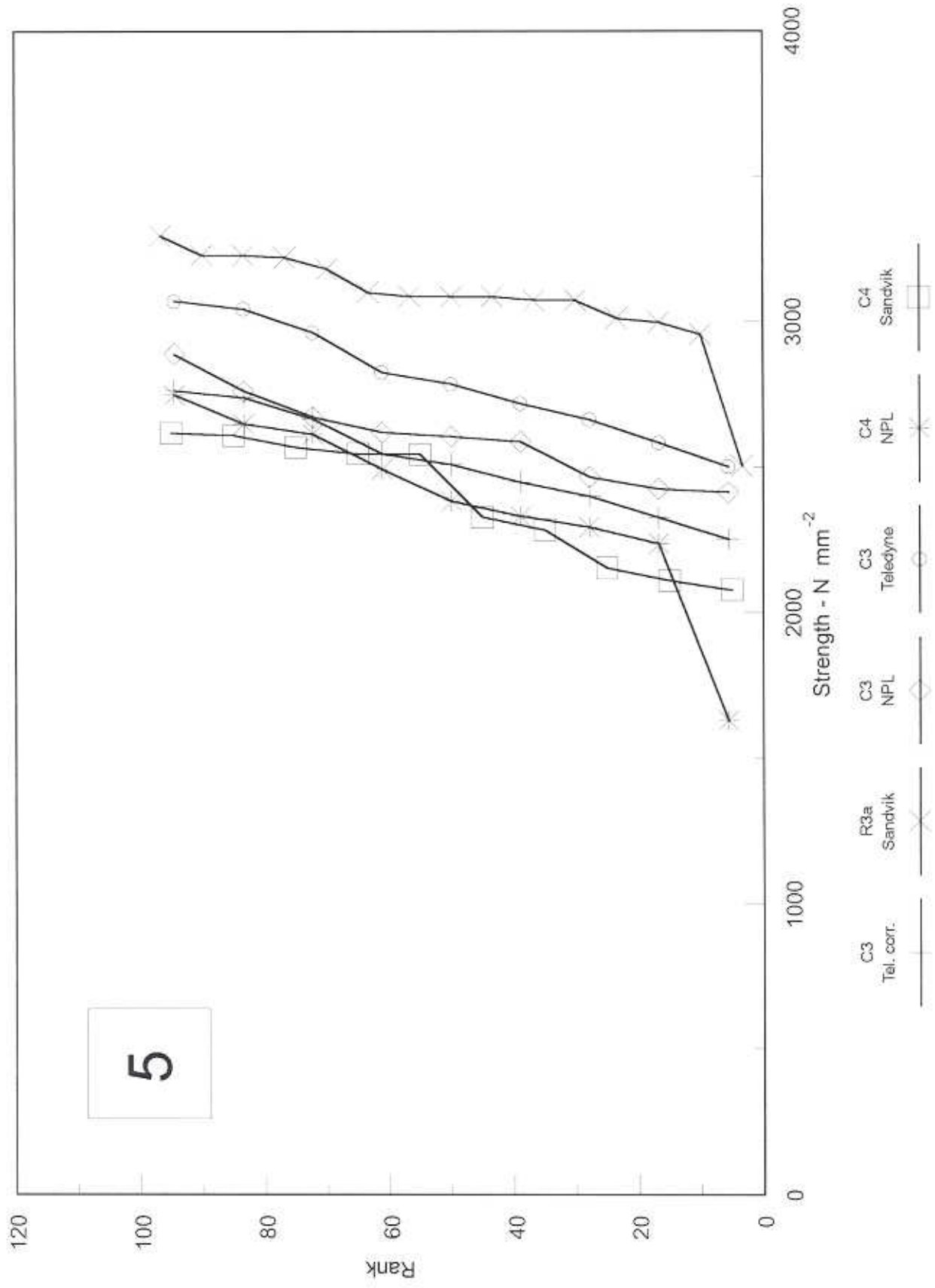
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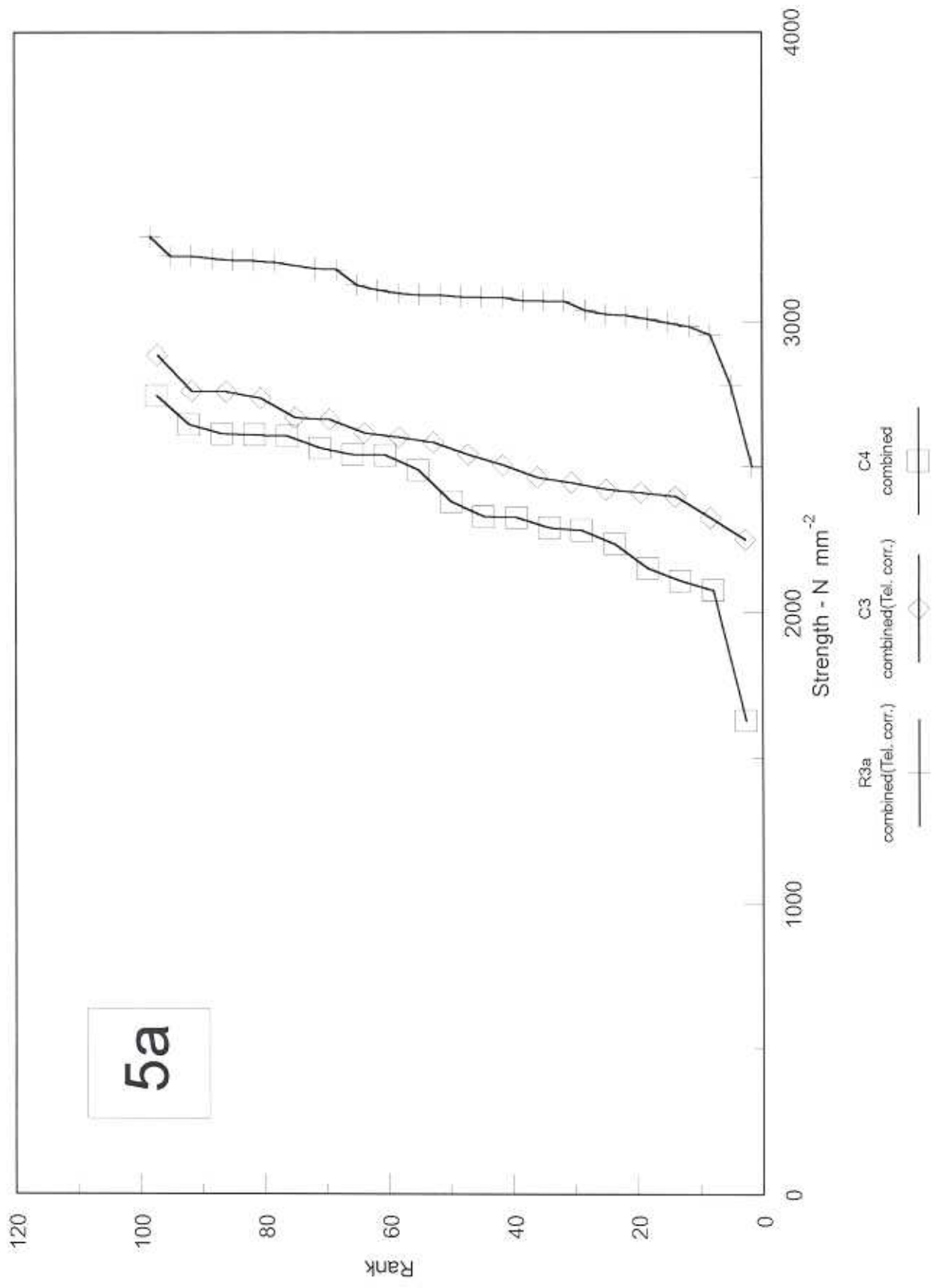
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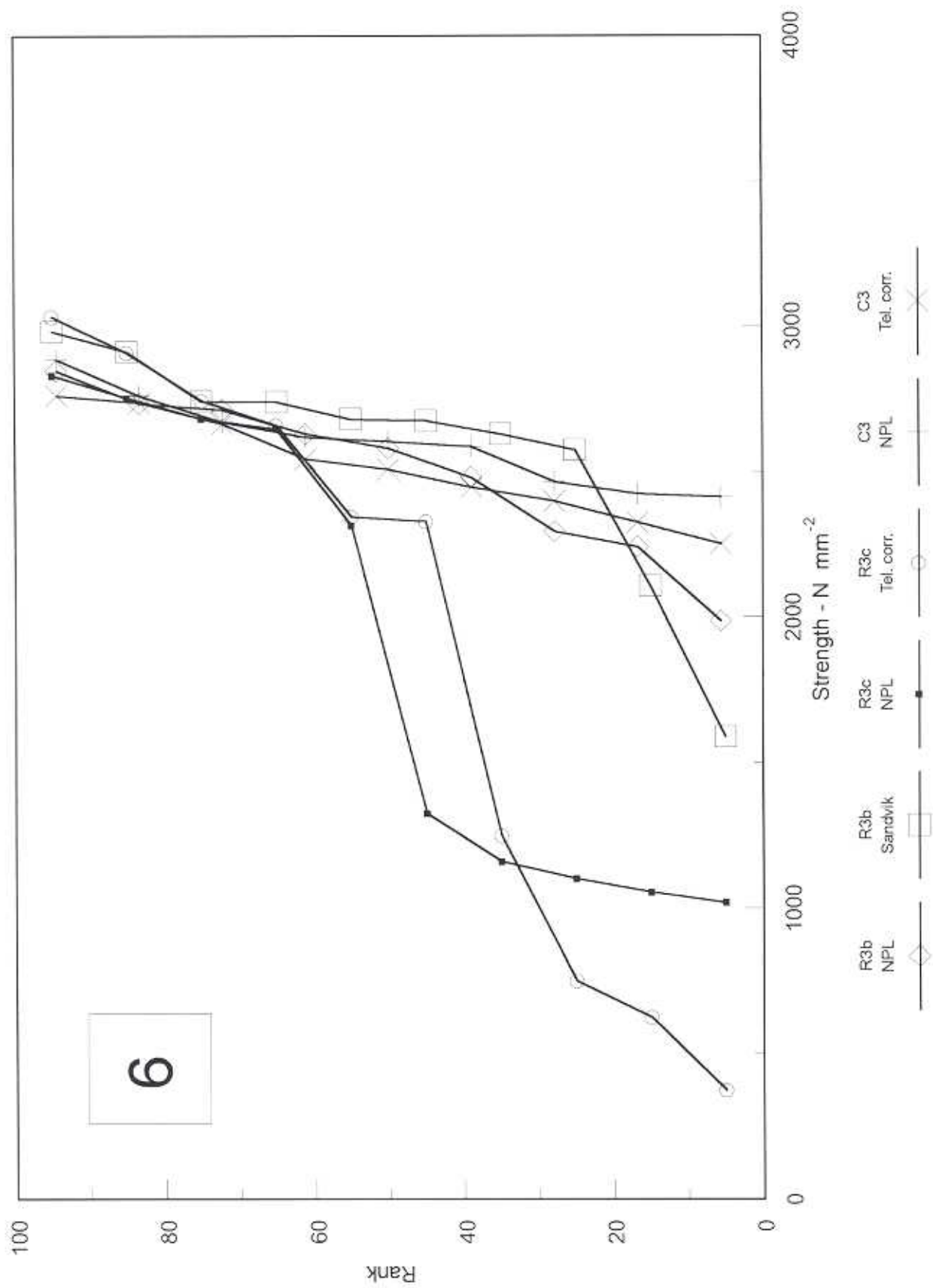
Bend Tests - Boart WC/Co (2)



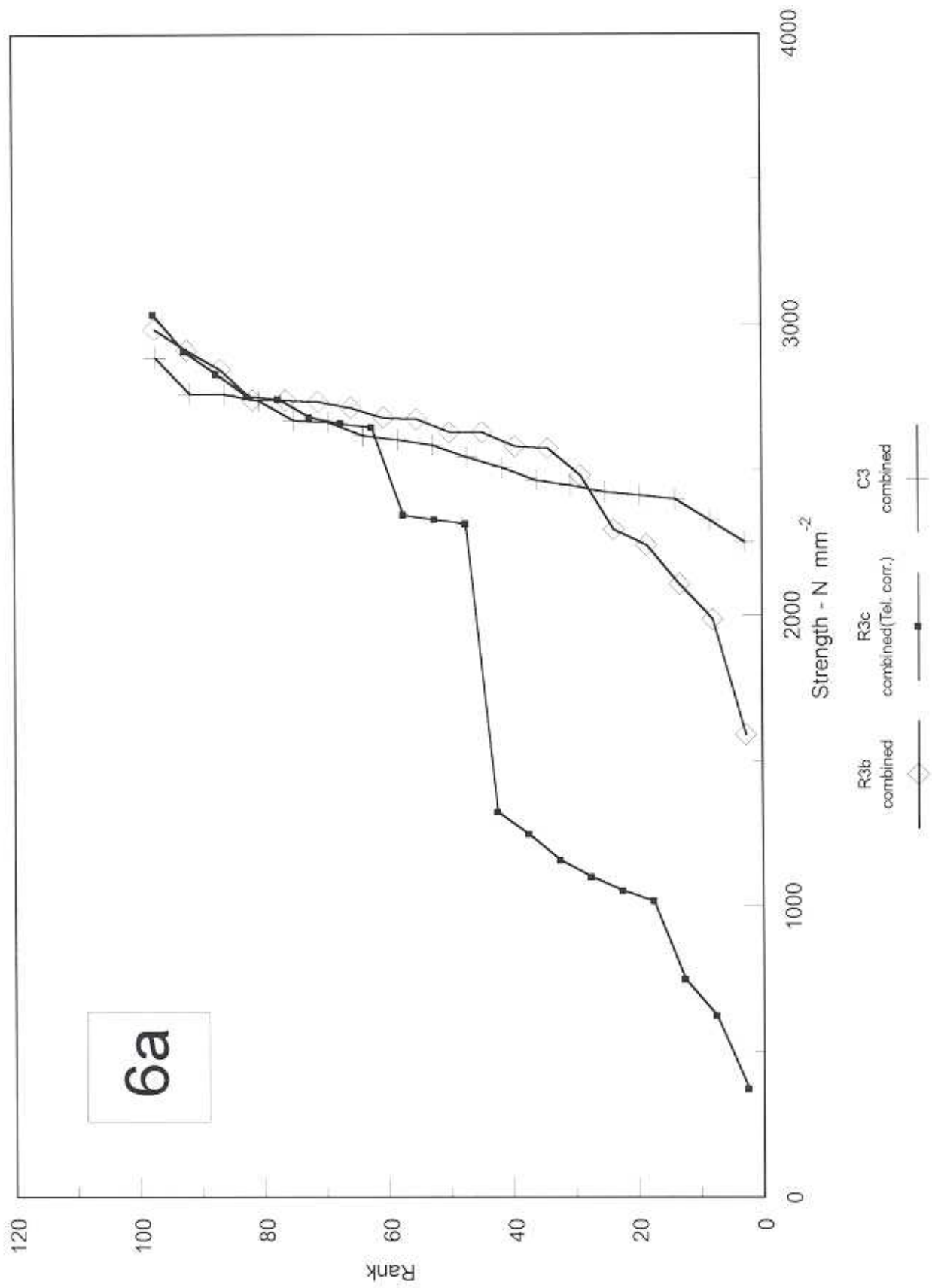
Bend Tests - Boart WC/Co (2)



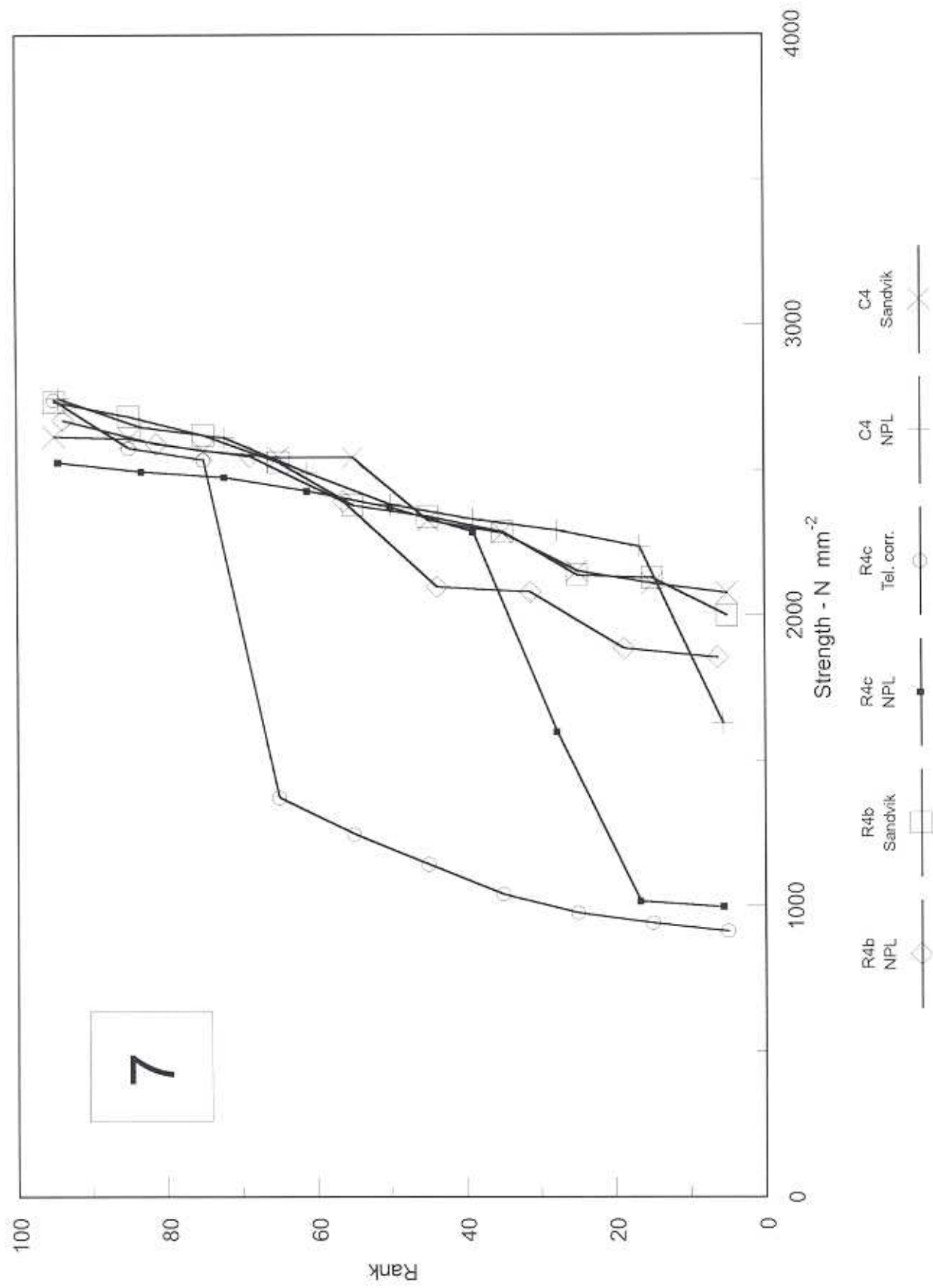
Bend Tests - Boart WC/Co (2)



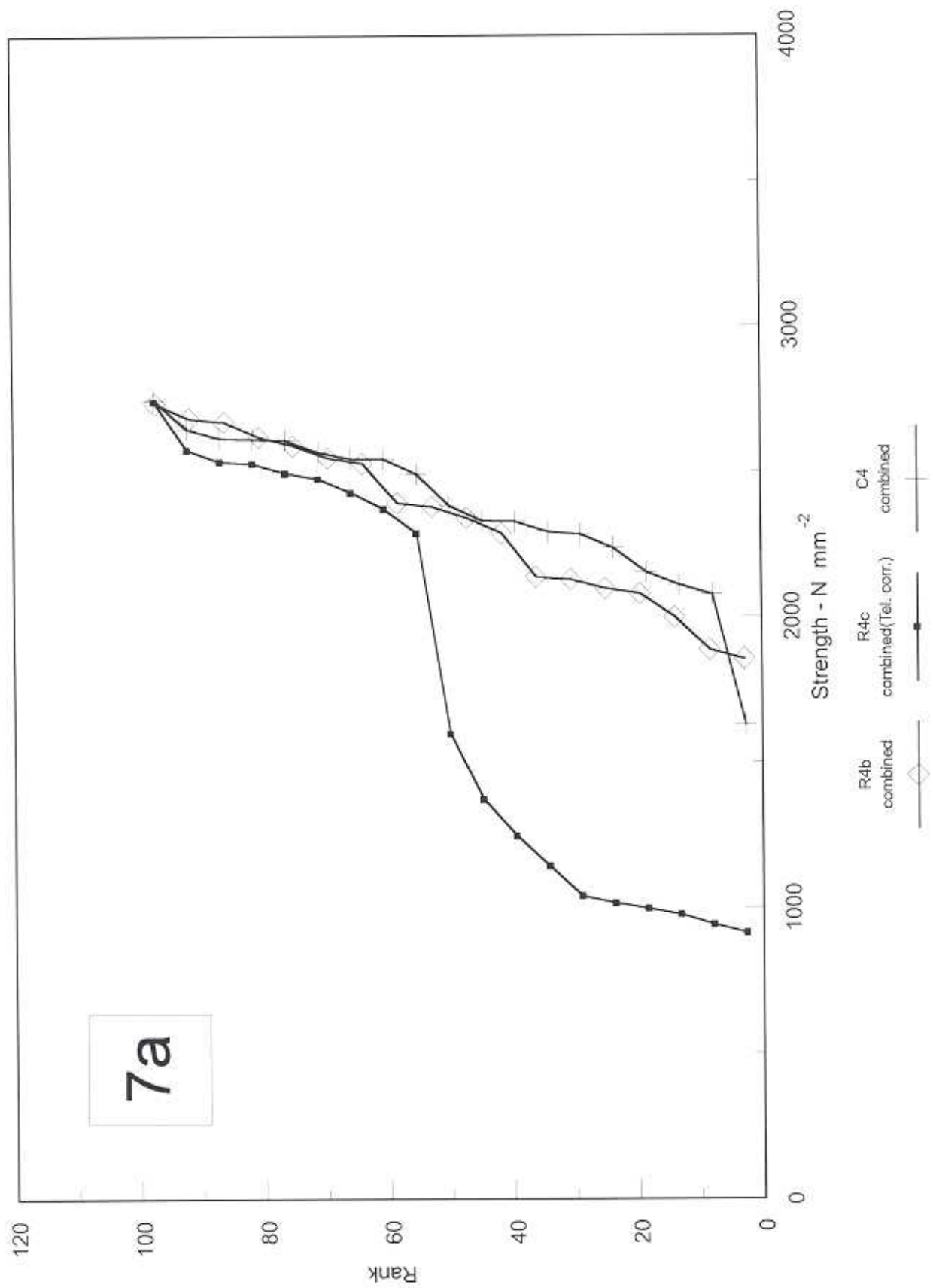
Bend Tests - Boart WC/Co (2)



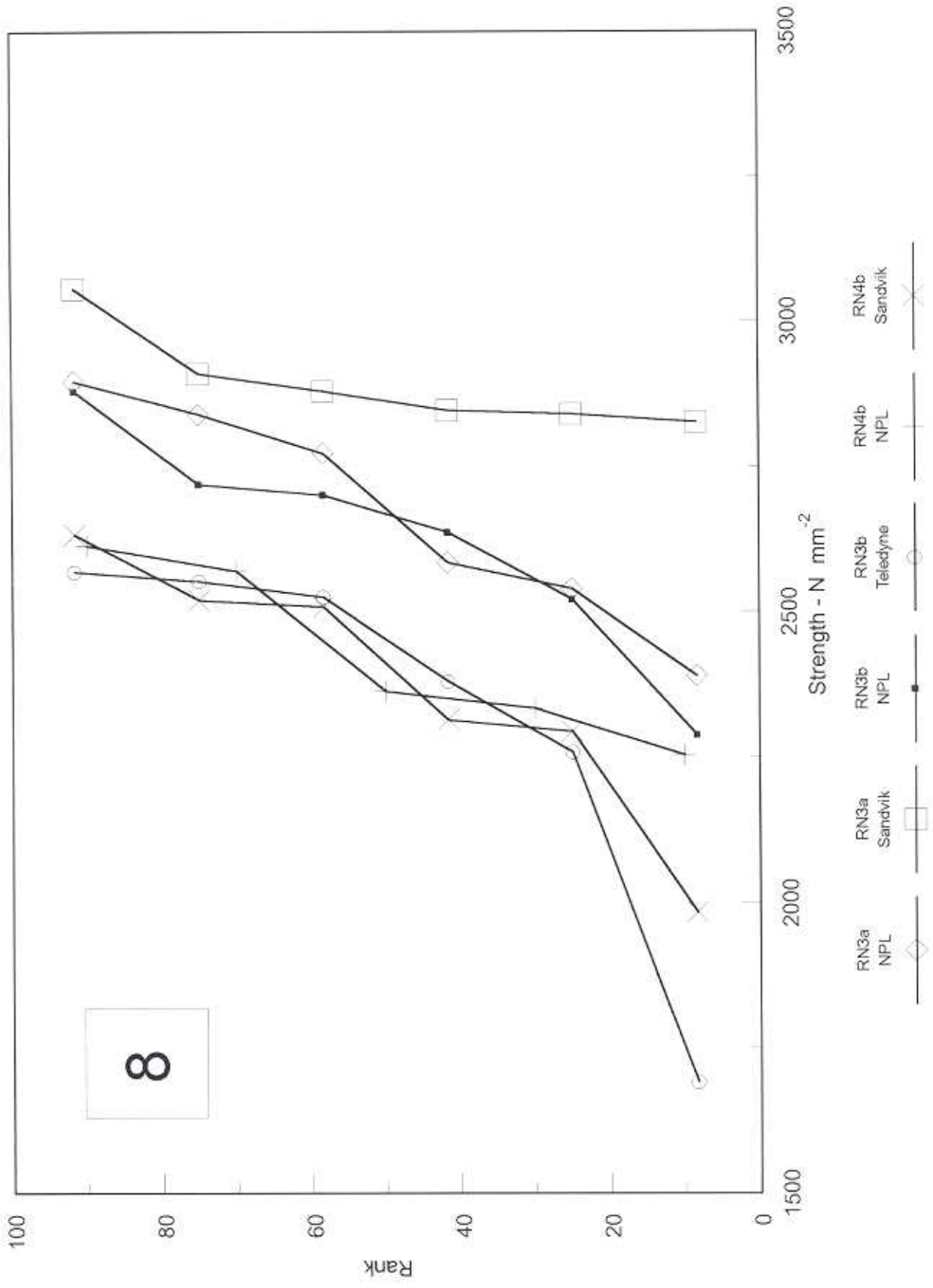
Bend Tests - Boart WC/Co (2)



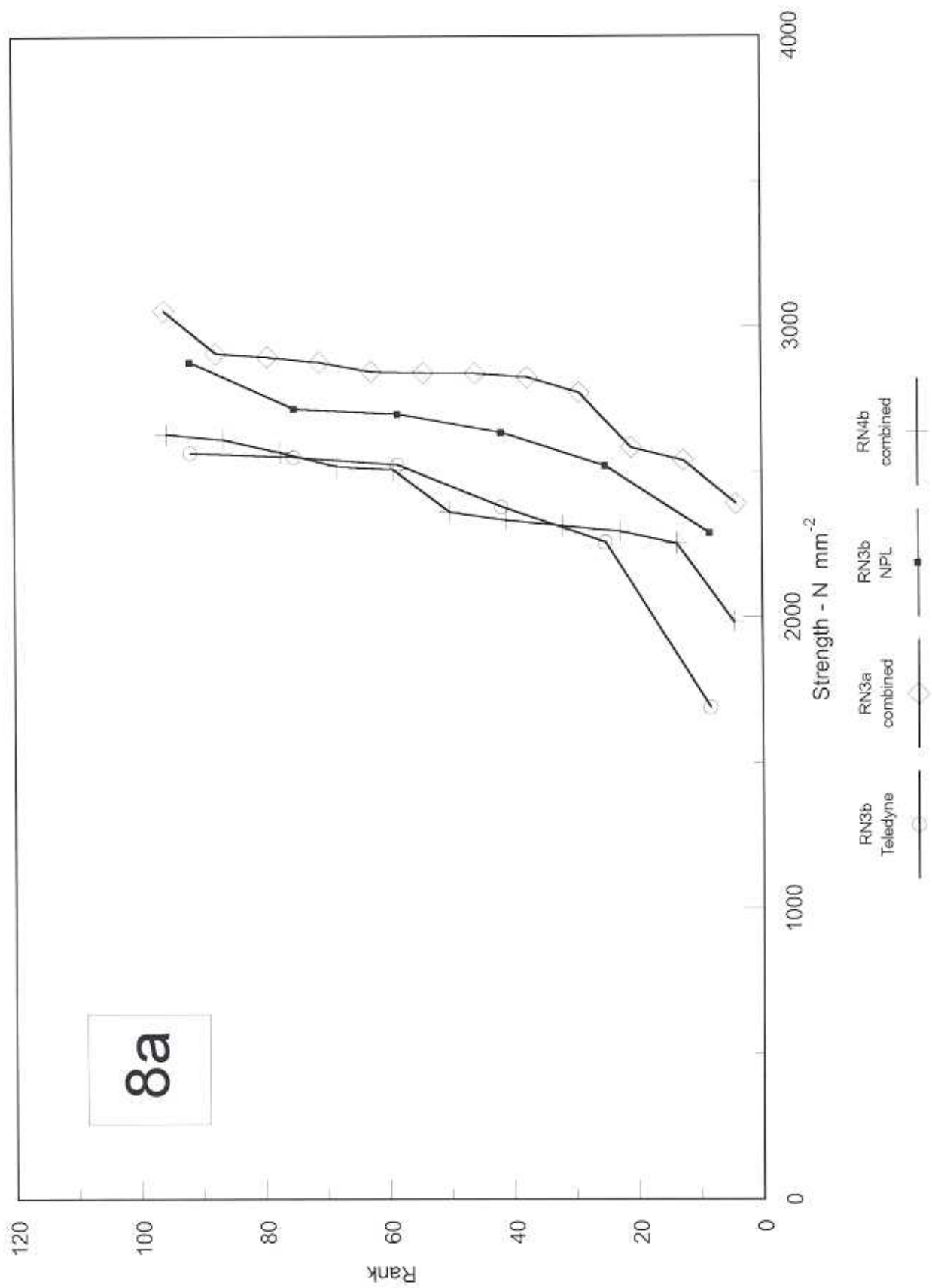
Bend Tests - Boart WC/Co (2)



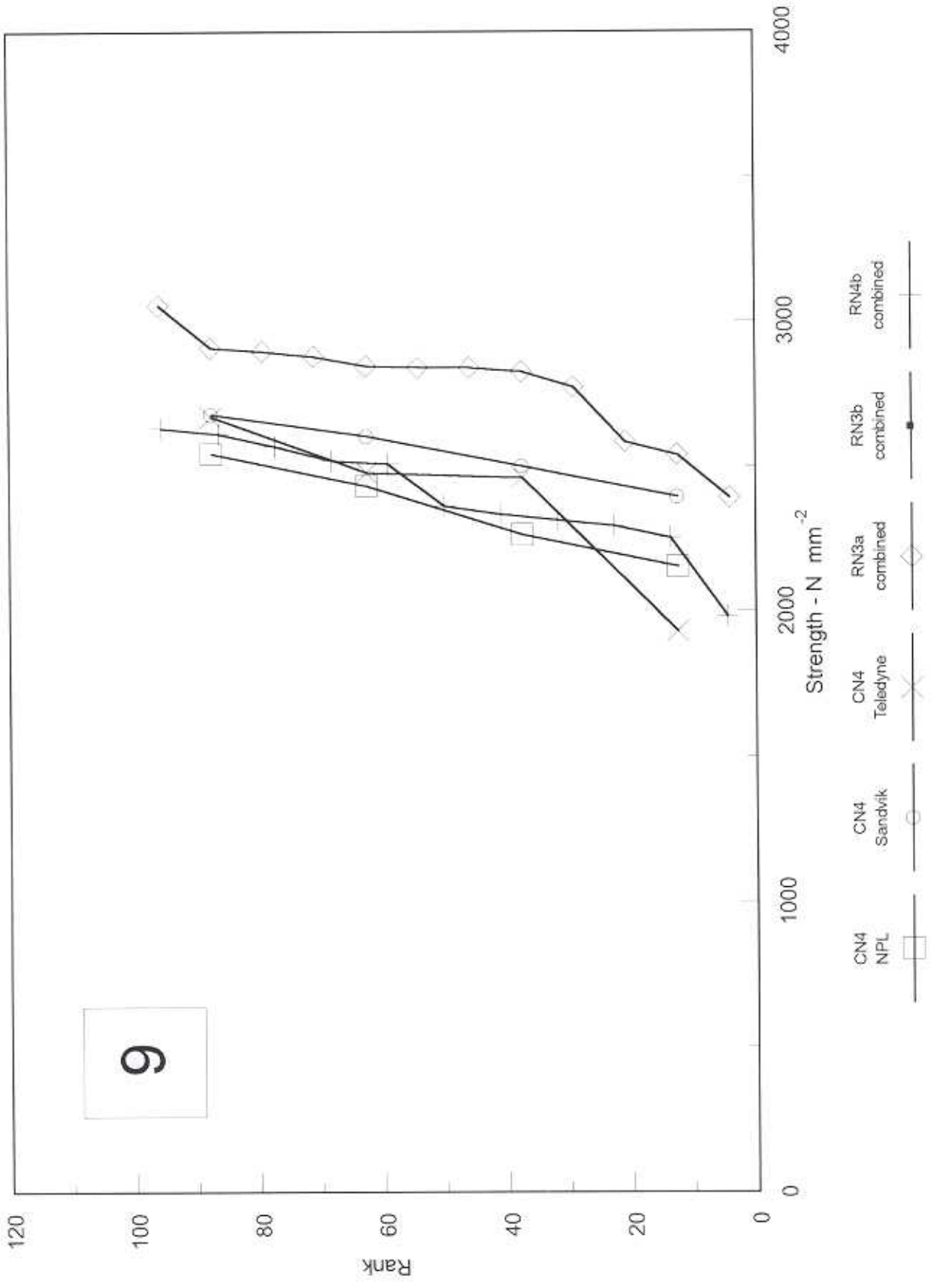
Bend Tests - Boart WC/Co (2)



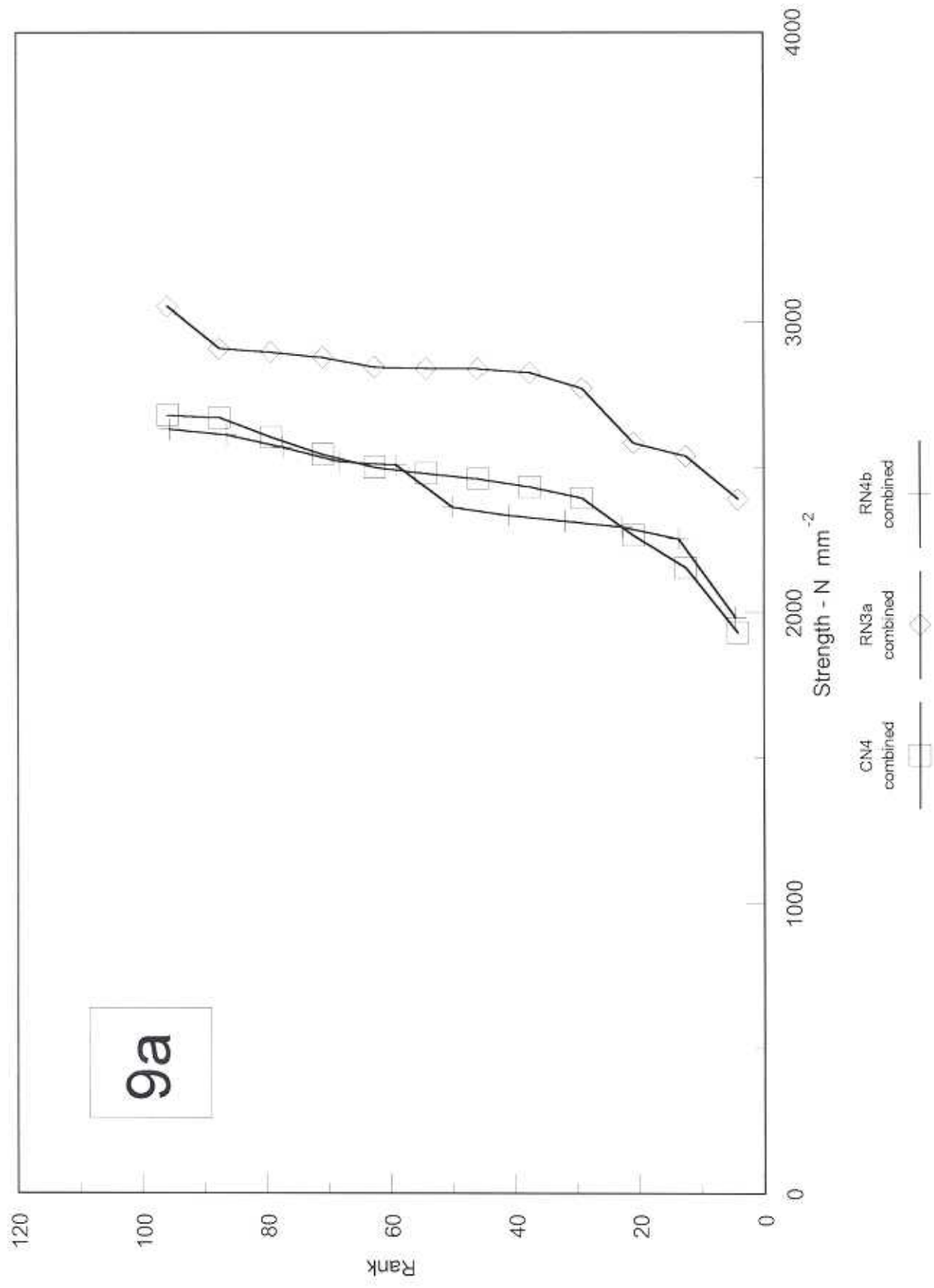
Bend Tests - Boart WC/Co (2)



Bend Tests - Boart WC/Co (2)



Bend Tests - Boart WC/Co (2)



RESULTS SET

(3) SANDVIK HARD MATERIALS

Fine, WC/Co

Data Tables

Supplementary Comments

Data Plots

HARDMETAL BEND TESTS INTERNATIONAL INTERCOMPARISON

TABLES OF RESULTS

SET 3

WC/Co (Fine grained) - Source: Sandvik Hard Materials

<i>Geometry</i>		<i>Organisation</i>
3 pt TRS	R3a	Standard Tests (Boart/Teledyne)
3,4 pt Rectangular	R3, R4	NPL
3,4 pt Rectangular	R3, R4	Dymet
3,4 pt Rectangular	R3, R4	Boart
3,4 pt Rectangular Notched	RN3, RN4	NPL
3,4 pt Rectangular Notched	RN4	Dymet
3,4 pt Rectangular Notched	RN3	Boart
Round	C3, C4, CN4	NPL
Round	C4, CN4	Dymet
Round	C3, CN4	Boart

**SANDVIK HM WC/Co(3) - FINE
STANDARD TRS TESTS - R3a**

Boart			Span 14.5 mm		Rate 90 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.20	5.00	23498	3297	13	4291	1	96.7
2	6.20	5.00	23398	3283	4	3954	2	90.0
3	6.20	5.00	25826	3624	14	3862	3	83.3
4	6.20	5.00	28178	3954	6	3750	4	76.7
5	6.20	5.00	20195	2834	8	3725	5	70.0
6	6.20	5.10	27803	3750	7	3663	6	63.3
7	6.20	5.00	26101	3663	3	3624	7	56.7
8	6.20	5.00	26547	3725	15	3571	8	50.0
9	6.20	5.00	20646	2897	12	3529	9	43.3
10	6.19	5.00	23373	3285	1	3297	10	36.7
11	6.20	5.00	19194	2693	10	3285	11	30.0
12	6.20	5.00	25150	3529	2	3283	12	23.3
13	6.20	4.99	30455	4291	9	2897	13	16.7
14	6.19	5.00	27477	3862	5	2834	14	10.0
15	6.20	5.00	25450	3571	11	2693	15	3.3

Teledyne			Span 15 mm		Rate 445 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
16	6.20	5.01	28146	3880	6	4280	1	96.7
17	6.20	5.00	27234	3769	11	4218	2	90.0
18	6.20	5.00	25320	3504	9	4077	3	83.3
19	6.20	5.00	27367	3787	5	4058	4	76.7
20	6.20	5.00	29326	4058	12	3954	5	70.0
21	6.20	5.00	30928	4280	7	3892	6	63.3
22	6.20	5.00	28124	3892	1	3880	7	56.7
23	6.20	5.00	23630	3270	4	3787	8	50.0
24	6.20	5.00	29459	4077	2	3769	9	43.3
25	6.20	5.00	25500	3529	13	3603	10	36.7
26	6.20	5.00	30483	4218	15	3578	11	30.0
27	6.20	5.00	28569	3954	10	3529	12	23.3
28	6.20	5.00	26033	3603	3	3504	13	16.7
29	6.20	5.00	20693	2864	8	3270	14	10.0
30	6.20	5.00	25855	3578	14	2864	15	3.3

**SANDVIK HM WC/Co(3) - FINE
NPL BEND TESTS (R3b, R3c, R4b, R4c)**

R3b			Span 30 mm		Rate		200 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	95%
1	4.80	4.80	8435	3432	8	3739	1	95
2	4.80	4.80	5822	2369	3	3589	2	85
3	4.80	4.80	8821	3589	1	3432	3	75
4	4.80	4.80	8193	3334	6	3421	4	65
5	4.80	4.80	8097	3295	4	3334	5	55
6	4.80	4.80	8408	3421	5	3295	6	45
7	4.80	4.80	7154	2911	9	3063	7	35
8	4.80	4.80	9188	3739	7	2911	8	25
9	4.80	4.80	7528	3063	2	2369	9	15
10	4.80	4.80	5044	2052	10	2052	10	5

R3c			Span 40 mm		Rate		40 N s ⁻¹	
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.90	2.85	1955	3703	1	3703	1	91.7
2	3.90	2.85	1320	2500	6	3491	2	75.0
3	3.91	2.85	1821	3416	3	3416	3	58.3
4	3.91	2.85	1744	3295	5	3362	4	41.7
5	3.90	2.85	1775	3362	4	3295	5	25.0
6	3.90	2.85	1843	3491	2	2500	6	8.3
7								
8								
9								
10								

R4b								
Outer Span 10 mm					Rate 125 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.80	4.80	9879	2680	6	3350	1	95
2	4.80	4.80	10190	2764	5	3054	2	85
3	4.80	4.80	10700	2903	8	3025	3	75
4	4.80	4.80	9113	2472	3	2903	4	65
5	4.80	4.80	11260	3054	9	2783	5	55
6	4.80	4.80	12350	3350	2	2764	6	45
7	4.80	4.80	6368	1727	1	2680	7	35
8	4.80	4.80	11150	3025	4	2472	8	25
9	4.80	4.80	10260	2783	10	2241	9	15
10	4.80	4.80	8260	2241	7	1727	10	5

R4c								
Outer Span 10 mm					Rate 50 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.90	2.85	3337	3160	4	3368	1	92.9
2	3.90	2.85	2790	2642	6	3347	2	78.6
3	3.90	2.85	3145	2978	1	3160	3	64.3
4	3.90	2.85	3556	3368	3	2978	4	50.0
5	3.90	2.85	2845	2694	5	2694	5	35.7
6	3.90	2.85	3534	3347	2	2642	6	21.4
7	3.90	2.85	2548	2413	7	2413	7	7.1
8								
9								
10								

**SANDVIK HM WC/Co(3) - FINE
DYMET BEND TESTS (R3b, R4b)**

R3b			Span 30 mm		Rate 25 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4.79	4.80	6463	2635	7	3361	1	95
12	4.77	4.80	6763	2769	8	3255	2	85
13	4.80	4.80	6907	2810	4	3162	3	75
14	4.80	4.80	7772	3162	10	3148	4	65
15	4.79	4.80	6421	2618	3	2810	5	55
16	4.80	4.80	6895	2806	6	2806	6	45
17	4.80	4.80	8259	3361	2	2769	7	35
18	4.80	4.80	8000	3255	1	2635	8	25
19	4.81	4.81	6421	2596	5	2618	9	15
20	4.80	4.80	7737	3148	9	2596	10	5

R4b			Outer Span 10 mm		Rate 100 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4.79	4.80	7368	2003	5	3332	1	95
12	4.80	4.80	11233	3047	10	3110	2	85
13	4.80	4.80	11166	3029	6	3065	3	75
14	4.79	4.80	8338	2267	2	3047	4	65
15	4.81	4.81	12360	3332	9	3039	5	55
16	4.80	4.80	11299	3065	3	3029	6	45
17	4.80	4.80	8833	2396	8	3024	7	35
18	4.79	4.80	11125	3024	7	2396	8	25
19	4.80	4.81	11250	3039	4	2267	9	15
20	4.80	4.80	11466	3110	1	2003	10	5

**SANDVIK HM WC/Co(3) - FINE
BOART BEND TESTS (R3c, R4c)**

R3c								
Span 30 mm					Rate 80 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.91	2.86	1563	2932	7	3745	1	95
2	3.90	2.85	1388	2629	10	3363	2	85
3	3.90	2.85	1769	3351	3	3351	3	75
4	3.90	2.85	1725	3267	5	3335	4	65
5	3.90	2.85	1761	3335	6	3286	5	55
6	3.90	2.86	1747	3286	9	3277	6	45
7	3.90	2.85	1977	3745	4	3267	7	35
8	3.90	2.85	1625	3078	8	3078	8	25
9	3.90	2.85	1730	3277	1	2932	9	15
10	3.91	2.85	1780	3363	2	2629	10	5

R4c								
Outer Span 10 mm					Rate 80 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.90	2.85	3263	3090	2	3466	1	95
2	3.89	2.84	3625	3466	5	3291	2	85
3	3.90	2.85	3231	3060	10	3291	3	75
4	3.90	2.85	3050	2888	8	3156	4	65
5	3.90	2.85	3475	3291	1	3090	5	55
6	3.90	2.85	2881	2728	3	3060	6	45
7	3.90	2.85	2931	2776	4	2888	7	35
8	3.90	2.85	3333	3156	9	2847	8	25
9	3.90	2.85	3006	2847	7	2776	9	15
10	3.90	2.85	3475	3291	6	2728	10	5

**SANDVIK HM WC/Co(3) - FINE
NPL BEND TESTS (RN3a, RN3b, RN4b)**

RN3a (annealed 800 °C for 1h in vacuum)				Span 13.8 mm		Rate 200 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.50	5.00	2778	2875	4	2937	1	91.7
2	2.50	5.00	2698	2792	6	2877	2	75.0
3	2.50	5.00	2560	2650	1	2875	3	58.3
4	2.50	5.00	2838	2937	5	2804	4	41.7
5	2.50	5.00	2709	2804	2	2792	5	25.0
6	2.49	5.00	2769	2877	3	2650	6	8.3

RN3b (annealed 800 °C for 1h in vacuum)				Span 30 mm		Rate 80 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.78	4.85	643	2383	6	2762	1	91.7
2	1.78	4.85	588	2180	5	2569	2	75.0
3	1.78	4.85	574	2128	4	2535	3	58.3
4	1.78	4.85	684	2535	1	2383	4	41.7
5	1.78	4.85	693	2569	2	2180	5	25.0
6	1.78	4.85	745	2762	3	2128	6	8.3

RN4b (annealed 800 °C for 1h in vacuum)				Outer Span 10 mm		Rate 100 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.78	4.85	1062	2540	1	2540	1	91.7
2	1.78	4.85	900	2152	3	2537	2	75.0
3	1.78	4.85	1061	2537	5	2377	3	58.3
4	1.78	4.85	831	1987	2	2152	4	41.7
5	1.78	4.85	994	2377	4	1987	5	25.0
6	1.78	4.85	817	1954	6	1954	6	8.3

**SANDVIK HM WC/Co(3) - FINE
DYMET BEND TESTS (RN4b)**

RN4b (annealed 800 °C for 1h in vacuum)			Span 10 mm		Rate 40 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.78	4.85	825	1973	2	2624	1	91.7
2	1.78	4.85	1097	2624	3	2583	2	75.0
3	1.78	4.85	1080	2583	5	2461	3	58.3
4	1.78	4.83	951	2298	6	2332	4	41.7
5	1.78	4.85	1029	2461	4	2298	5	25.0
6	1.78	4.86	980	2332	1	1973	6	8.3

**SANDVIK WC/Co(3) - FINE
BOART BEND TESTS (RN3a, RN3b)**

RN3a (annealed 800 °C for 1h in vacuum)				Span 14.5 mm		Rate 42 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	2.50	5.01	2697	2918	1	2987	1	91.7
2	2.50	5.01	2745	2970	3	2970	2	75
3	2.50	5.00	2747	2987	2	2918	3	58.3
4	2.50	5.01	2643	2860	4	2860	4	41.7
5	2.50	5.01	2301	2490	6	2628	5	25
6	2.50	5.01	2429	2628	5	2490	6	8.3

RN3b (annealed 800 °C for 1h in vacuum)				Span 30 mm		Rate 75 N s ⁻¹		
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	1.78	4.83	739	2768	1	2768	1	90
2	1.78	4.85	669	2480	4	2687	2	70
3	1.78	4.85	652	2417	5	2573	3	50
4	1.78	4.85	725	2687	2	2480	4	30
5	1.78	4.85	694	2573	3	2417	5	10
6								

**SANDVIK WC/Co(3) - FINE
NPL BEND TESTS (C3, C4, CN4)**

C3		Span 30 mm		Rate		100 N s ⁻¹	
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	5507	3366	6	4120	1	95
2	5.00	5777	3531	10	3950	2	85
3	5.00	5792	3540	9	3922	3	75
4	5.00	3114	1903	8	3847	4	65
5	5.00	5498	3360	7	3685	5	55
6	5.00	6742	4120	3	3540	6	45
7	5.00	6030	3685	2	3531	7	35
8	5.00	6294	3847	1	3366	8	25
9	5.00	6417	3922	5	3360	9	15
10	5.00	6463	3950	4	1903	10	5

C4		Outer Span 10 mm		Rate		200 N s ⁻¹	
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	6683	2723	3	3720	1	95
2	5.00	9114	3713	2	3713	2	85
3	5.00	9130	3720	6	3570	3	75
4	5.00	8337	3397	4	3397	4	65
5	5.00	7911	3223	8	3275	5	55
6	5.00	8762	3570	5	3223	6	45
7	5.00	6530	2661	10	3009	7	35
8	5.00	8037	3275	1	2723	8	25
9	5.00	5982	2437	7	2661	9	15
10	5.00	7384	3009	9	2437	10	5

CN4 (annealed 800 °C for 1h in vacuum)		Outer Span 10 mm		Rate		100 N s ⁻¹	
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	1724	2496	2	2564	1	87.5
2	5.00	1771	2564	4	2511	2	62.5
3	5.00	1692	2450	1	2496	3	37.5
4	5.00	1734	2511	3	2450	4	12.5

**SANDVIK HM WC/Co(3) - FINE
DYMET BEND TESTS (C4, CN4)**

C4							
Outer Span 10 mm				Rate 10 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	9348	3809	1	3809	1	95
2	5.00	7332	2987	7	3787	2	85
3	5.00	6666	2716	10	3606	3	75
4	5.00	6813	2776	6	3592	4	65
5	5.00	8532	3476	9	3569	5	55
6	5.00	8815	3592	5	3476	6	45
7	5.00	9294	3787	8	3256	7	35
8	5.00	7991	3256	2	2987	8	25
9	5.00	8759	3569	4	2776	9	15
10	5.00	8851	3606	3	2716	10	5

CN4 (annealed 800 °C for 1h in vacuum)							
Outer Span 10 mm				Rate 60 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	1780	2577	3	2579	1	87.5
2	5.00	1675	2425	1	2577	2	62.5
3	5.00	1781	2579	4	2570	3	37.5
4	5.00	1775	2570	2	2425	4	12.5

**SANDVIK HM WC/Co(3) - FINE
BOART BEND TESTS - (C3, CN4)**

C3							
Span 30 mm				Rate 26 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	5388	3293	6	4079	1	95
2	5.00	6475	3957	8	3988	2	85
3	5.00	6369	3892	2	3957	3	75
4	5.00	4438	2712	10	3957	4	65
5	5.00	5730	3502	9	3930	5	55
6	5.00	6675	4079	3	3892	6	45
7	5.00	6012	3674	7	3674	7	35
8	5.00	6525	3988	5	3502	8	25
9	5.00	6431	3930	1	3293	9	15
10	5.00	6475	3957	4	2712	10	5

CN4							
Outer Span 10 mm				Rate 26 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	1809	2619	1	2619	1	87.5
2	5.00	1764	2554	3	2599	2	62.5
3	5.00	1795	2599	2	2554	3	37.5
4	5.00	1747	2530	4	2530	4	12.5

HARDMETAL BEND TESTS

Results Comment Sheet

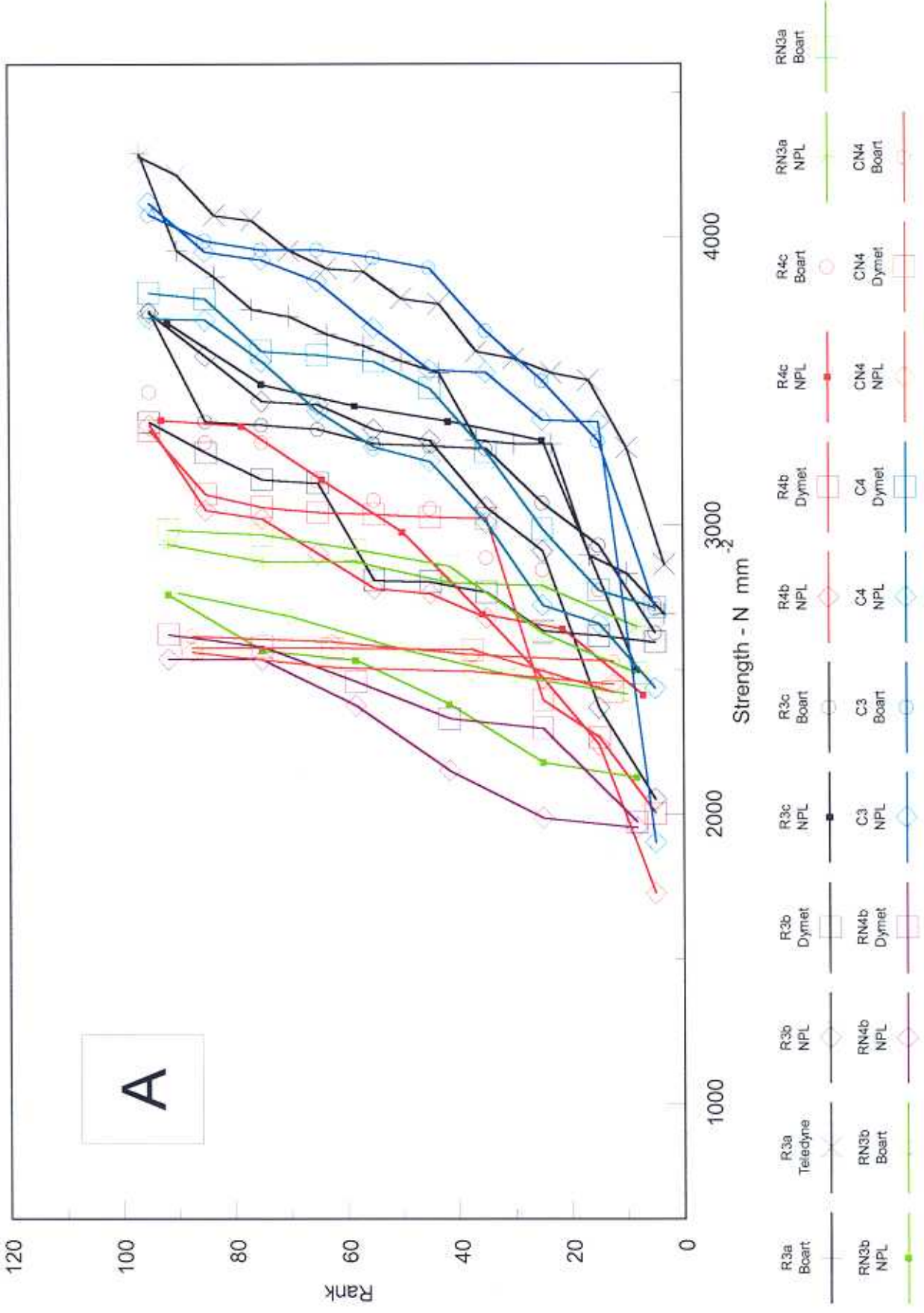
Sandvik Hard Materials - Category (3) Fine WC/Co Hardmetal

PLOT SEQUENCE

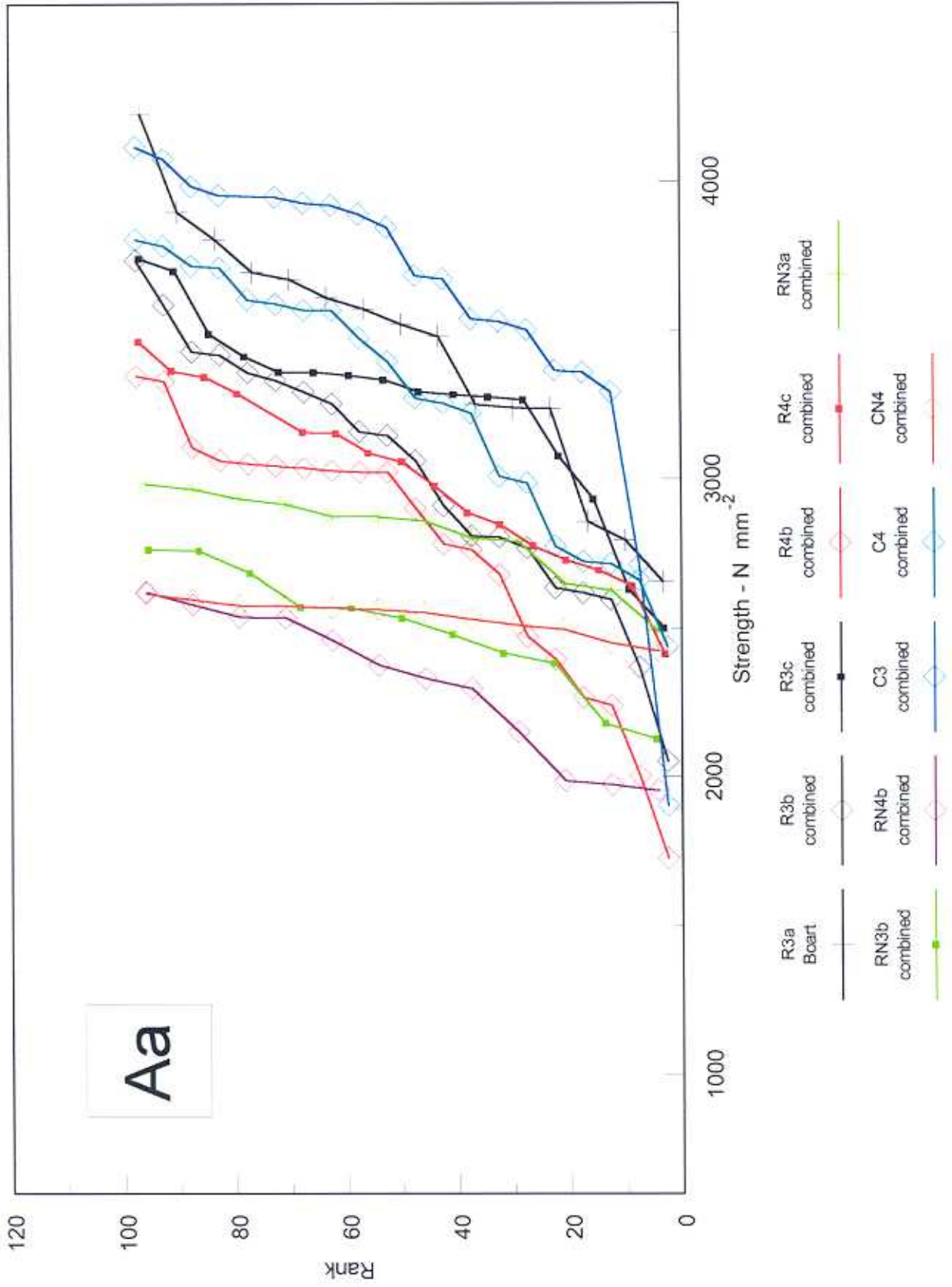
- A - Complete set of all strength values.
- Aa - Complete set, different laboratories combined.
- 1 - Standard tests, ISO type B (R3a), including corrected Teledyne data*.
- 1a - Combined R3a.
- 2 - 3 pt rectangular tests; (R3a, R3b, R3c).
- 2a - Combined R3a, R3b and R3c.
- 3 - 4 pt rectangular tests, compared with Boart standard ISO type B; (R3a, R4b, R4c).
- 3a - Combined R3a, R4b and R4c.
- 4 - Individual 3 pt vs 4 pt tests; R3b, R3c, R4b, R4c; not including R3a.
- 4a - Combined 3 pt vs 4 pt tests; R3b, R3c, R4b and R4c.
- 5 - Round testpieces, compared with standard R3a; (C3, C4 and R3a).
- 5a - Combined C3, C4 and R3a.
- 6 - 3 pt rectangular and round; R3b, R3c and C3; not including R3a.
- 6a - Combined C3 compared with R3b combined and R3c combined.
- 7 - 4 pt rectangular and round (R4b, R4c and C4).
- 7a - Combined C4 compared with combined R4b and combined R4c.
- 8 - Notched rectangular testpieces; (RN3a, RN3b and RN4b).
- 8a - Combined notched testpieces; (RN3a, RN3b and RN4b).
- 9 - Notched round compared with combined notched rectangular; (CN4, RN3a, RB3b and RN4b).
- 9a - Combined notched round compared with combined notched rectangular; (CN4 and RN3a, RN3b and RN4b).

*NB *The R3a Teledyne data have been multiplied by 0.945 in the corrected data set.*

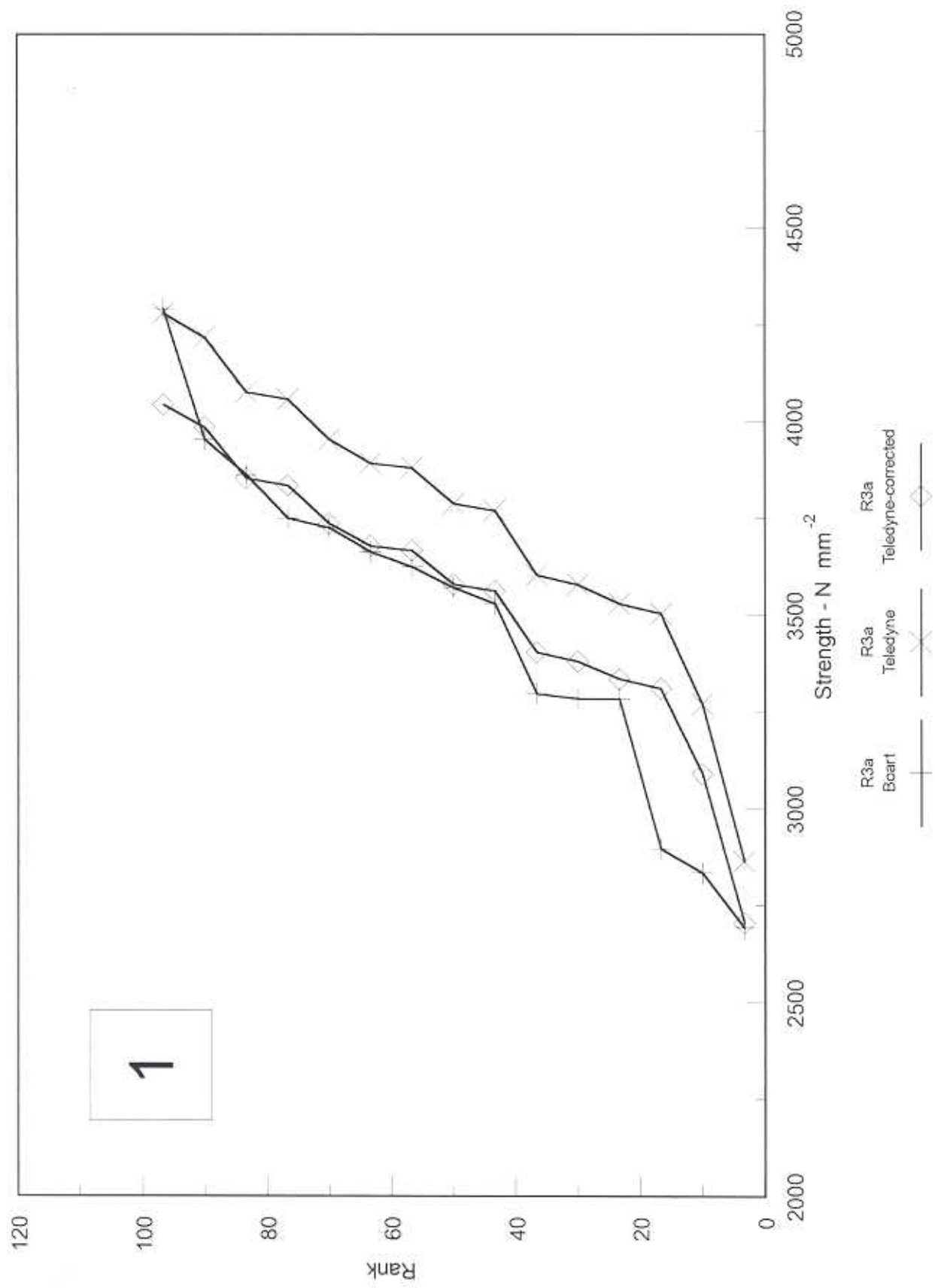
Bend Tests - Sandvik HM WC/Co (2)



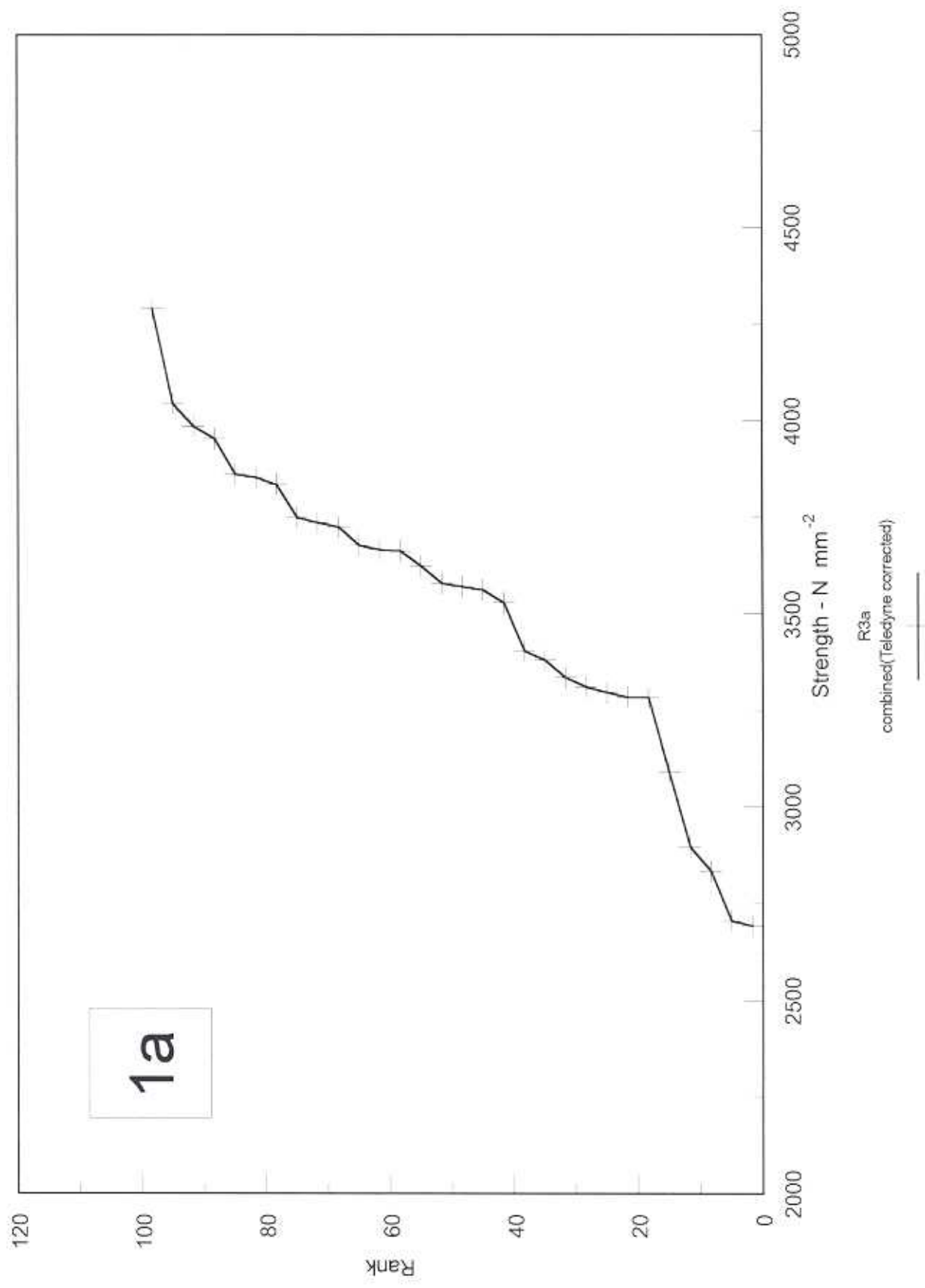
Bend Tests - Sandvik HM WC/Co (2)



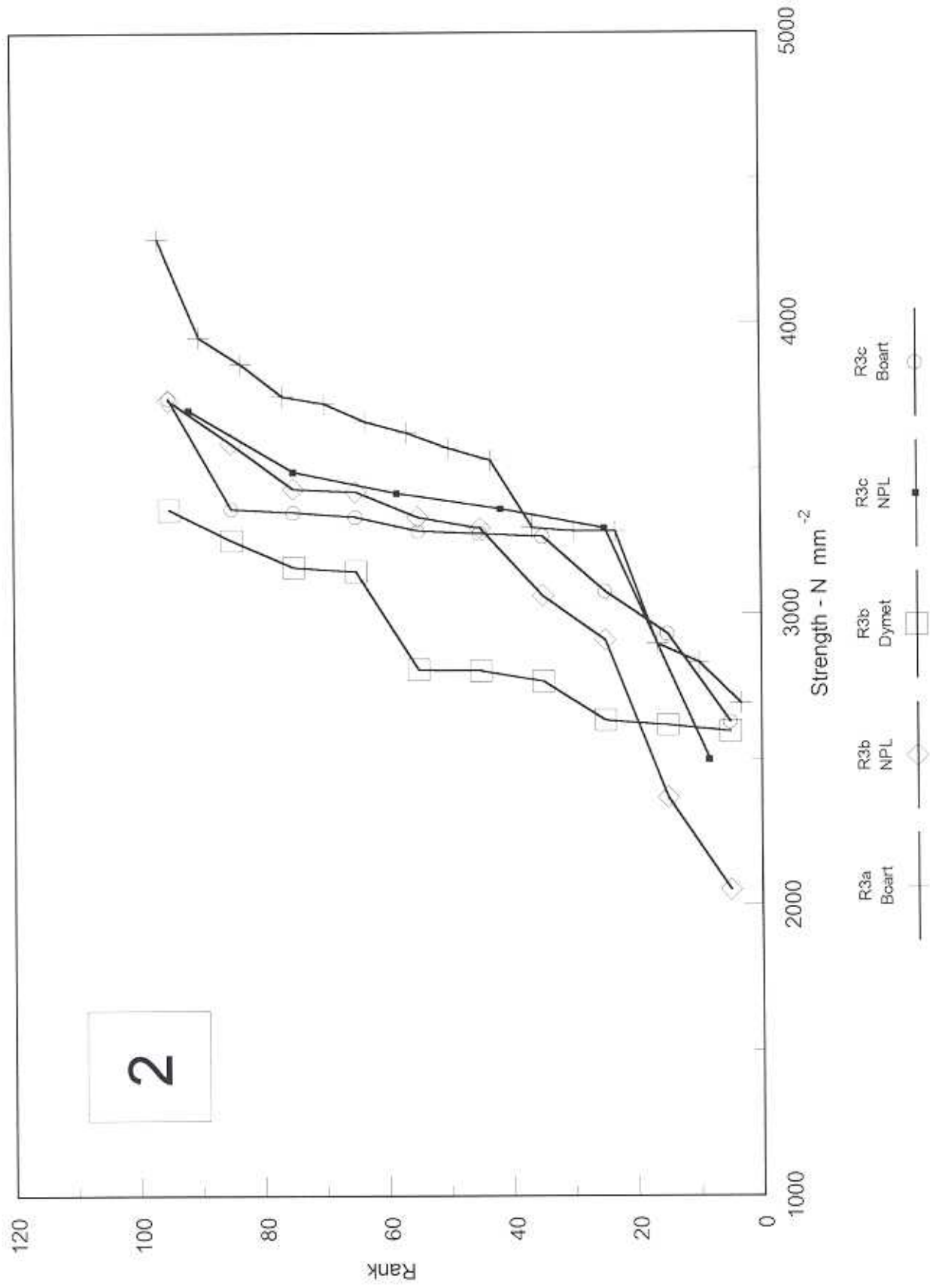
Bend Tests - Sandvik HM WC/Co (2)



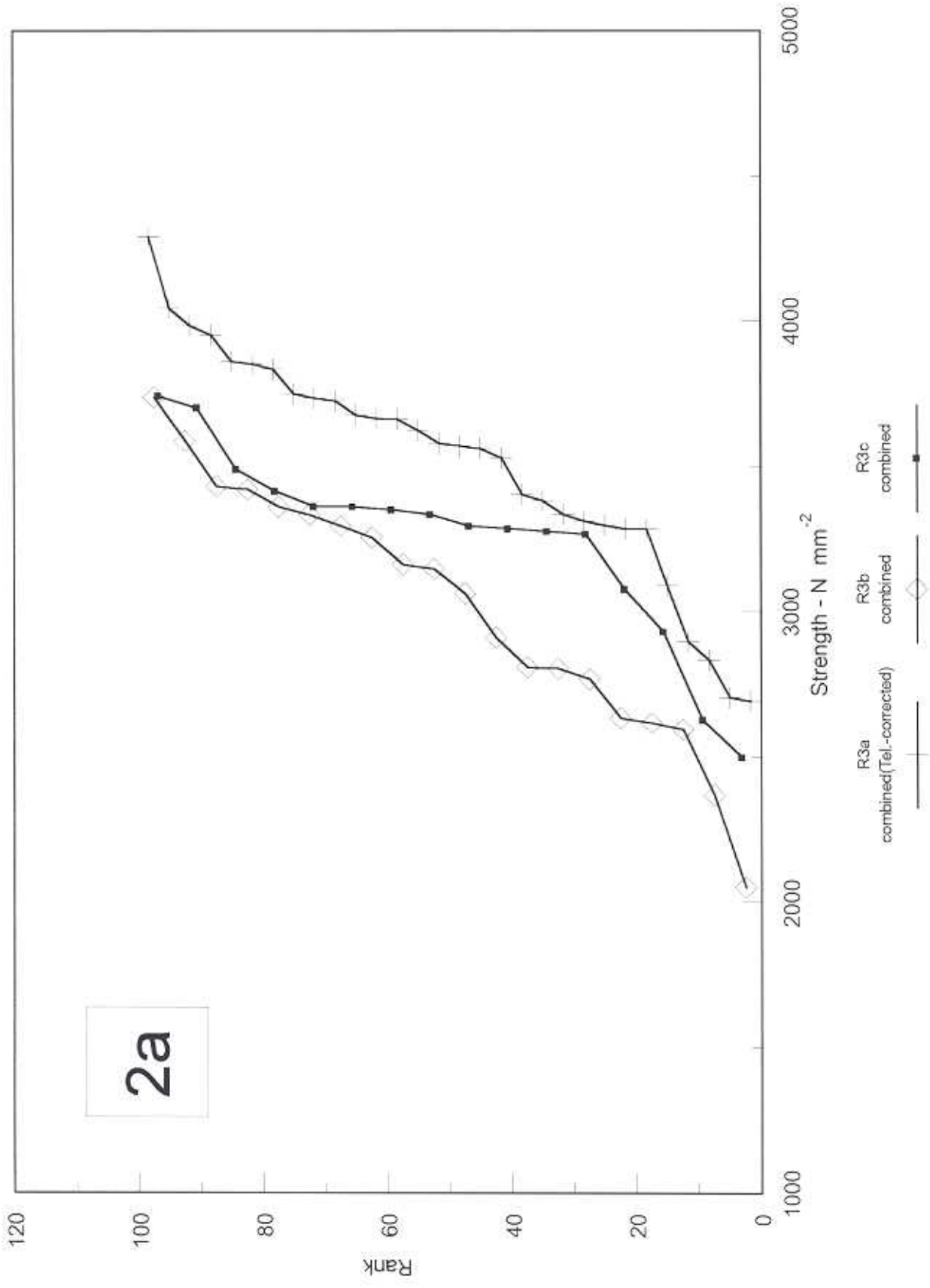
Bend Tests - Sandvik HM WC/Co (2)



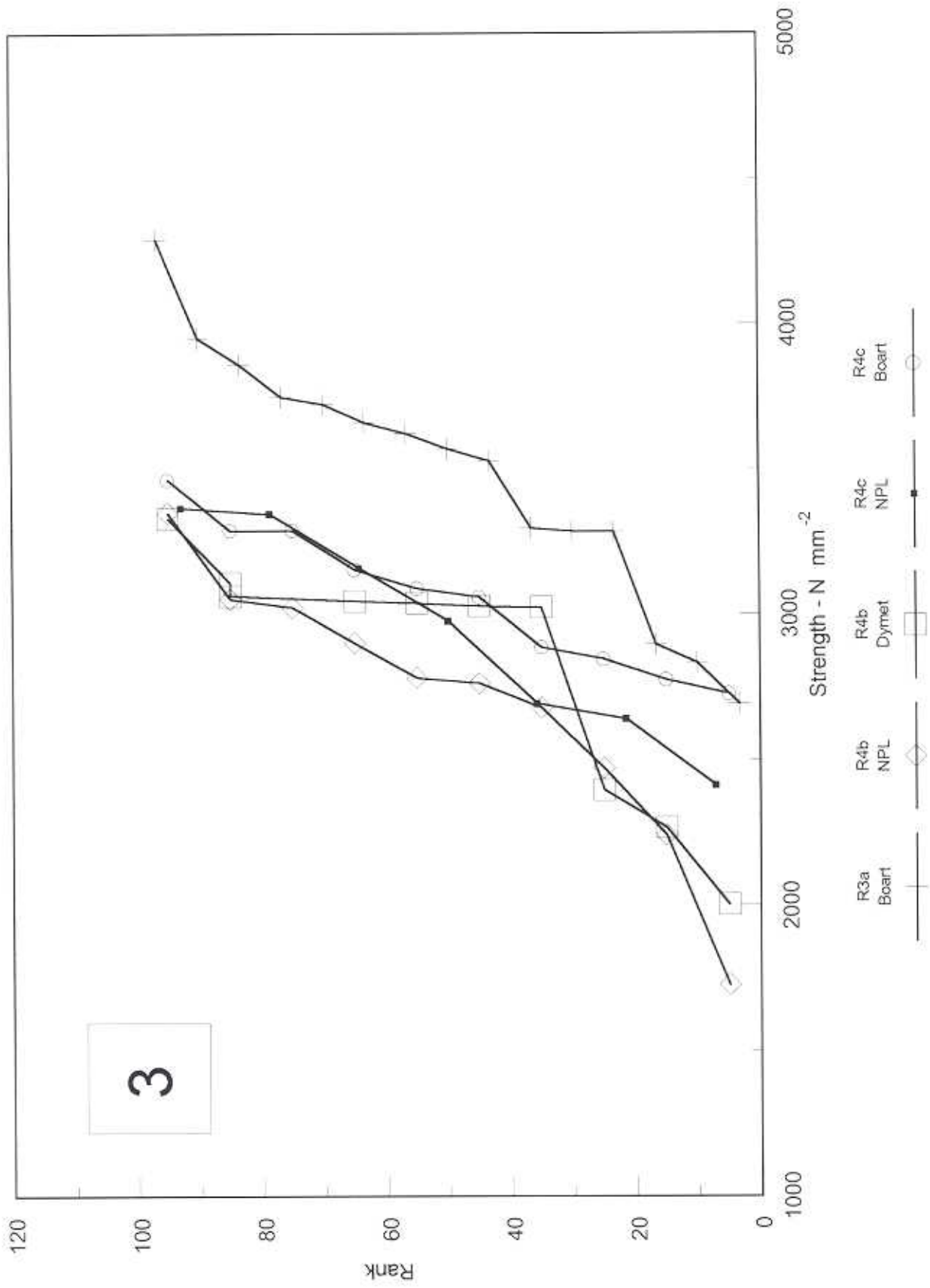
Bend Tests - Sandvik HM WC/Co (2)



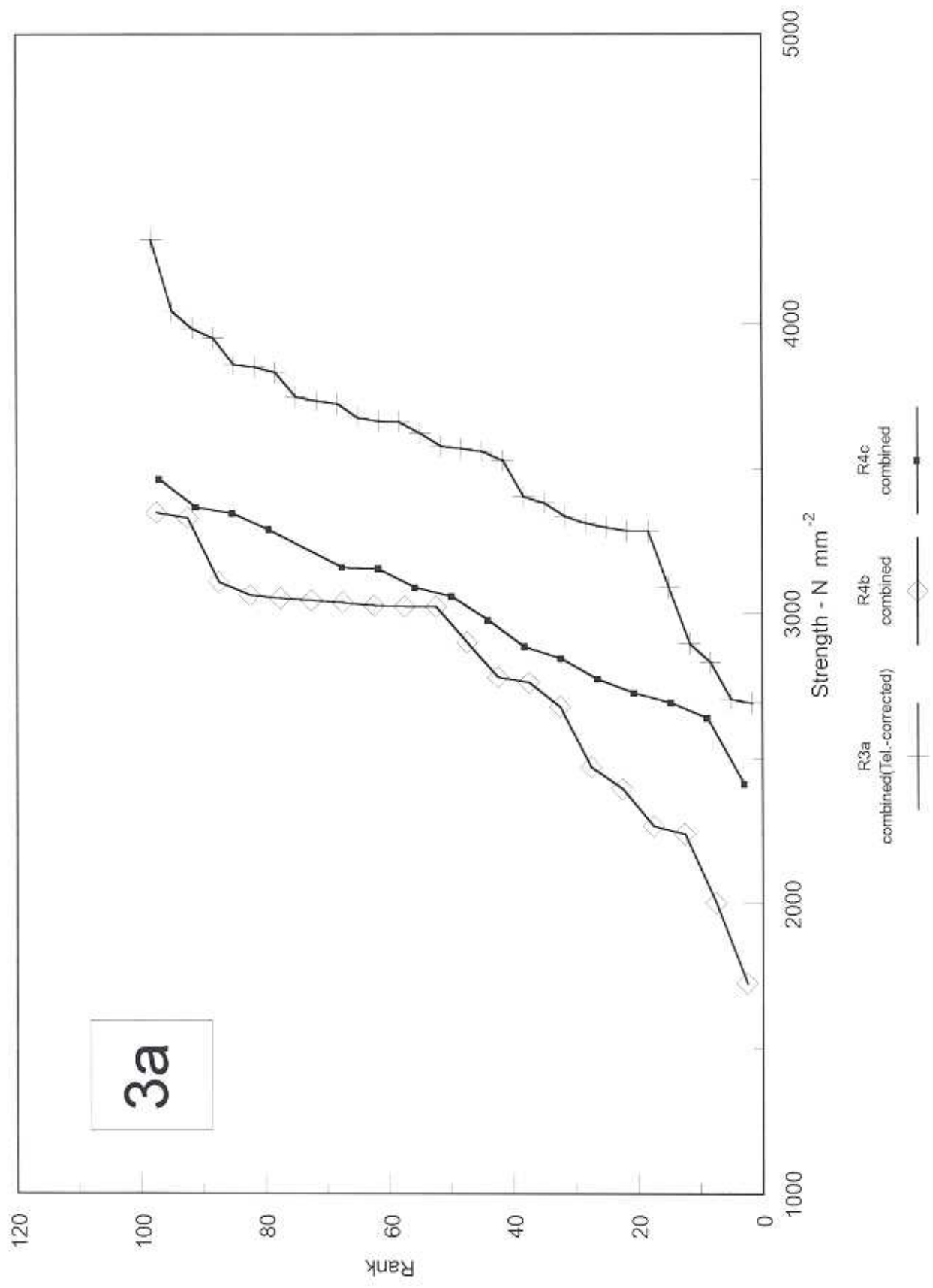
Bend Tests - Sandvik HM WC/Co (2)



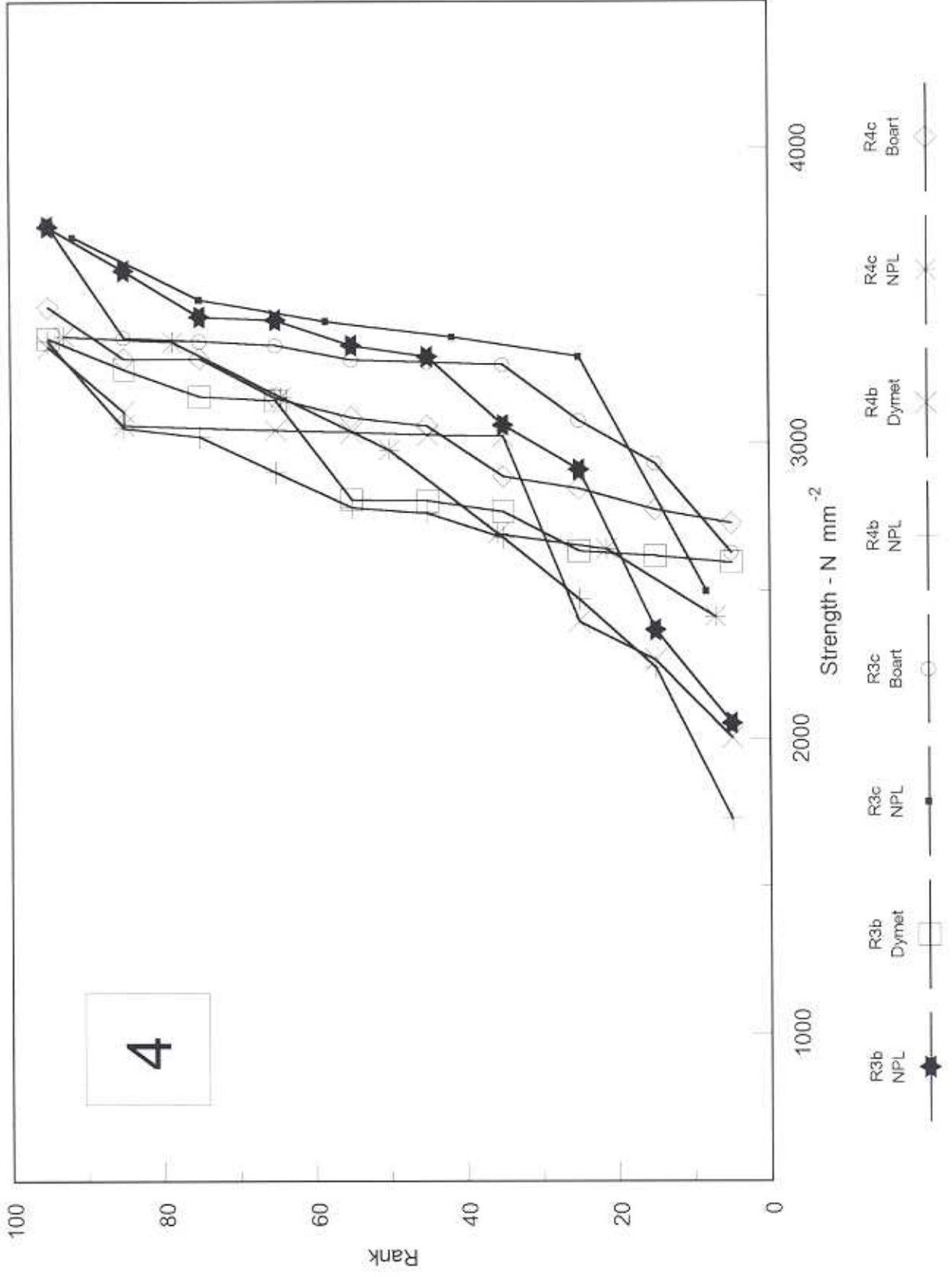
Bend Tests - Sandvik HM WC/Co (2)



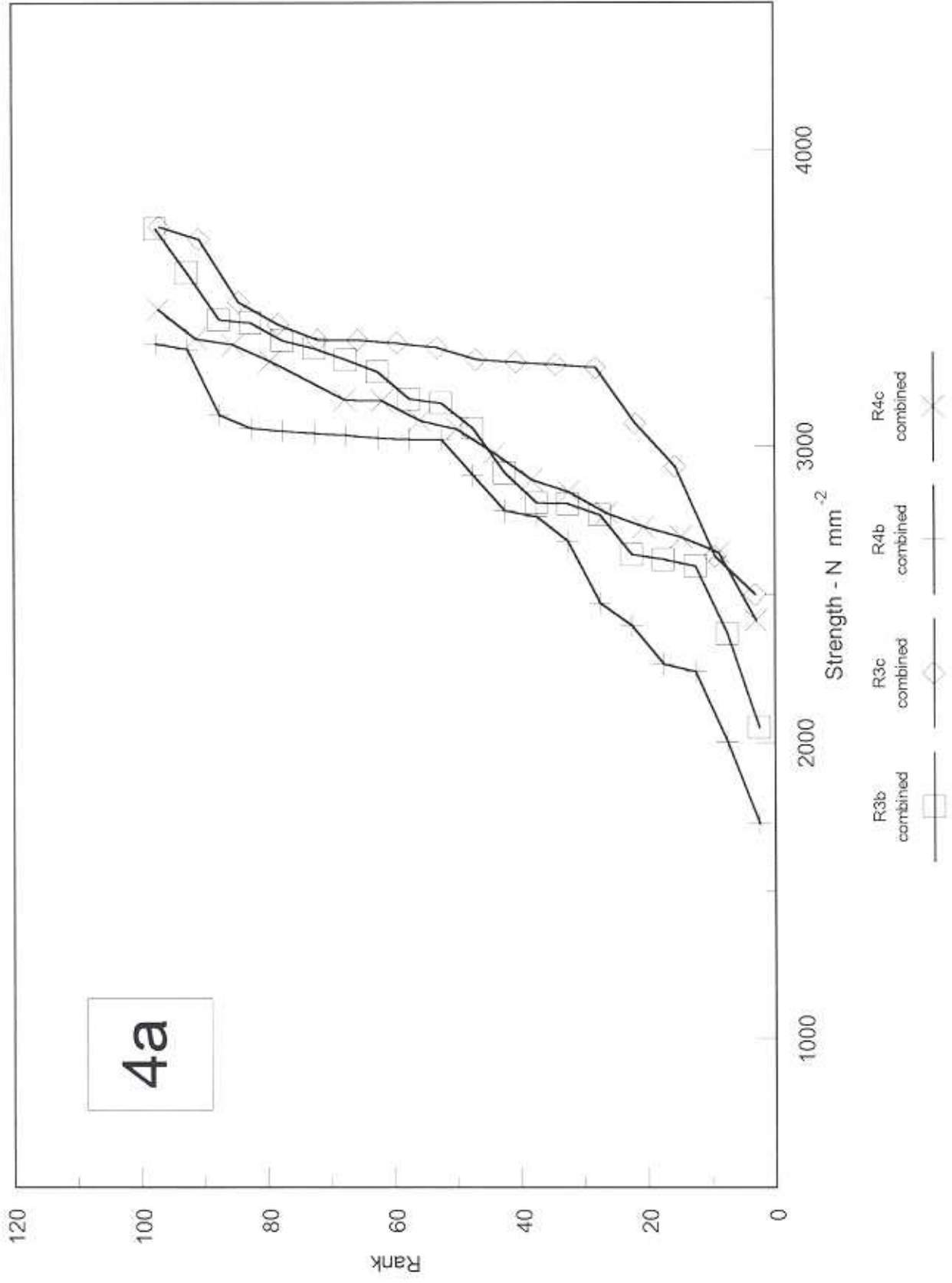
Bend Tests - Sandvik HM WC/Co (2)



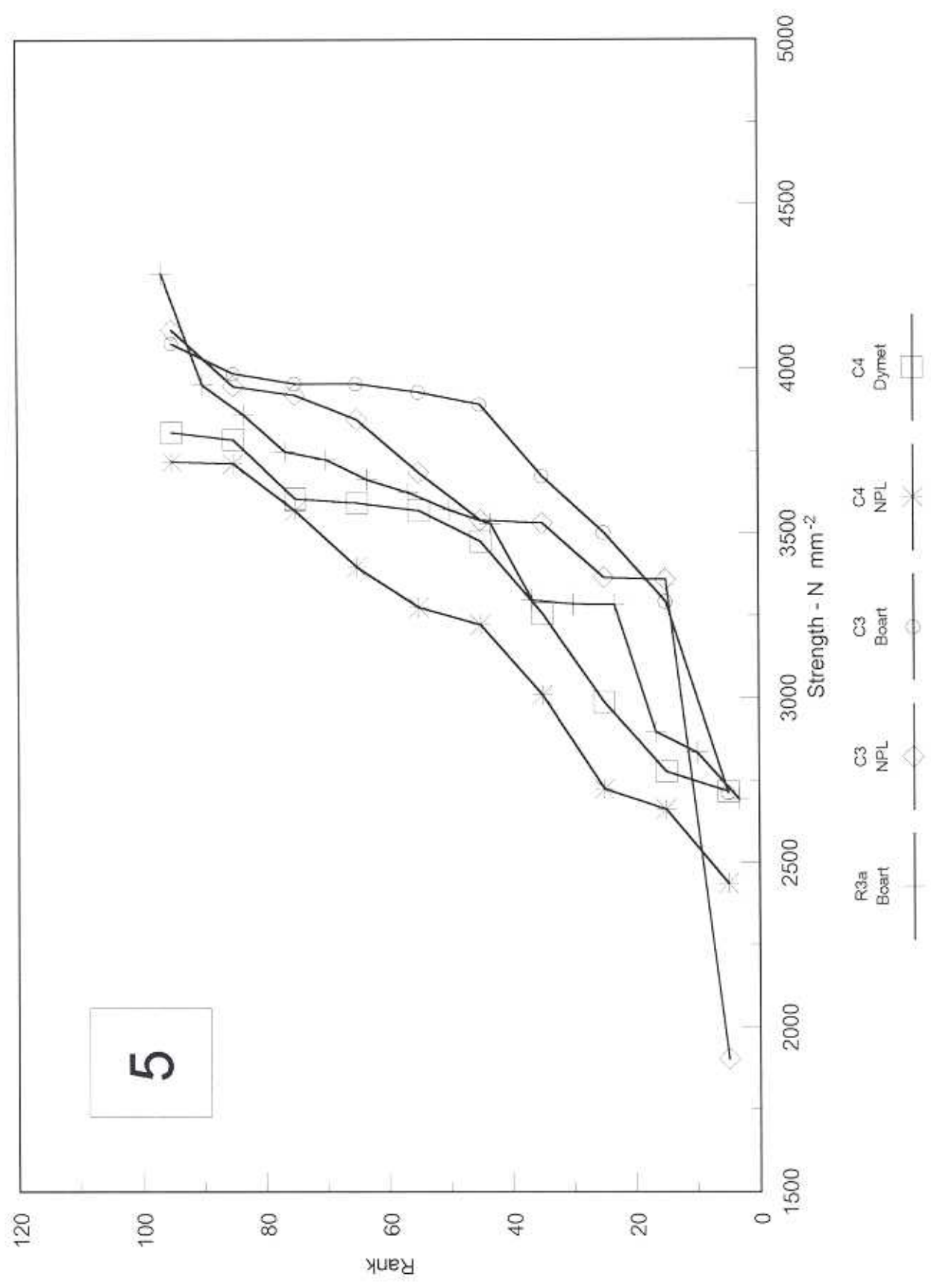
Bend Tests - Sandvik HM WC/Co (2)



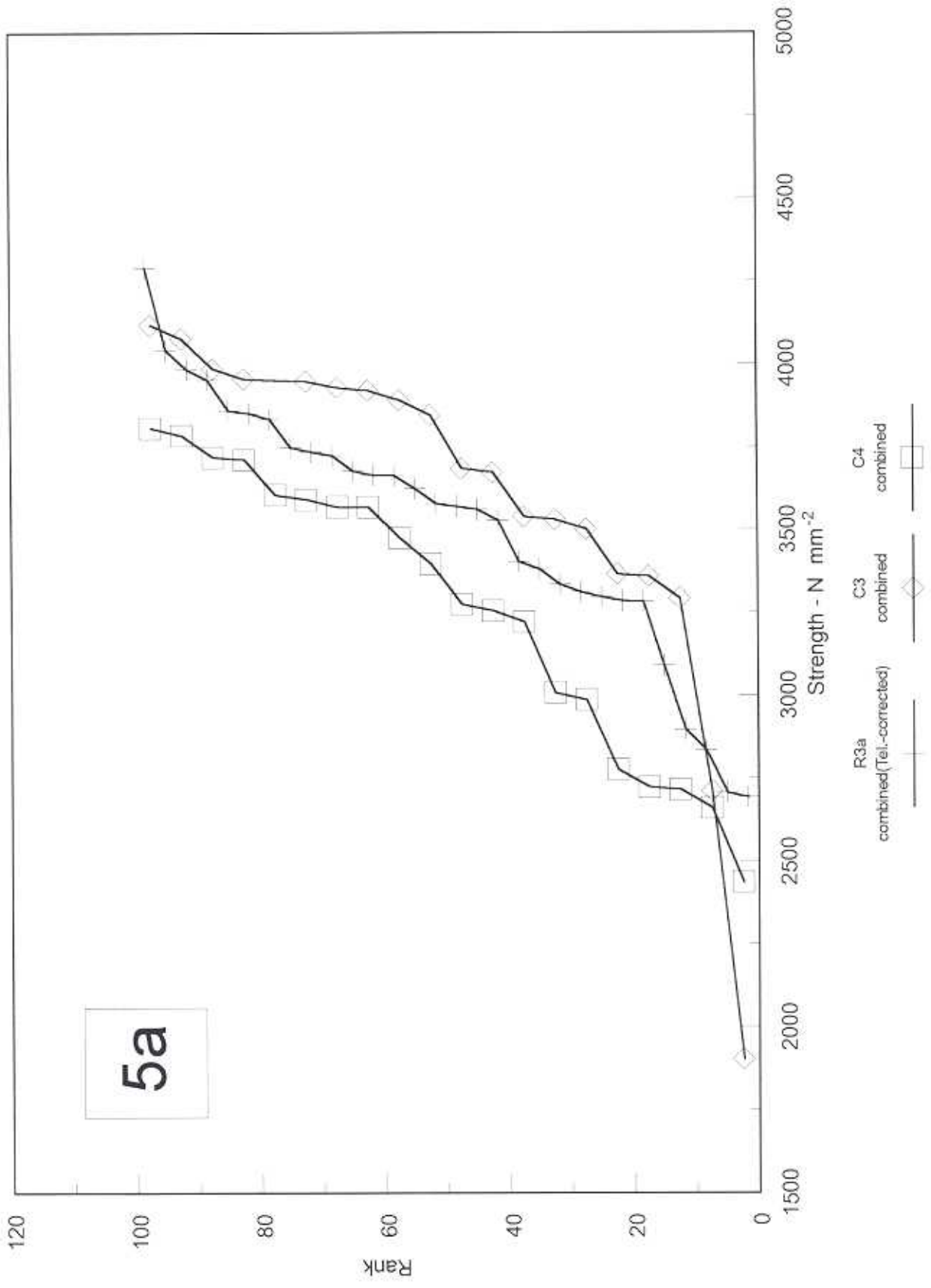
Bend Tests - Sandvik HM WC/Co (2)



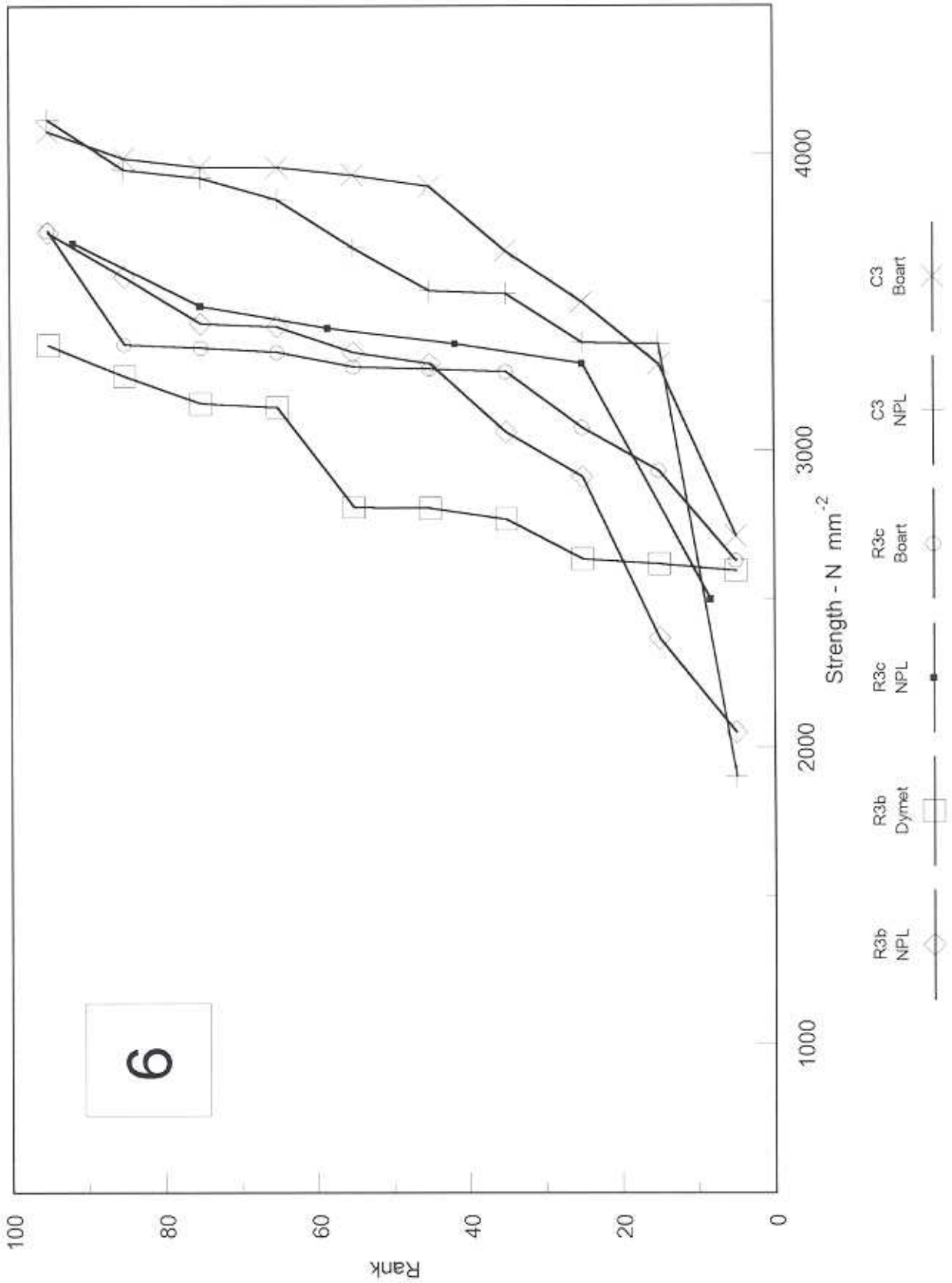
Bend Tests - Sandvik HM WC/Co (2)



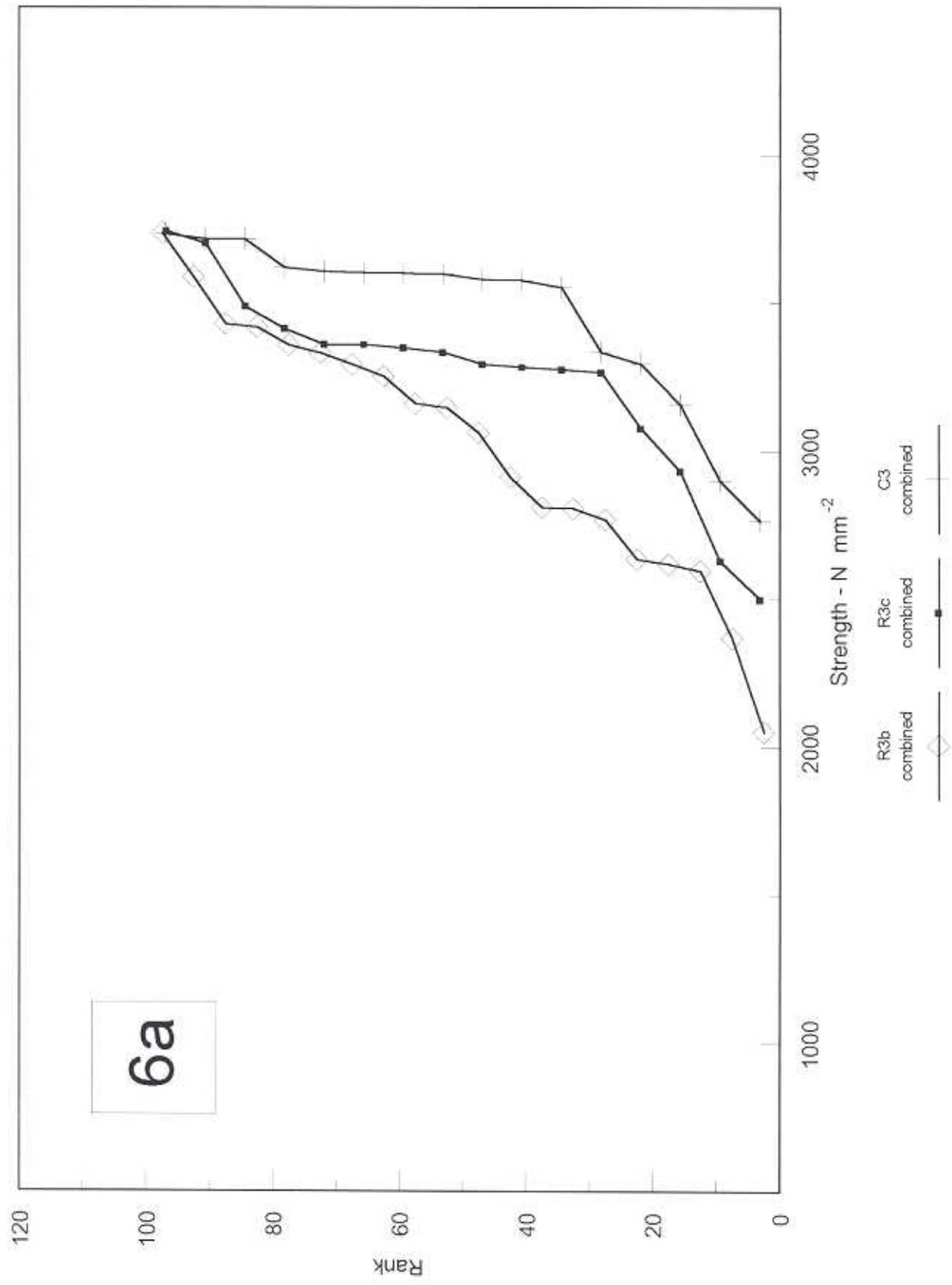
Bend Tests - Sandvik HM WC/Co (2)



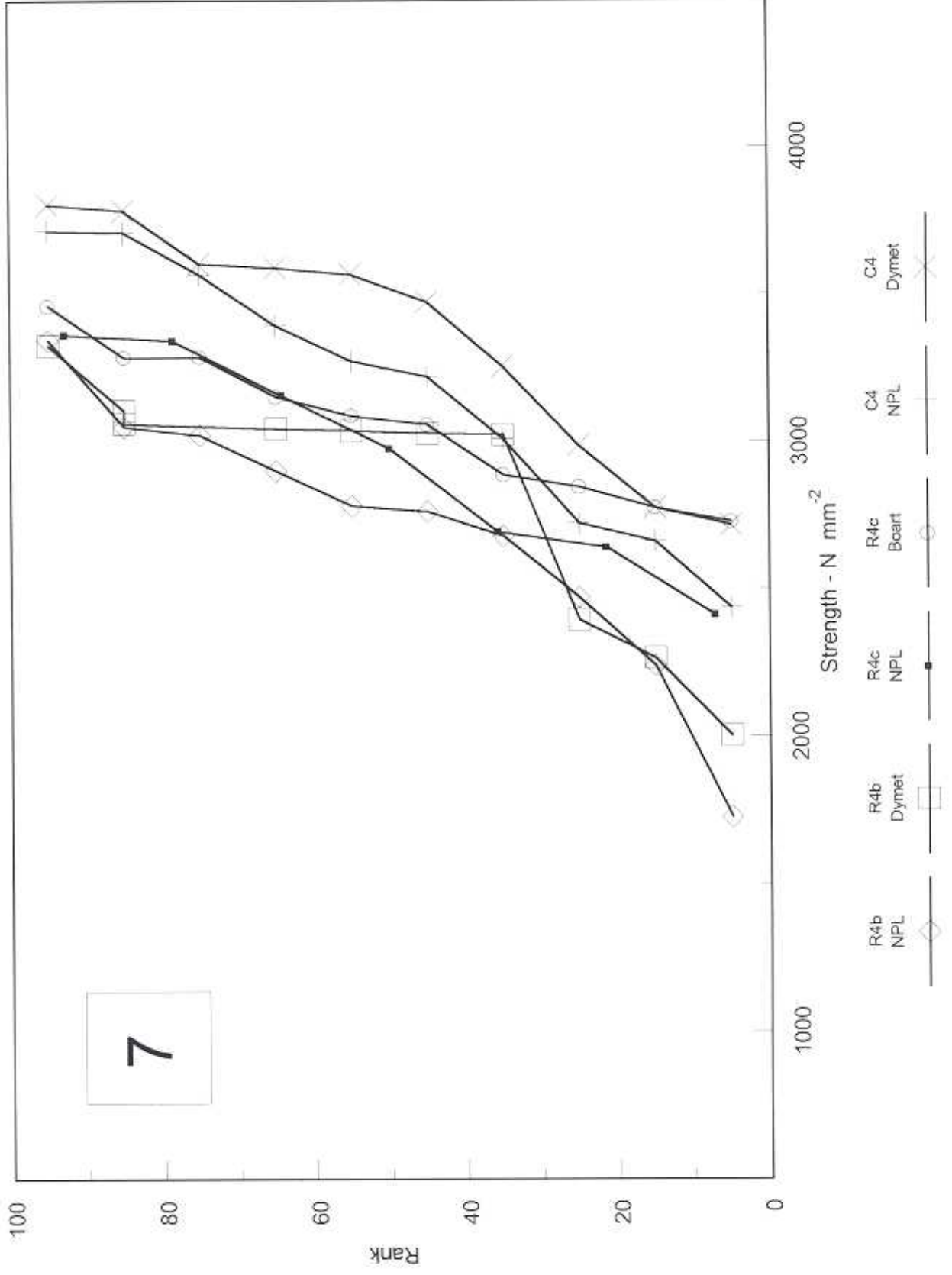
Bend Tests - Sandvik HM WC/Co (2)



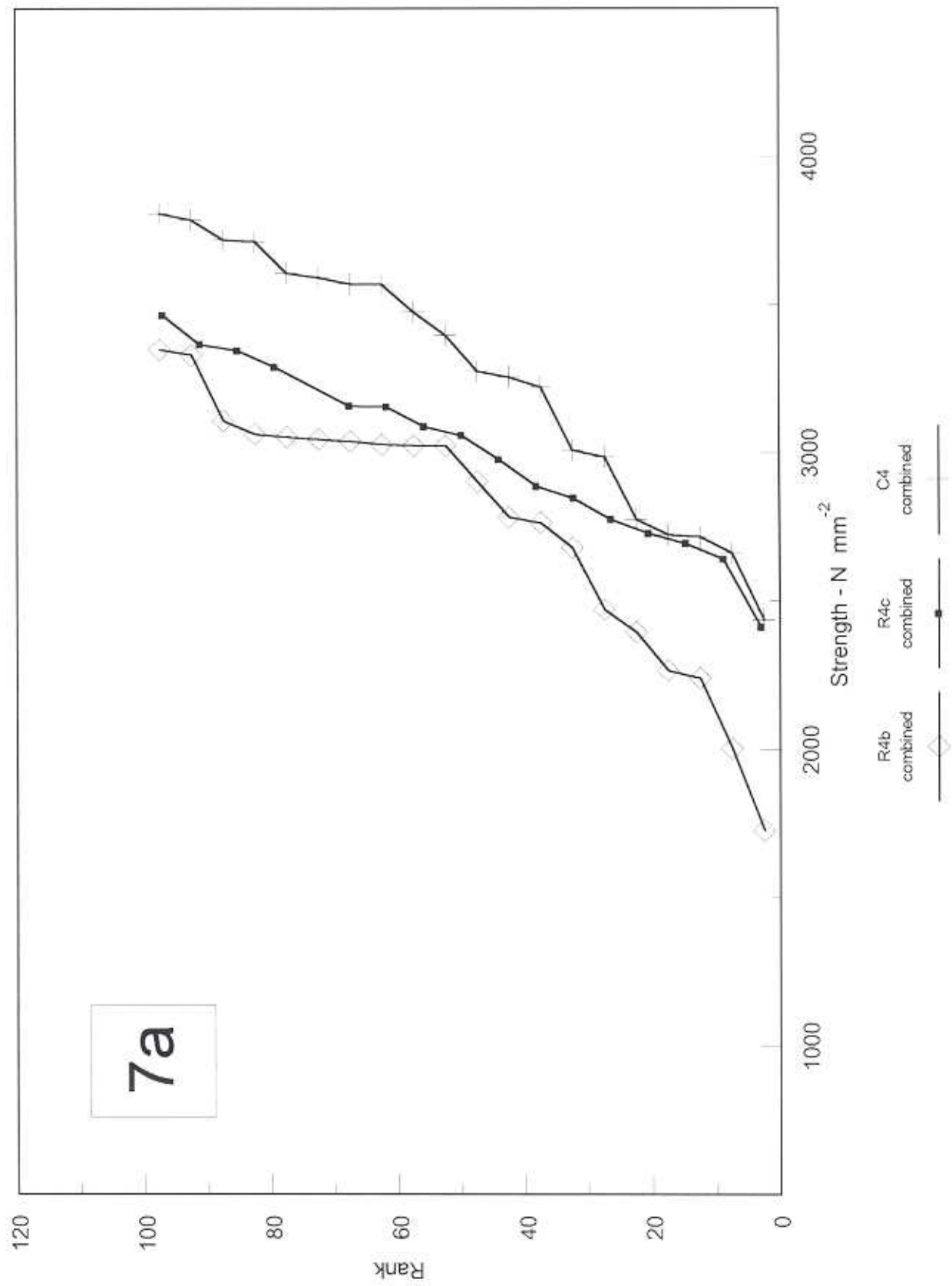
Bend Tests - Sandvik HM WC/Co (2)



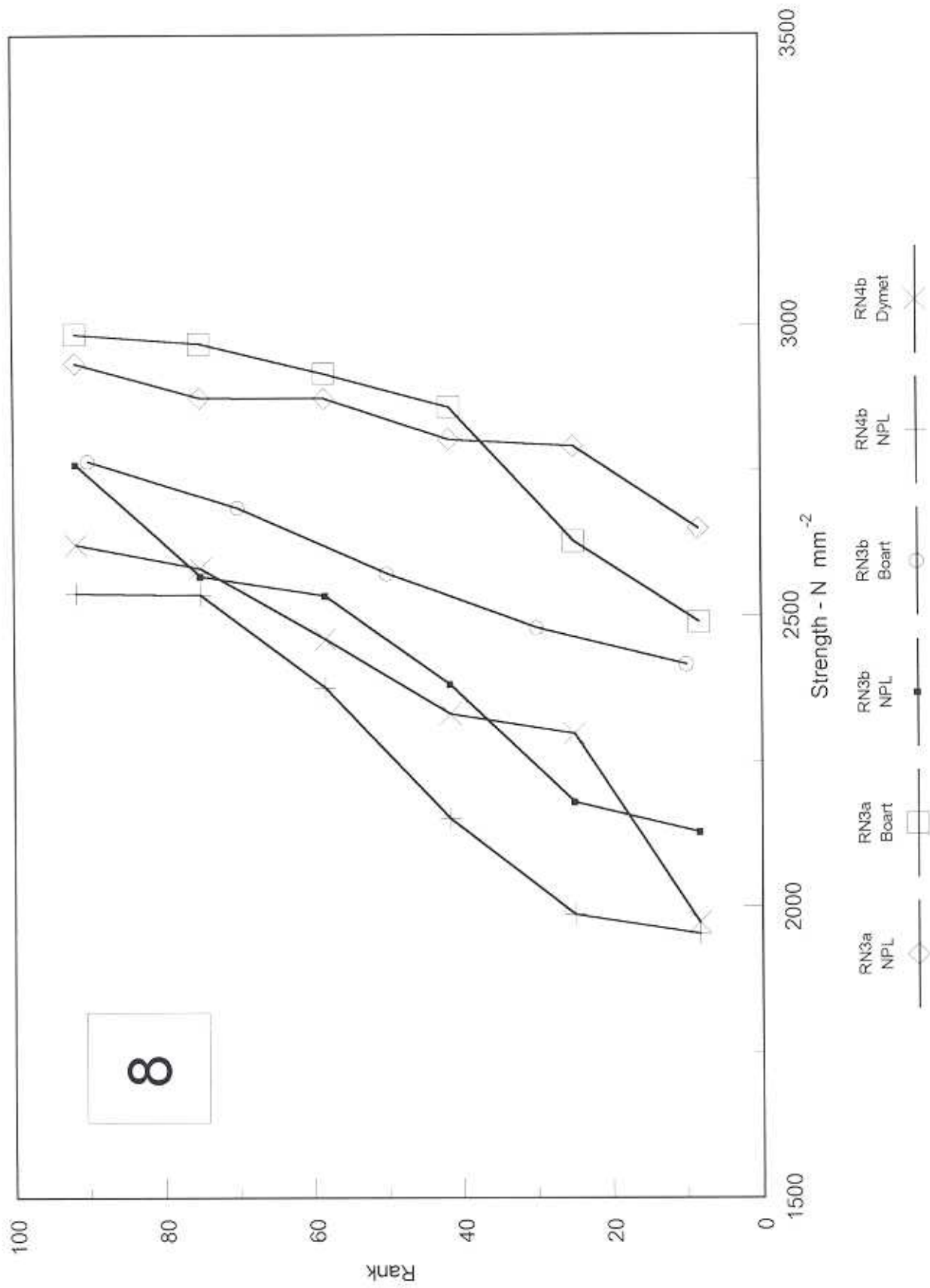
Bend Tests - Sandvik HM WC/Co (2)



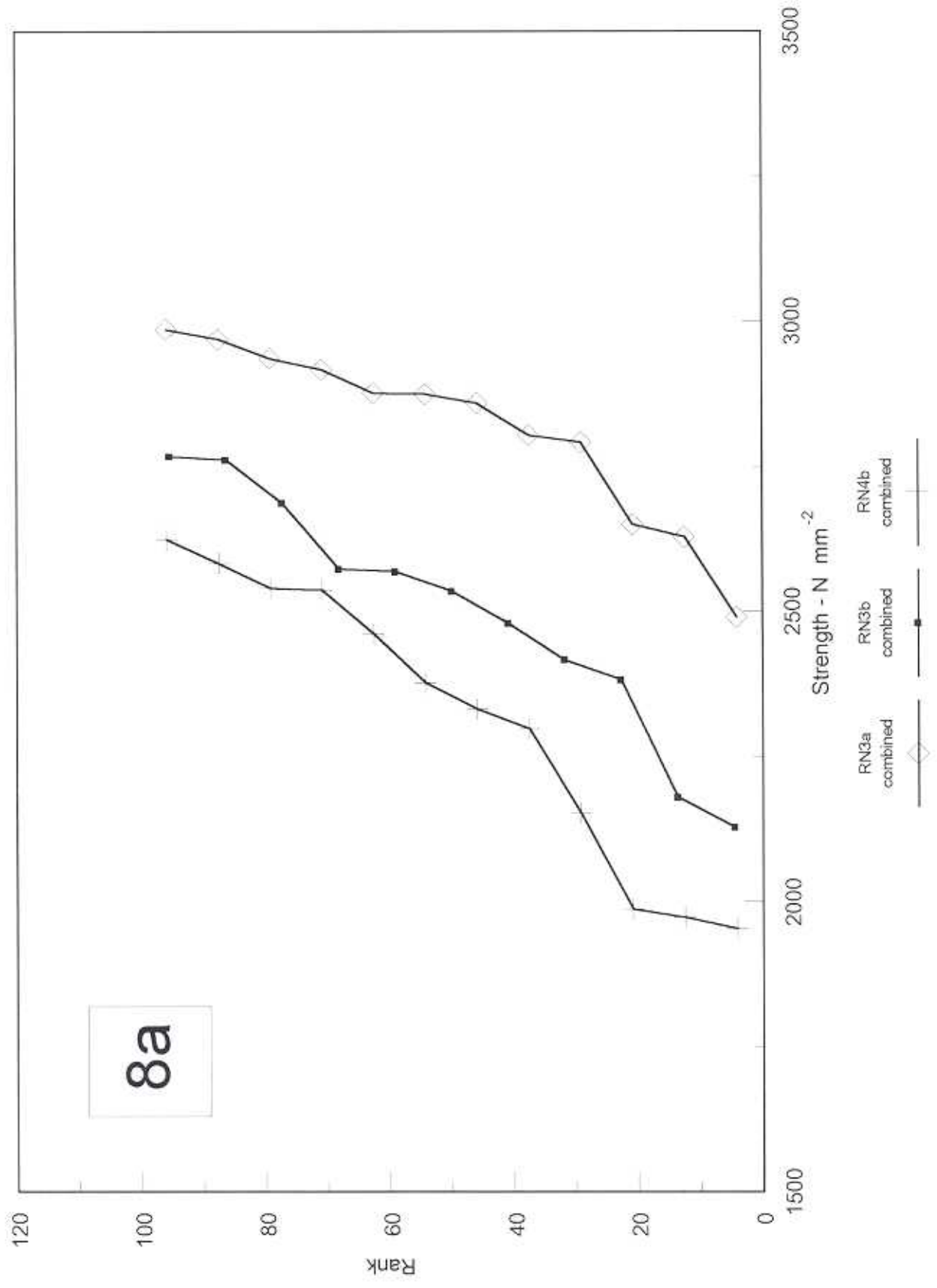
Bend Tests - Sandvik HM WC/Co (2)



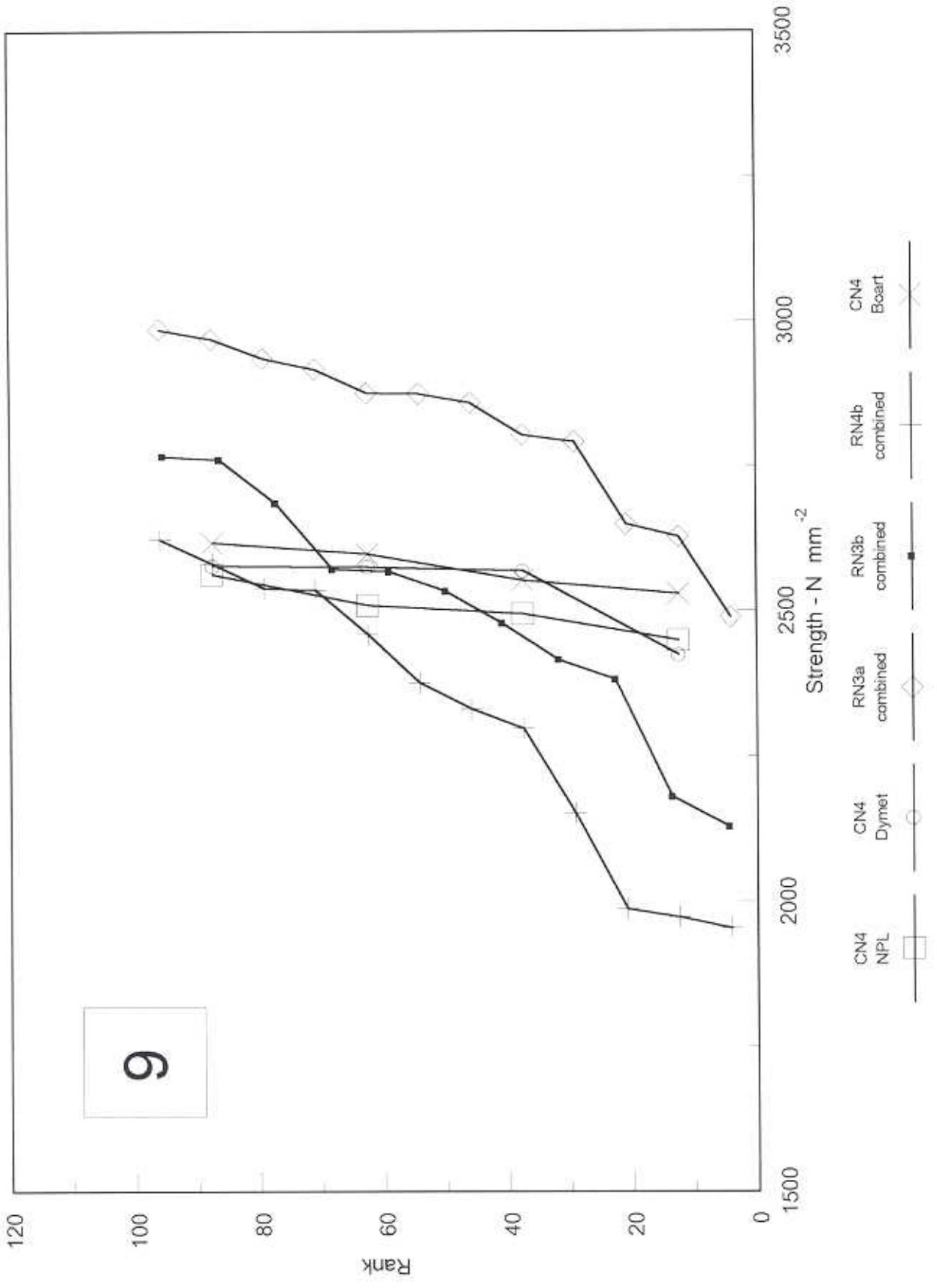
Bend Tests - Sandvik HM WC/Co (2)



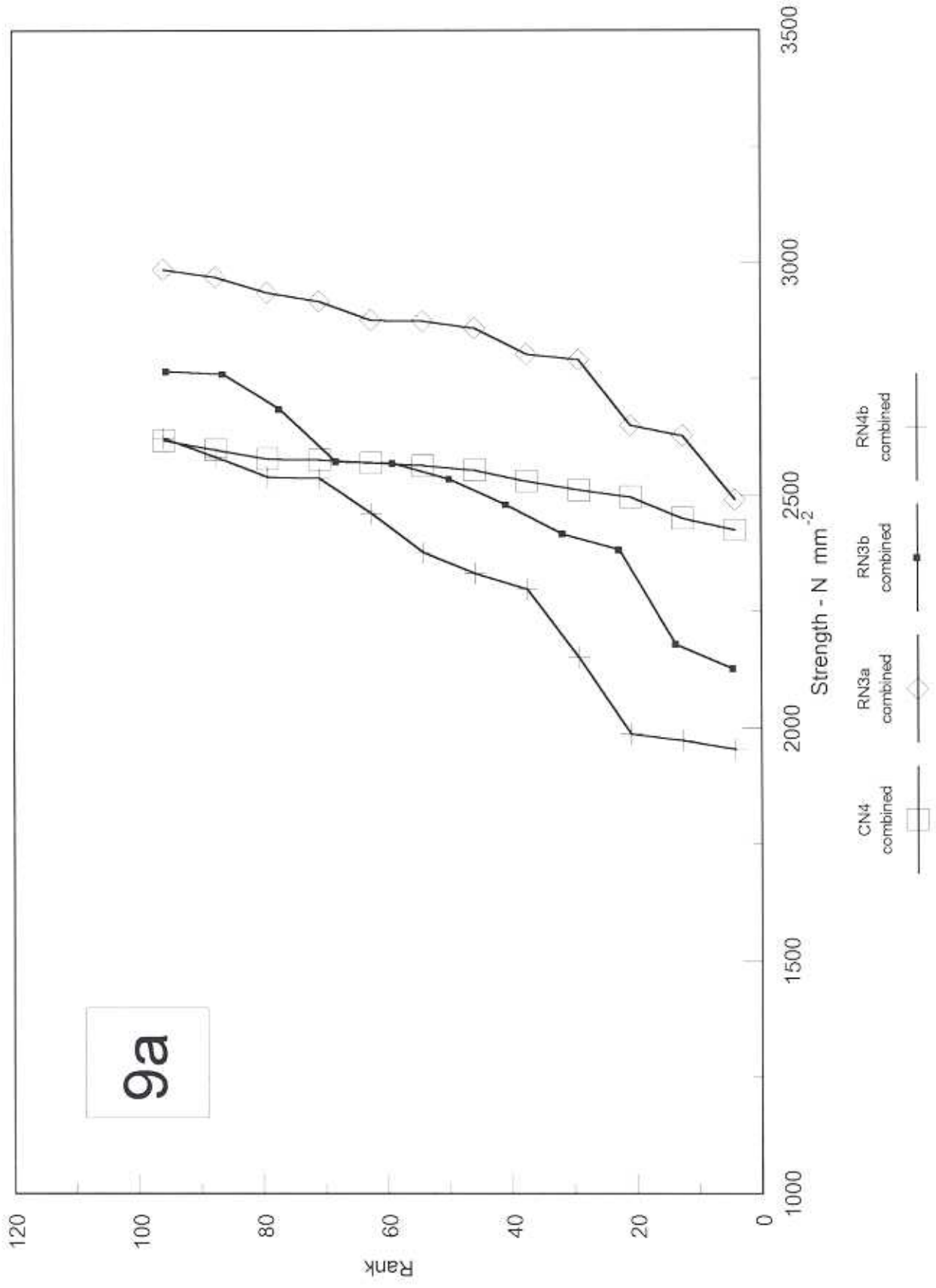
Bend Tests - Sandvik HM WC/Co (2)



Bend Tests - Sandvik HM WC/Co (2)



Bend Tests - Sandvik HM WC/Co (2)



RESULTS SET

(4) KENNAMETAL

Medium/Fine, WC/CC/Co

Data Tables

Supplementary Comments

Data Plots

HARDMETAL BEND TESTS INTERNATIONAL INTERCOMPARISON

TABLES OF RESULTS

SET 4

WC/CC/Co (Med/Fine grained) - Source: Kennametal

<i>Geometry</i>		<i>Organisation</i>
3 pt TRS	R3a	Standard Tests (CERMeP/Gen Carbide)
3,4 pt Rectangular	R3, R4	NPL
3,4 pt Rectangular	R3, R4	United Hardmetals
3,4 pt Rectangular Notched	RN3, RN4	NPL
3,4 pt Rectangular Notched	RN3, RN4	United Hardmetals
Round	C3, C4, CN4) No tests on round
Round	C4, CN4) testpieces
Round	C3, CN4)

**KENNAMETAL WC/CC/Co(4) - FINE/MEDIUM
STANDARD TRS TESTS - R3a**

Gen Carbide (Set 1)					Span 14.3 mm Rate 1300 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
16	6.36	5.08	17236	2253	8	2386	1	96.7
17	6.35	5.07	16458	2163	14	2371	2	90
18	6.35	5.08	16902	2212	5	2318	3	83.3
19	6.35	5.07	16791	2207	15	2285	4	76.7
20	6.34	5.08	17681	2318	1	2253	5	70
21	6.34	5.08	13122	1720	3	2212	6	63.3
22	6.35	5.07	14345	1885	4	2207	7	56.7
23	6.34	5.07	18125	2386	13	2198	8	50
24	6.34	5.08	13789	1808	11	2187	9	43.3
25	6.34	5.07	14234	1873	2	2163	10	36.7
26	6.34	5.08	16680	2187	7	1885	11	30
27	6.34	5.08	11565	1516	10	1873	12	23.3
28	6.35	5.08	16791	2198	9	1808	13	16.7
29	6.34	5.07	18014	2371	6	1720	14	10
30	6.35	5.08	17458	2285	12	1516	15	3.3

Standard, R3a, Tests

The batch of standard, R3a, testpieces originally mailed to CERMeP (set 1) were lost in the post. Therefore a second batch (set 2) of R3a geometry testpieces were obtained from Kennametal and tested at CERMeP and General Carbide. The agreement between CERMeP and General Carbide was good for the set 2 materials (but different to set 1) - see plots. Therefore the General Carbide set 1 data, R3a, were used for comparison with all the other geometry tests (completed on set 1 material).

Gen Carbide (Set 2)					Span 14.3 mm Rate 1300 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.5	5.25	20994	2514	4	2756	1	96.7
2	6.5	5.25	22574	2703	9	2743	2	90
3	6.5	5.25	22685	2716	11	2737	3	83.3
4	6.5	5.25	23018	2756	3	2716	4	76.7
5	6.5	5.25	22462	2689	2	2703	5	70
6	6.5	5.25	21128	2530	7	2703	5	63.3
7	6.5	5.25	22574	2703	5	2689	7	56.7
8	6.5	5.25	20906	2503	10	2649	8	50
9	6.5	5.25	22907	2743	13	2649	8	43.3
10	6.5	5.25	22129	2649	14	2588	10	36.7
11	6.5	5.25	22863	2737	6	2530	11	30
12	6.5	5.25	18570	2223	15	2530	11	23.3
13	6.5	5.25	22129	2649	1	2514	13	16.7
14	6.5	5.25	21617	2588	8	2503	14	10
15	6.5	5.25	21128	2530	12	2223	15	3.3

CERMeP (Set 2)					Span 14.5 mm Rate 0.5 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.48	5.24	21400	2616	13	2784	1	96.7
2	6.48	5.24	18500	2261	7	2749	2	90
3	6.48	5.24	21300	2604	9	2749	2	83.3
4	6.48	5.24	20200	2469	1	2616	4	76.7
5	6.48	5.24	21400	2616	5	2616	4	70
6	6.48	5.23	19900	2442	3	2604	6	63.3
7	6.48	5.23	22400	2749	8	2589	7	56.7
8	6.48	5.23	21100	2589	15	2587	8	50
9	6.48	5.23	22400	2749	11	2527	9	43.3
10	6.48	5.23	16800	2062	4	2469	10	36.7
11	6.49	5.24	20700	2527	14	2451	11	30
12	6.48	5.23	17800	2184	6	2442	12	23.3
13	6.48	5.22	22600	2784	2	2261	13	16.7
14	6.48	5.22	19900	2451	12	2184	14	10
15	6.48	5.22	21000	2587	10	2062	15	3.3

**KENNAMETAL WC/CC/Co(4) - FINE/MEDIUM
NPL BEND TESTS (R3b, R3c, R4b, R4c)**

R3b					Span 30 mm Rate 200 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.95	4.94	6095	2271	6	2293	1	91.7
2	4.93	4.94	5289	1978	1	2271	2	75
3	4.95	4.95	5753	2134	3	2134	3	58.3
4	4.95	4.94	4955	1846	2	1978	4	41.7
5	4.95	4.95	4685	1738	4	1846	5	25
6	4.95	4.95	6179	2293	5	1738	6	8.3
7	4.95*	4.94	5726	2124	14	2235	1	93.75
8	4.95*	4.94	3424	1270	10	2197	2	81.25
9	4.95*	4.94	5248	1947	11	2168	3	68.75
10	4.95*	4.94	5921	2197	13	2128	4	56.25
11	4.95*	4.95	5844	2168	7	2124	5	43.75
12	4.95*	4.95	5556	2061	12	2061	6	31.25
13	4.95*	4.95	5735	2128	9	1947	7	18.75
14	4.95*	4.95	6024	2235	8	1270	8	6.25

*annealed

R3c					Span 40 mm Rate 40 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.94	2.94	1209	2130	6	2320	1	95
2	3.94	2.93	1239	2198	10	2239	2	85
3	3.94	2.94	1261	2222	5	2228	3	75
4	3.94	2.94	1139	2007	3	2222	4	65
5	3.94	2.93	1256	2228	7	2216	5	55
6	3.94	2.94	1317	2320	2	2198	6	45
7	3.94	2.94	1258	2216	1	2130	7	35
8	3.94	2.94	1115	1964	4	2007	8	25
9	3.94	2.94	935	1647	8	1964	9	15
10	3.94	2.94	1271	2239	9	1647	10	5

R4b				Outer Span 10 mm Rate 200 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.94	4.95	8089	2005	5	2066	1	91.7
2	4.95	4.95	5542	1371	1	2005	2	75
3	4.94	4.94	7344	1828	6	1953	3	58.3
4	4.95	4.95	7471	1848	4	1848	4	41.7
5	4.95	4.95	8352	2066	3	1828	5	25
6	4.95	4.95	7895	1953	2	1371	6	8.3

R4c				Outer Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	3.94	2.94	2453	2161	1	2161	1	95
2	3.94	2.93	2386	2116	2	2116	2	85
3	3.94	2.94	2327	2050	6	2074	3	75
4	3.94	2.94	2330	2053	4	2053	4	65
5	3.94	2.93	2059	1826	3	2050	5	55
6	3.94	2.93	2338	2074	7	1977	6	45
7	3.94	2.94	2244	1977	9	1963	7	35
8	3.94	2.94	2181	1921	8	1921	8	25
9	3.94	2.94	2228	1963	5	1826	9	15
10	3.94	2.94	1967	1733	10	1733	10	5

**KENNAMETAL WC/CC/Co(4) - FINE/MEDIUM
UNITED HARDMETALS BEND TESTS (R3b, R4b)**

R3b					Span 30 mm Rate 400 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4.95	4.95	4809	1784	7	2153	1	95
12	4.95	4.95	4847	1798	10	2134	2	85
13	4.95	4.96	5603	2066	5	2091	3	75
14	4.95	4.95	5173	1919	6	2090	4	65
15	4.95	4.95	5637	2091	3	2066	5	55
16	4.95	4.95	5632	2090	8	1965	6	45
17	4.95	4.95	5804	2153	4	1919	7	35
18	4.95	4.95	5297	1965	2	1798	8	25
19	4.95	4.95	4756	1765	1	1784	9	15
20	4.95	4.95	5752	2134	9	1765	10	5

R4b					Outer Span 10 mm Rate 310 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4.95	4.95	7398	1830	8	2011	1	95
12	4.95	4.95	7941	1964	6	1977	2	85
13	4.95	4.95	7383	1826	2	1964	3	75
14	4.95	4.95	7431	1838	7	1899	4	65
15	4.95	4.95	6816	1686	4	1838	5	55
16	4.95	4.95	7991	1977	1	1830	6	45
17	4.94	4.96	7692	1899	3	1826	7	35
18	4.95	4.95	8132	2011	5	1686	8	25
19	4.93	4.95	6426	1596	9	1596	9	15
20	4.95	4.95	4082	1010	10	1010	10	5

**KENNAMETAL WC/CC/Co(4) - FINE/MEDIUM
UNITED HARDMETALS BEND TESTS (R3c, R4c)**

R3c					Span 30 mm Rate 90 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	3.94	2.94	1146	2019	3	2214	1	95
12	3.93	2.94	1238	2187	7	2190	2	85
13	3.94	2.93	1248	2214	2	2187	3	75
14	3.94	2.94	1192	2100	8	2172	4	65
15	3.94	2.94	1154	2033	4	2100	5	55
16	3.94	2.94	1097	1933	9	2100	5	45
17	3.94	2.94	1243	2190	10	2058	7	35
18	3.94	2.94	1233	2172	5	2033	8	25
19	3.94	2.94	1192	2100	1	2019	9	15
20	3.94	2.94	1168	2058	6	1933	10	5

R4c					Outer Span 10 mm Rate 90 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	3.94	2.93	2124	1884	10	2160	1	95
12	3.94	2.93	2373	2105	6	2143	2	85
13	3.94	2.93	2301	2041	2	2105	3	75
14	3.94	2.93	1977	1753	5	2054	4	65
15	3.94	2.94	2332	2054	9	2048	5	55
16	3.94	2.94	2433	2143	3	2041	6	45
17	3.94	2.93	2224	1973	8	1975	7	35
18	3.94	2.94	2242	1975	7	1973	8	25
19	3.94	2.93	2309	2048	1	1884	9	15
20	3.93	2.95	2463	2160	4	1753	10	5

KENNAMETAL WC/CC/Co(4) - FINE/MEDIUM
NPL BEND TESTS (RN3a, RN3b, RN4b)

RN3a				Span 13.8 mm Rate 200 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.33	5.02	1825	2007	4	2177	1	91.7
2	2.33	5.02	1614	1775	5	2100	2	75
3	2.33	5.02	1811	1991	1	2007	3	58.3
4	2.33	5.02	1980	2177	3	1991	4	41.7
5	2.33	5.02	1910	2100	2	1775	5	25
6	2.33	5.02	1599	1758	6	1758	6	8.3

RN3b				Span 30 mm Rate 80 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.87	5	595	1945	5	1982	1	91.7
2	1.86	5.01	584	1910	6	1965	2	75
3	1.86	5.01	560	1831	4	1955	3	58.3
4	1.86	4.99	592	1955	1	1945	4	41.7
5	1.86	4.99	600	1982	2	1910	5	25
6	1.86	5	598	1965	3	1831	6	8.3

RN4b				Outer Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.87	5	815	1719	5	1976	1	91.7
2	1.86	5	777	1647	4	1874	2	75
3	1.87	4.98	850	1811	3	1811	3	58.3
4	1.87	4.99	884	1874	6	1738	4	41.7
5	1.87	5	937	1976	1	1719	5	25
6	1.87	4.99	820	1738	2	1647	6	8.3

KENNAMETAL WC/CC/Co(4) - FINE/MEDIUM
UNITED HARDMETAL BEND TESTS (RN3a, RN3b, RN4b)

RN3a				Span 14.34 mm Rate 210 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
7	2.33	5.02	1919	2192	2	2233	1	91.7
8	2.33	5.01	1945	2233	1	2192	2	75
9	2.33	5.02	1727	1973	5	2013	3	58.3
10	2.32	5.02	1704	1955	6	2011	4	41.7
11	2.33	5.03	1771	2013	3	1973	5	25
12	2.33	5.02	1760	2011	4	1955	6	8.3

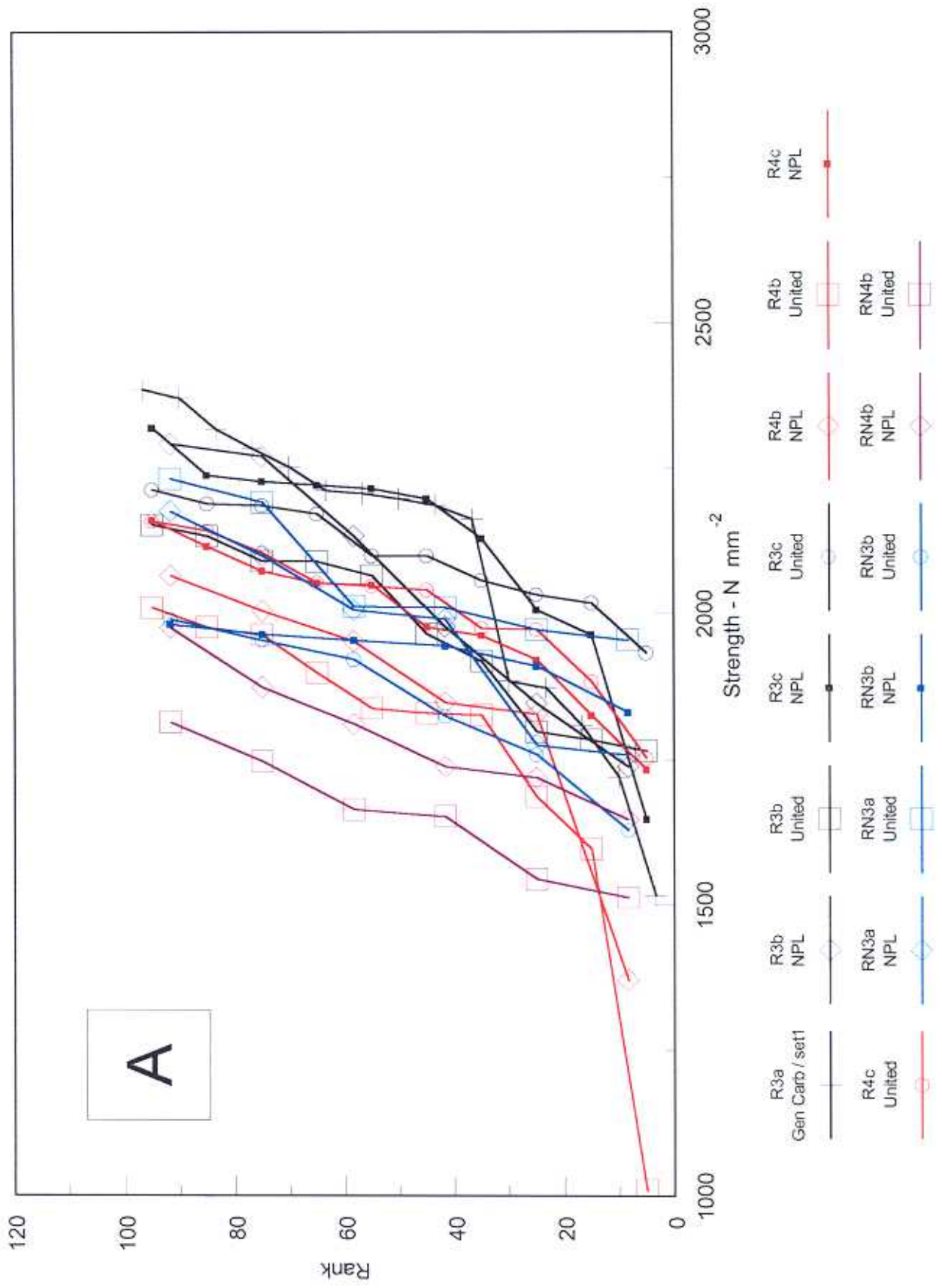
RN3b				Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
7	1.87	5	609	1991	1	1991	1	91.7
8	1.87	5.01	601	1955	2	1955	2	75
9	1.87	5	498	1628	6	1922	3	58.3
10	1.87	5.01	561	1825	4	1825	4	41.7
11	1.87	5	538	1759	5	1759	5	25
12	1.86	4.99	582	1922	3	1628	6	8.3

RN4b				Span 10 mm Rate 80 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
7	1.86	5.01	717	1513	2	1814	1	91.7
8	1.87	5	860	1814	3	1747	2	75
9	1.86	5.02	832	1747	5	1664	3	58.3
10	1.86	5.01	783	1652	4	1652	4	41.7
11	1.87	5.01	793	1664	6	1544	5	25
12	1.87	5.01	736	1544	1	1513	6	8.3

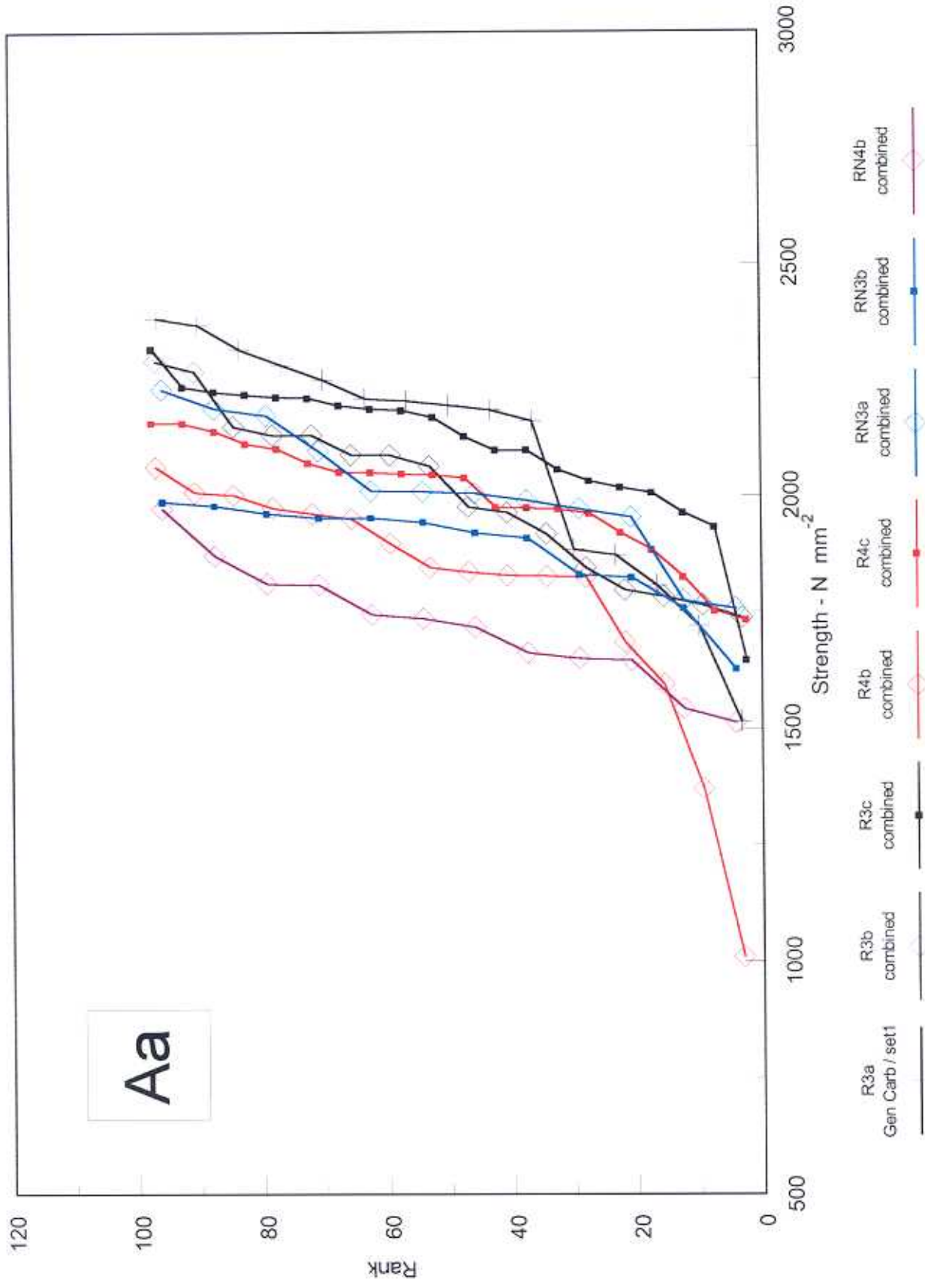
HARDMETAL BEND TESTS**Results Comment Sheet****Kennametal - Category (4) WC/CC/Co Hardmetal****PLOT SEQUENCE**

- A - Complete set of all strength values.
- Aa - Complete set, different laboratories combined.
- 1 - Standard tests, ISO type B (R3a).
- 2 - 3 pt rectangular tests; R3a, R3b, R3c.
- 2a - Combined R3a, R3b and R3c.
- 3 - 4 pt rectangular tests, compared with standard ISO type B; R3a, R4b, R4c.
- 3a - Combined R3a, R4b and R4c.
- 4 - Individual 3 pt vs 4 pt tests; R3b, R3c, R4b, R4c; not including R3a.
- 4a - Combined R3b, R3c, R4b and R4c.
- 8 - Notched rectangular testpieces, RN3a, RN3b and RN4b.
- 8a - Combined notched testpieces; RN3a, RN3b and RN4b.

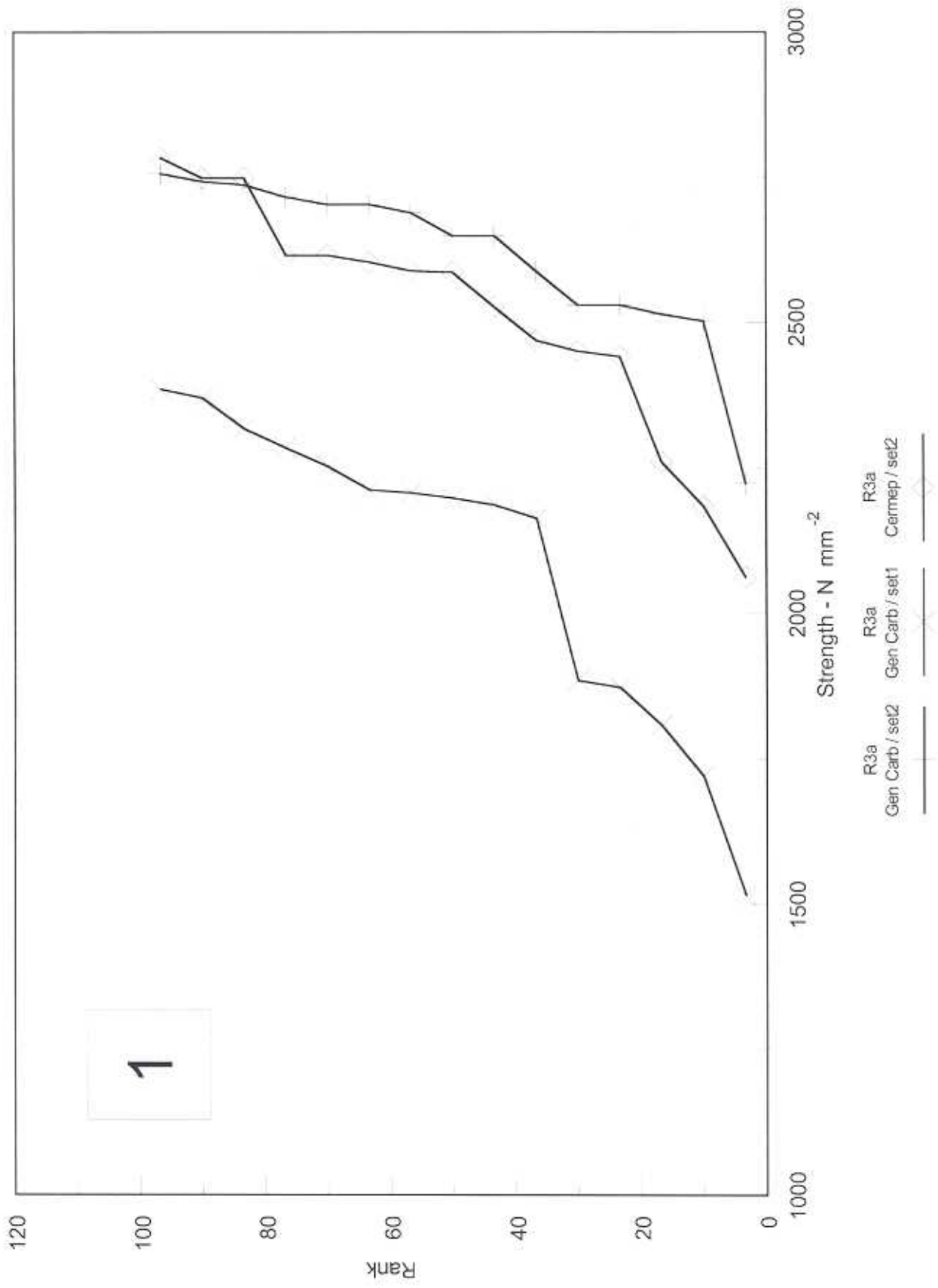
Bend Tests - Kennametal WC/CC/Co (4)



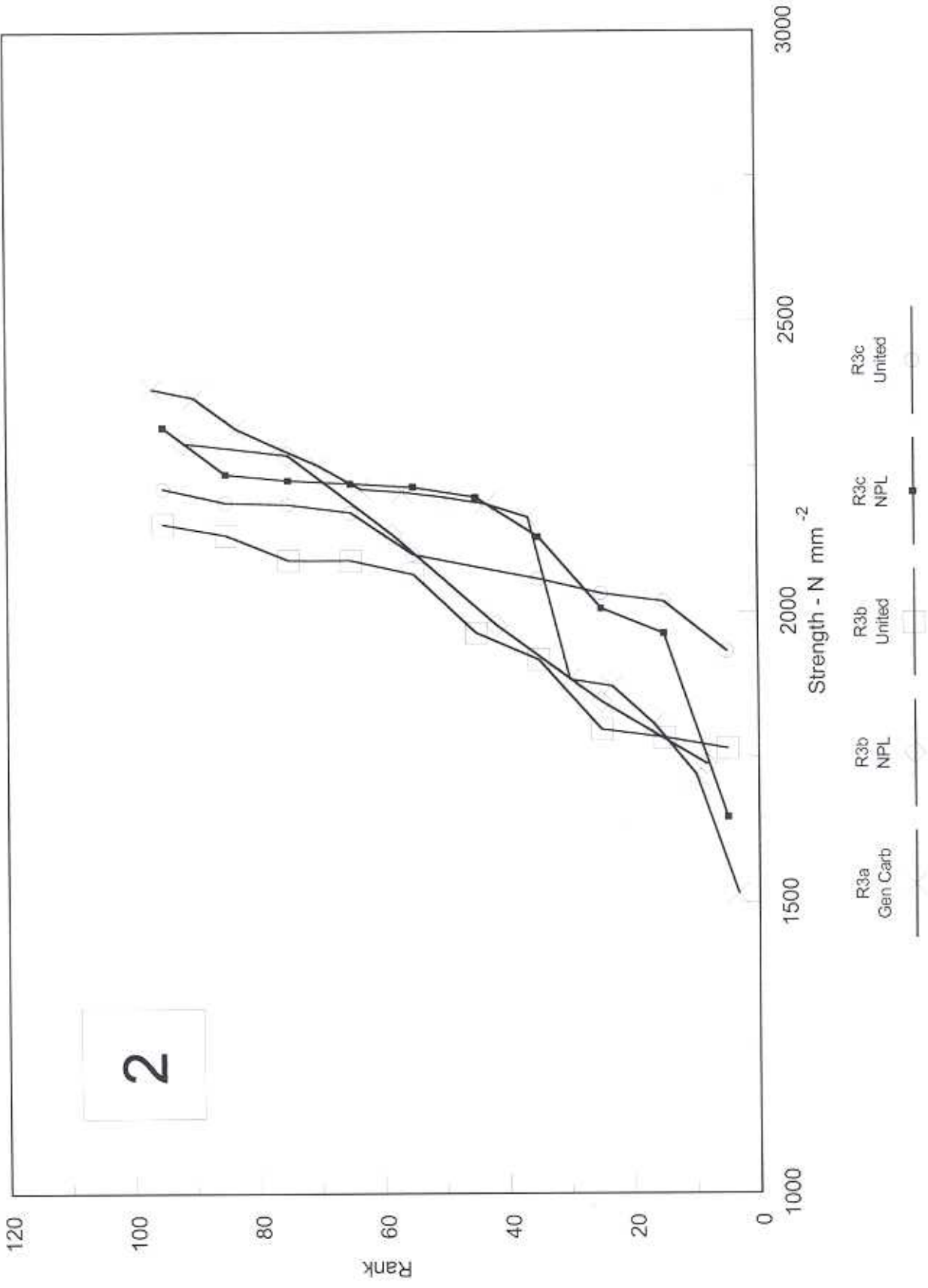
Bend Tests - Kennametal WC/CC/Co (4)



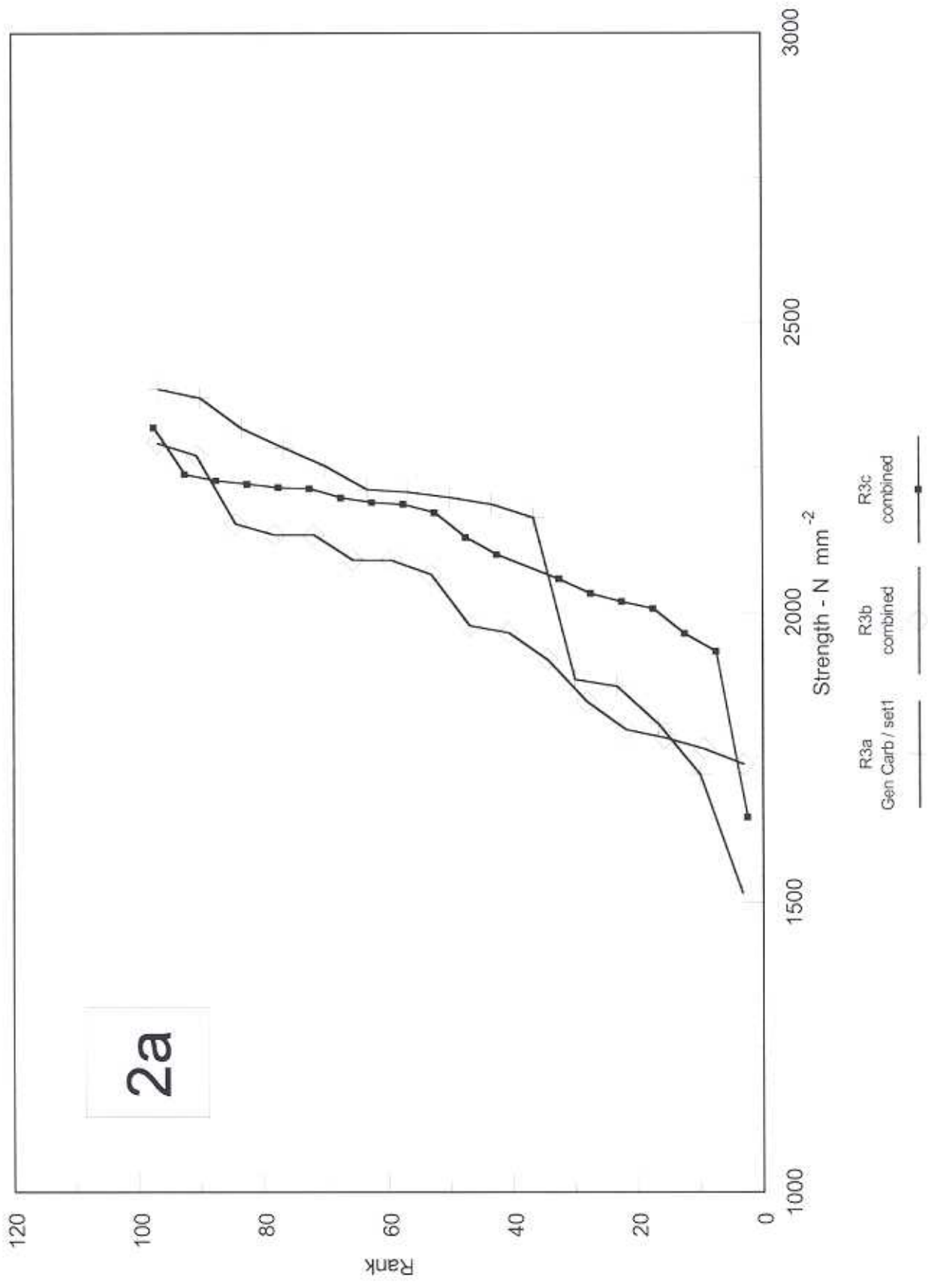
Bend Tests - Kennametal WC/CC/Co (4)



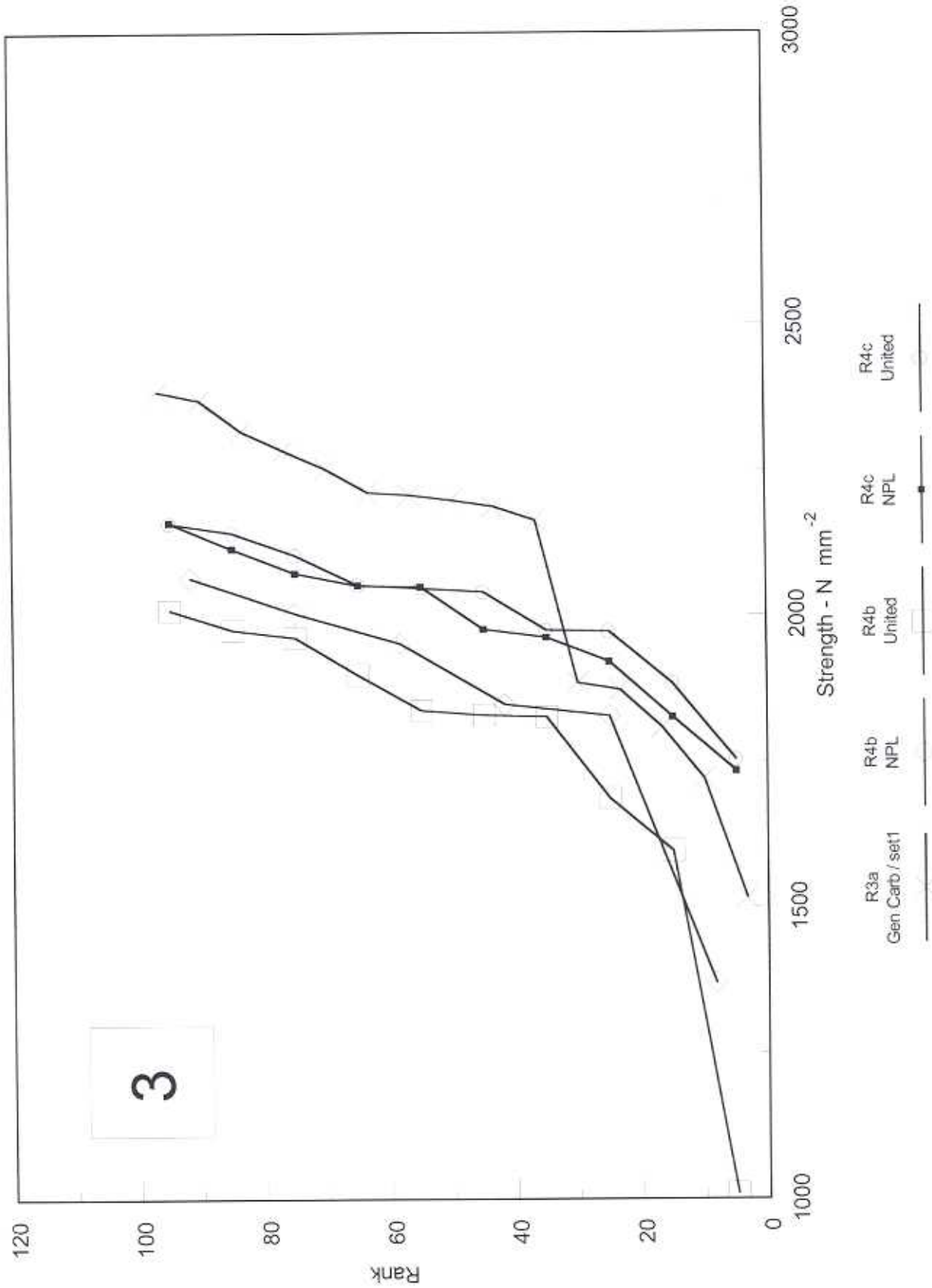
Bend Tests - Kennametal WC/CC/Co (4)



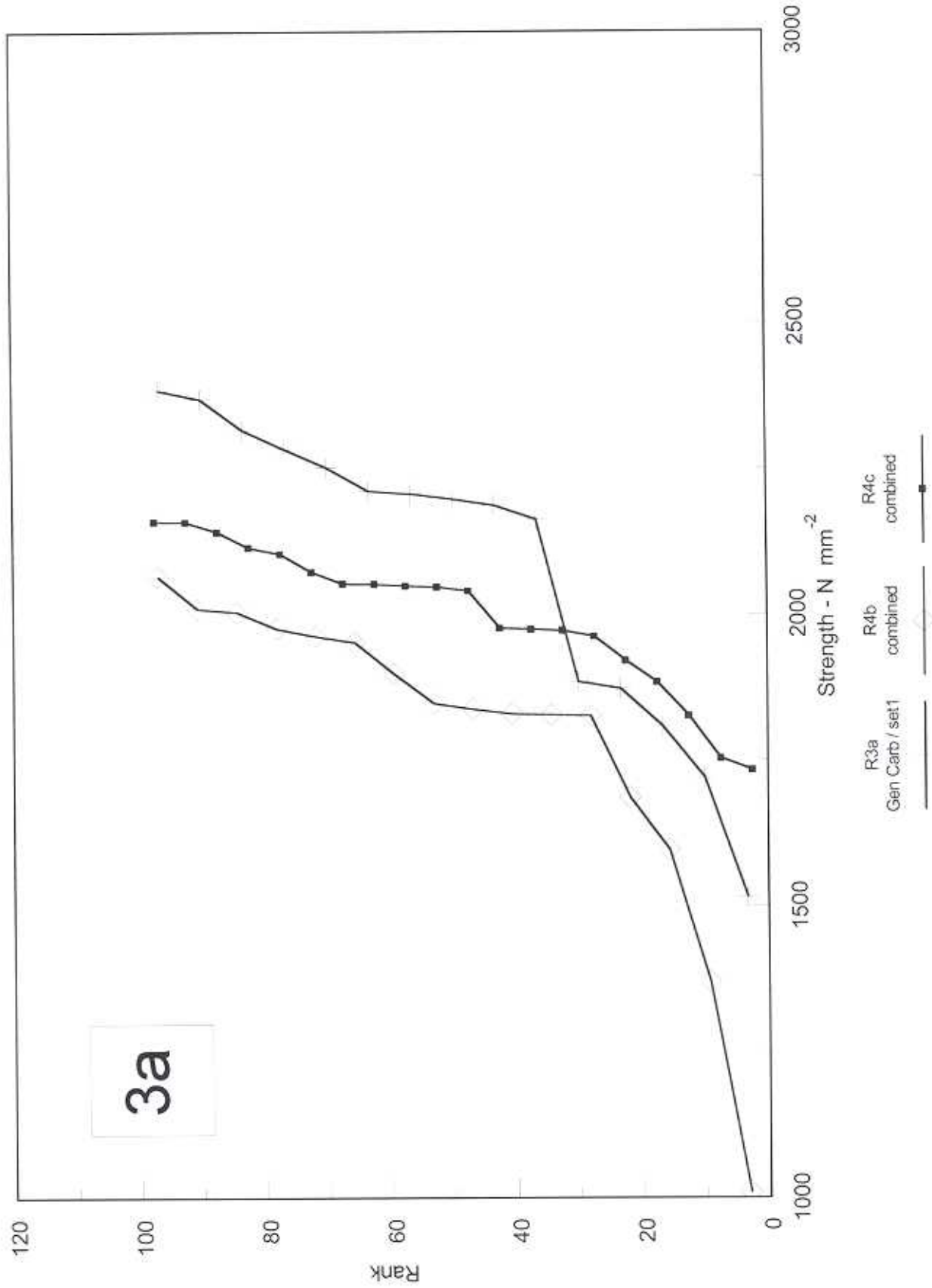
Bend Tests - Kennametal WC/CC/Co (4)



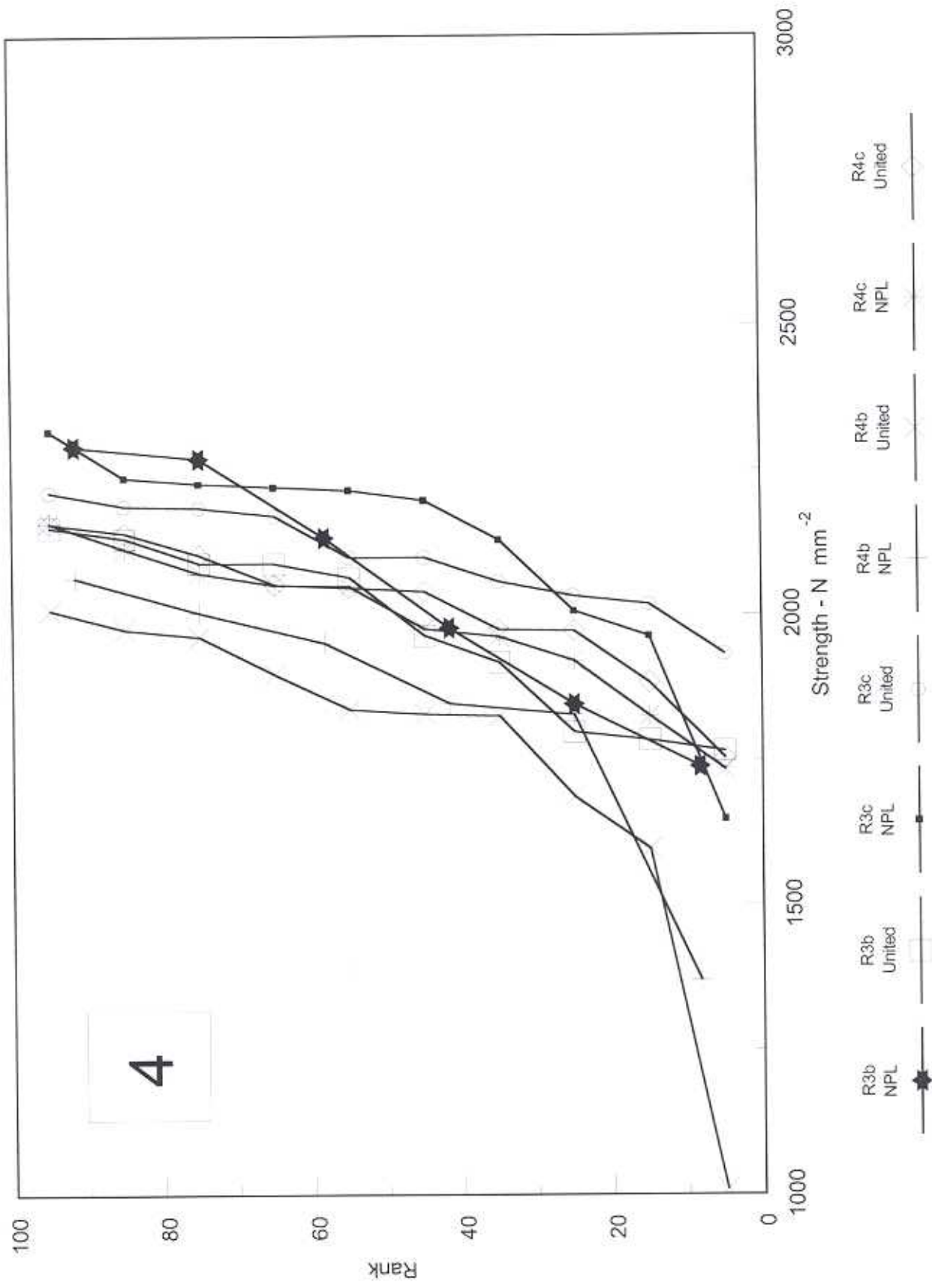
Bend Tests - Kennametal WC/CC/Co (4)



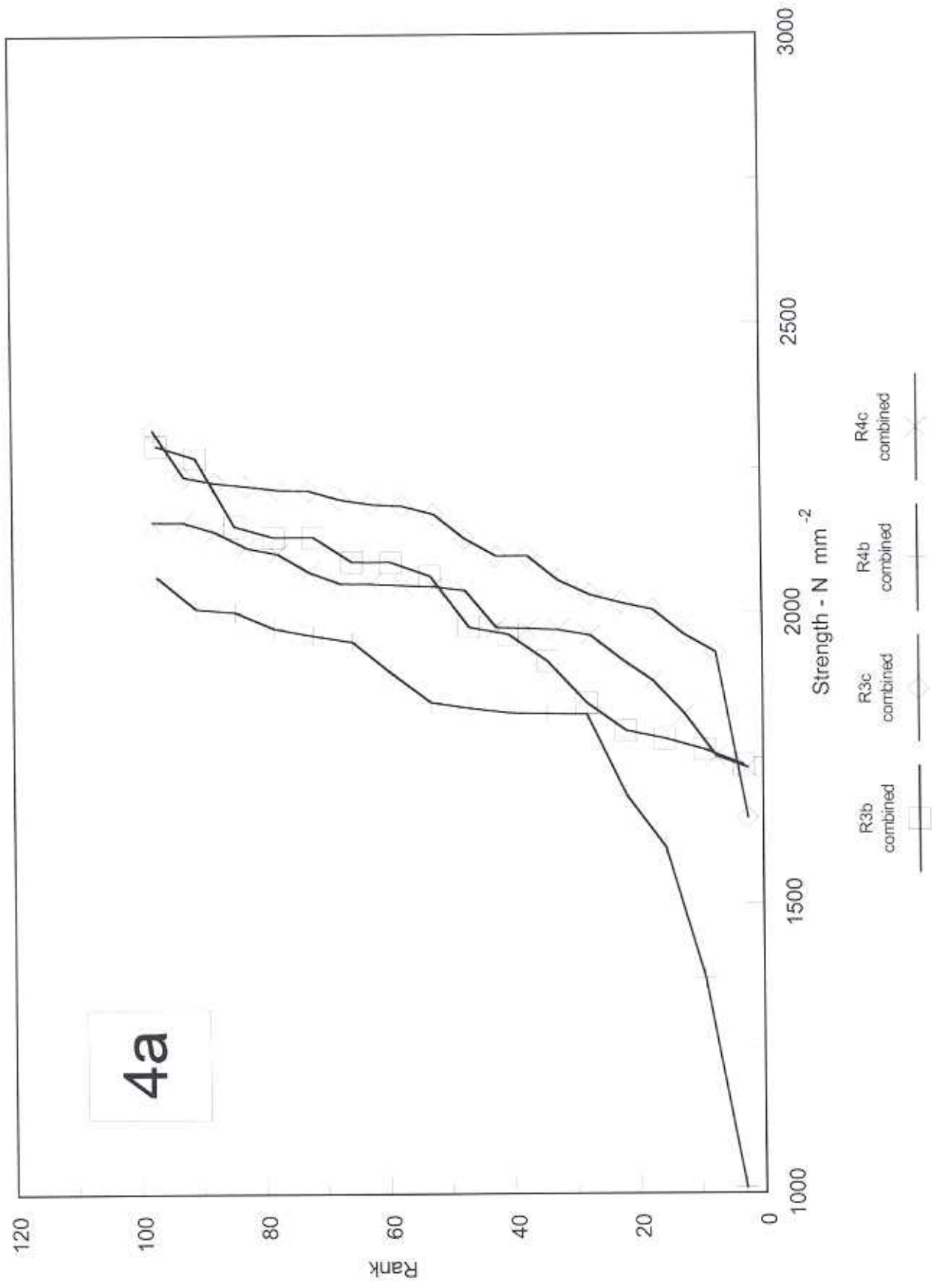
Bend Tests - Kennametal WC/CC/Co (4)



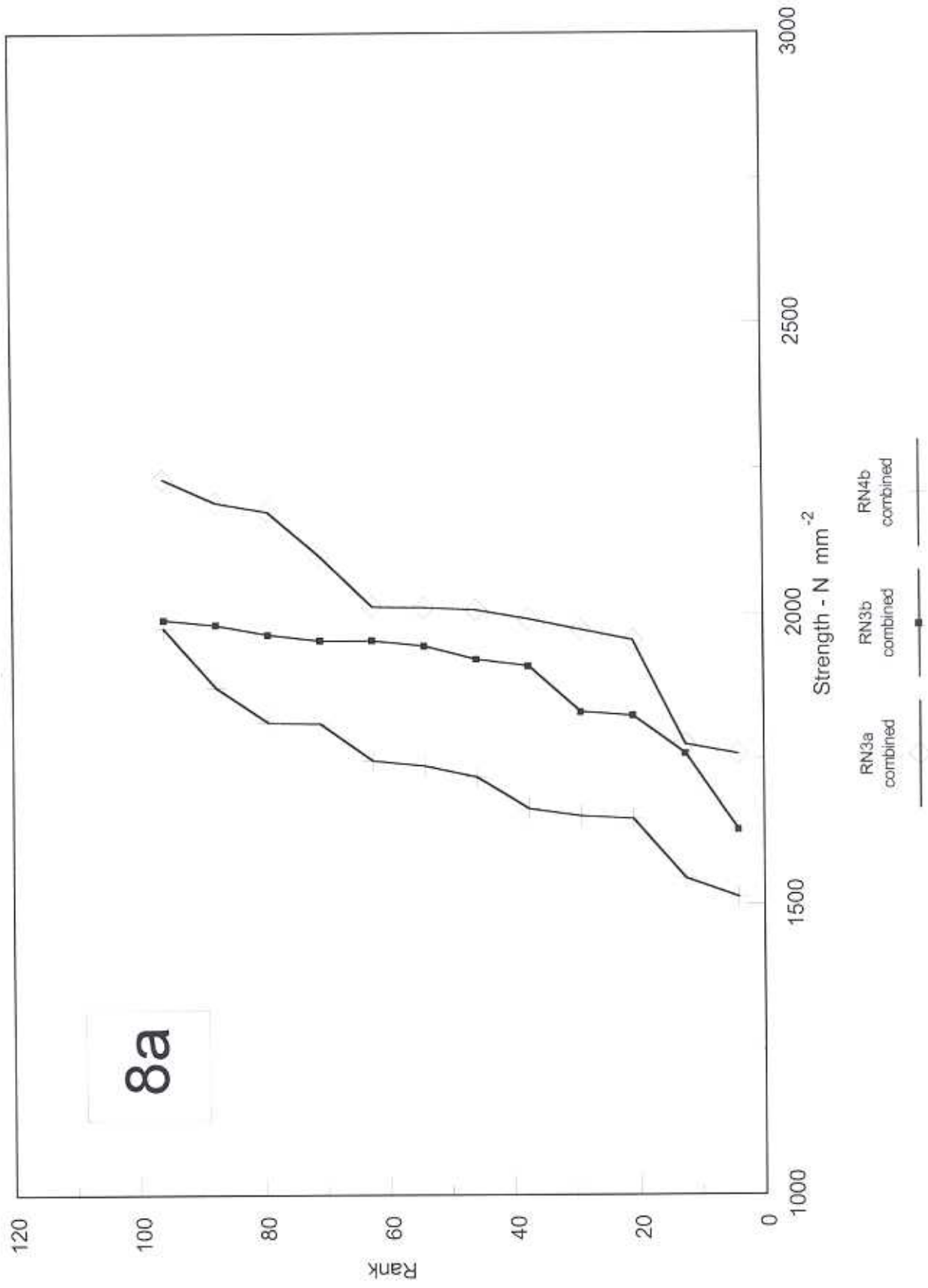
Bend Tests - Kennametal WC/CC/Co (4)



Bend Tests - Kennametal WC/CC/Co (4)



Bend Tests - Kennametal WC/CC/Co (4)



RESULTS SET

(5) SANDVIK COROMANT

Ti(C,N) Cermet

Data Tables

Supplementary Comments

Data Plots

HARDMETAL BEND TESTS INTERNATIONAL INTERCOMPARISON

TABLES OF RESULTS

SET 5

Ti(C,N) Cermet - Source: Sandvik Coromant

<i>Geometry</i>		<i>Organisation</i>
3 pt TRS	R3a	Standard Tests (Kennametal/CERMeP)
3,4 pt Rectangular	R3, R4	NPL
3,4 pt Rectangular	R3, R4	Sandvik
3,4 pt Rectangular	R3, R4	BAM
3,4 pt Rectangular Notched	RN3, RN4	NPL
3,4 pt Rectangular Notched	RN3, RN4	Sandvik
3,4 pt Rectangular Notched	RN3	BAM
Round	C3, C4, CN4	NPL
Round	C4, CN4	Sandvik
Round	C3, CN4	BAM

**SANDVIK Ti(C,N) CERMET(5) - FINE
STANDARD TRS TESTS - R3a**

Kennametal					Span 14.3 mm Rate 2670 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.01	5.01	11654	1655	3	1896	1	96.7
2	6.01	5.01	13167	1874	2	1874	2	90
3	6.01	5.01	13345	1896	7	1795	3	83.3
4	6.01	5.01	11743	1673	6	1773	4	76.7
5	6.01	5.01	11210	1598	12	1738	5	70
6	6.01	5.01	12455	1773	9	1706	6	63.3
7	6.01	5.01	12633	1795	4	1673	7	56.7
8	6.01	5.01	10498	1494	1	1655	8	50
9	6.01	5.01	12010	1706	5	1598	9	43.3
10	6.01	5.02	9430	1337	15	1518	10	36.7
11	6.01	5.00	7117	1015	14	1506	11	30
12	6.01	5.00	12188	1738	8	1494	12	23.3
13	6.01	5.01	9341	1330	10	1337	13	16.7
14	6.01	5.01	10587	1506	13	1330	14	10
15	6.01	5.01	10876	1518	11	1015	15	3.3

CERMeP					Span 15 mm Rate 5 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
16	6	5.02	11444	1646	7	2183	1	96.7
17	6.01	5.01	11405	1644	6	2084	2	90
18	6.01	5.01	13000	1874	3	1874	3	83.3
19	6	5	6216	901	14	1853	4	76.7
20	6.01	5.01	10678	1540	11	1833	5	70
21	6	5	14373	2084	8	1822	6	63.3
22	6.01	5.01	15140	2183	9	1798	7	56.7
23	6	5.01	12618	1822	10	1735	8	50
24	6.01	5	12424	1798	15	1712	9	43.3
25	6.02	5.01	12055	1735	1	1646	10	36.7
26	6.01	5.01	12715	1833	2	1644	11	30
27	6.02	5.02	10503	1506	13	1566	12	23.3
28	6.01	5.01	10862	1566	5	1540	13	16.7
29	6	5.01	12831	1853	12	1506	14	10
30	6.01	5.01	11871	1712	4	901	15	3.3

**SANDVIK Ti(C,N) CERMET(5) - FINE
NPL BEND TESTS (R3b, R3c, R4b, R4c)**

R3b					Span 30 mm Rate 250 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	5.01	5	3091	1111	2	1495	1	90
2	5.01	5	4161	1495	3	1413	2	70
3	5.01	5	3933	1413	5	1186	3	50
4	5.01	5	2604	936	1	1111	4	30
5	5.01	5	3300	1186	4	936	5	10
6*	4.99	4.99	3300	1195	2*	1578	1	90
7*	4.99	4.99	4358	1578	4*	1461	2	70
8*	4.99	5	2478	894	1*	1195	3	50
9*	5	5	4059	1461	5*	1173	4	30
10*	5.01	5	3265	1173	3*	894	5	10

*Annealed

R3c					Span 40 mm Rate 40 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.01	3	702	1167	5	1706	1	94.4
2	4.01	3.01	985	1627	8	1650	2	83.3
3	4	3	935	1558	2	1627	3	72.2
4	4	3.01	440	728	6	1581	4	61.1
5	4.01	3.01	1033	1706	3	1558	5	50
6	4.01	3	951	1581	9	1191	6	38.9
7	4.01	3.02	509	835	1	1167	7	27.8
8	4.01	3.01	999	1650	7	835	8	16.7
9	4.01	3.01	721	1191	4	728	9	5.6
10								

R4b					Outer Span 10 mm Rate 150 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.99	5.01	3350	802	5	1359	1	94.4
2	4.99	4.99	5316	1284	2	1284	2	83.3
3	5.01	5.01	5314	1268	3	1268	3	72.2
4	5.01	4.95	4041	988	6	1250	4	61.1
5	5.01	4.98	5630	1359	8	1179	5	50
6	5.01	5.01	5241	1250	7	1150	6	38.9
7	5.01	5	4802	1150	4	988	7	27.8
8	5	5	4911	1179	9	984	8	16.7
9	5	5.01	4115	984	1	802	9	5.6
10								

R4c (NB 15 mm outer span)					Outer Span 15 mm Rate 25 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.01	3.01	936	1159	8	1570	1	94.4
2	4	3.01	582	723	9	1194	2	83.3
3	4	3.01	578	718	1	1159	3	72.2
4	4	3	843	1054	5	1071	4	61.1
5	4	3	857	1071	4	1054	5	50
6	4	3.02	693	855	6	855	6	38.9
7	4.01	3.01	276	342	2	723	7	27.8
8	4	2.76	1063	1570	3	718	8	16.7
9	4	3	955	1194	7	342	9	5.6
10								

SANDVIK Ti(C,N) CERMET(5) - FINE
SANDVIK BEND TESTS (R3b, R4b)

R3b					Span 30 mm Rate 200 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	5	5	2128	766	4	1495	1	95
12	5	5	3824	1377	9	1454	2	85
13	5	5.01	3597	1290	10	1405	3	75
14	5.01	5.01	4179	1495	2	1377	4	65
15	5.01	5.01	2874	1028	8	1359	5	55
16	5	5	3251	1170	3	1290	6	45
17	5	5	3393	1221	7	1221	7	35
18	5.01	5.01	3797	1359	6	1170	8	25
19	5	5.01	4056	1454	5	1028	9	15
20	5	5	3904	1405	1	766	10	5

R4b					Outer Span 10 mm Rate 200 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	5.01	5.01	2032	485	7	1361	1	95
12	5.01	5	2963	710	6	1281	2	85
13	5	5.01	4235	1012	8	1236	3	75
14	5	4.99	2998	722	3	1012	4	65
15	5	5	3267	784	10	876	5	55
16	5	5	5339	1281	5	784	6	45
17	5	4.98	5624	1361	4	722	7	35
18	5	5	5149	1236	2	710	8	25
19	5	5.01	1235	295	1	485	9	15
20	5	5	3648	876	9	295	10	5

**SANDVIK Ti(C,N) CERMET(5) - FINE
BAM BEND TESTS (R3c, R4c)**

R3c					Span 30 mm Rate 21 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4.01	3	968	1609	1	1609	1	95
12	4.01	3	954	1586	2	1586	2	85
13	4	3.01	562	930	4	1551	3	75
14	4	3.01	937	1551	9	1478	4	65
15	4	3.02	573	942	6	1366	5	55
16	4.01	3.01	827	1366	10	1287	6	45
17	4.01	3.01	743	1227	8	1245	7	35
18	4	3.01	752	1245	7	1227	8	25
19	4.01	3	889	1478	5	942	9	15
20	4	3	772	1287	3	930	10	5

R4c					Outer Span 10 mm Rate 39 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4	3.01	1155	956	9	1443	1	95
12	4.01	3	586	487	5	1317	2	85
13	4.01	3	1517	1261	3	1261	3	75
14	4	3.01	703	582	8	1067	4	65
15	4.01	3.01	1595	1317	1	956	5	55
16	4	3.01	793	656	10	793	6	45
17	4.01	3.01	877	724	7	724	7	35
18	4.01	3.01	1292	1067	6	656	8	25
19	4.01	3.02	1759	1443	4	582	9	15
20	4	3.01	958	793	2	487	10	5

**SANDVIK Ti(C,N) CERMET(5) - FINE
NPL BEND TESTS (RN3a, RN3b, RN4b)**

RN3a				Span 13.8 mm Rate 200 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2	5	1544	1998	3	2089	1	91.7
2	2	5	1505	1947	4	2017	2	75
3	2	5	1615	2089	1	1998	3	58.3
4	2	5	1559	2017	2	1947	4	41.7
5	2	5	1504	1946	5	1946	5	25
6	2	5	1350	1747	6	1747	6	8.3

RN3b				Span 30 mm Rate 60 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.01	5.01	484	1465	5	1690	1	91.7
2	2.01	5.01	535	1619	3	1684	2	75
3	2	5	551	1684	2	1619	3	58.3
4	2	5	505	1543	6	1571	4	41.7
5	2	5	553	1690	4	1543	5	25
6	2	5	514	1571	1	1465	6	8.3

RN4b				Outer Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.01	5.01	724	1413	4	1611	1	91.7
2	1.99	5.01	731	1441	6	1503	2	75
3	2.01	5.01	727	1419	2	1441	3	58.3
4	2.01	4.99	817	1611	3	1419	4	41.7
5	2.01	5	685	1344	1	1413	5	25
6	2	5	762	1503	5	1344	6	8.3

**SANDVIK Ti(C,N) CERMET(5) - FINE
SANDVIK BEND TESTS (RN3a, RN4b)**

RN3a				Span 15 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
7	1.99	5	1285	1816	4	2175	1	91.7
8	2	5	1199	1686	6	1990	2	75
9	1.99	5	1291	1825	5	1879	3	58.3
10	2	5	1547	2175	3	1825	4	41.7
11	2.01	5	1343	1879	1	1816	5	25
12	2	5	1415	1990	2	1686	6	8.3

RN4b				Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
7	1.99	5	812	1609	5	1621	1	91.7
8	2.01	5.01	709	1384	6	1615	2	75
9	2	4.98	716	1426	1	1609	3	58.3
10	1.99	5.01	776	1530	4	1530	4	41.7
11	2	5.01	826	1621	3	1426	5	25
12	2.01	4.99	819	1615	2	1384	6	8.3

**SANDVIK Ti(C,N) CERMET(5) - FINE
BAM BEND TESTS (RN3b)**

RN3b					Span 30 mm Rate 60 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
7	2	5	526	1608	5	1688	1	91.7
8	2	5.02	518	1567	4	1634	2	75
9	2.01	4.99	498	1522	1	1608	3	58.3
10	2.01	5.01	540	1634	2	1567	4	41.7
11	2	5.01	555	1688	3	1522	5	25
12	2.01	5	482	1466	6	1466	6	8.3

**SANDVIK Ti(C,N) CERMET(5) - FINE
NPL BEND TESTS (C3, C4, CN4)**

C3							
Span 30 mm Rate 200 N s ⁻¹							
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	5	2860	1748	1	1748	1	90
2	5	2621	1602	3	1689	2	70
3	5	2763	1689	5	1657	3	50
4	5	2372	1450	2	1602	4	30
5	5	2712	1657	4	1450	5	10
7*	5	2217	1355	2*	1650	1	87.5
8*	5	2699	1650	4*	1559	2	62.5
9*	5	2405	1470	3*	1470	3	37.5
10*	5	2551	1559	1*	1355	4	12.5

*Annealed

C4							
Outer Span 10 mm Rate 150 N s ⁻¹							
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	5	3326	1355	4	1520	1	90
2	5	2502	1019	1	1355	2	70
3	5	3197	1303	3	1303	3	50
4	5	3731	1520	5	1074	4	30
5	5	2635	1074	2	1019	5	10

CN4							
Outer Span 10 mm Rate 125 N s ⁻¹							
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	5.01	1341	1930	4	1932	1	87.5
2	5.01	1166	1678	1	1930	2	62.5
3	5.01	1331	1916	3	1916	3	37.5
4	5	1334	1932	2	1678	4	12.5

**SANDVIK Ti(C,N) CERMET(5) - FINE
SANDVIK BEND TESTS (C4, CN4)**

C4				Outer Span 10 mm Rate 200 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
11	5	3749	1527	2	1695	1	95
12	5	4160	1695	1	1527	2	85
13	5	3499	1426	6	1511	3	75
14	5	2950	1202	8	1504	4	65
15	5	3474	1415	10	1473	5	55
16	5	3709	1511	3	1426	6	45
17	5	2150	876	5	1415	7	35
18	5	3691	1504	9	1361	8	25
19	5	3341	1361	4	1202	9	15
20	5	3615	1473	7	876	10	5

CN4				Outer Span 10 mm Rate 100 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
9	5.01	1350	1943	3	1959	1	87.5
10	5	1352	1958	2	1958	2	62.5
11	5.01	1361	1959	1	1943	3	37.5
12	5.01	1340	1929	4	1929	4	12.5

**SANDVIK Ti(C,N) CERMET(5) - FINE
BAM BEND TESTS - (C3, CN4)**

C3				Span 30 mm Rate 98 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
11	5	2232	1364	6	1693	1	95
12	5	1061	648	7	1587	2	85
13	5	2390	1461	4	1569	3	75
14	5	2568	1569	3	1461	4	65
15	5	2314	1414	5	1414	5	55
16	5	2770	1693	9	1371	6	45
17	5	2597	1587	1	1364	7	35
18	5	1827	1117	10	1164	8	25
19	5	2244	1371	8	1117	9	15
20	5	1905	1164	2	648	10	5

CN4				Outer Span 10 mm Rate 104 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
9	5.01	1328	1911	4	1963	1	87.5
10	5.01	1232	1773	1	1911	2	62.5
11	5	1249	1809	3	1809	3	37.5
12	5.01	1364	1963	2	1773	4	12.5

HARDMETAL BEND TESTS

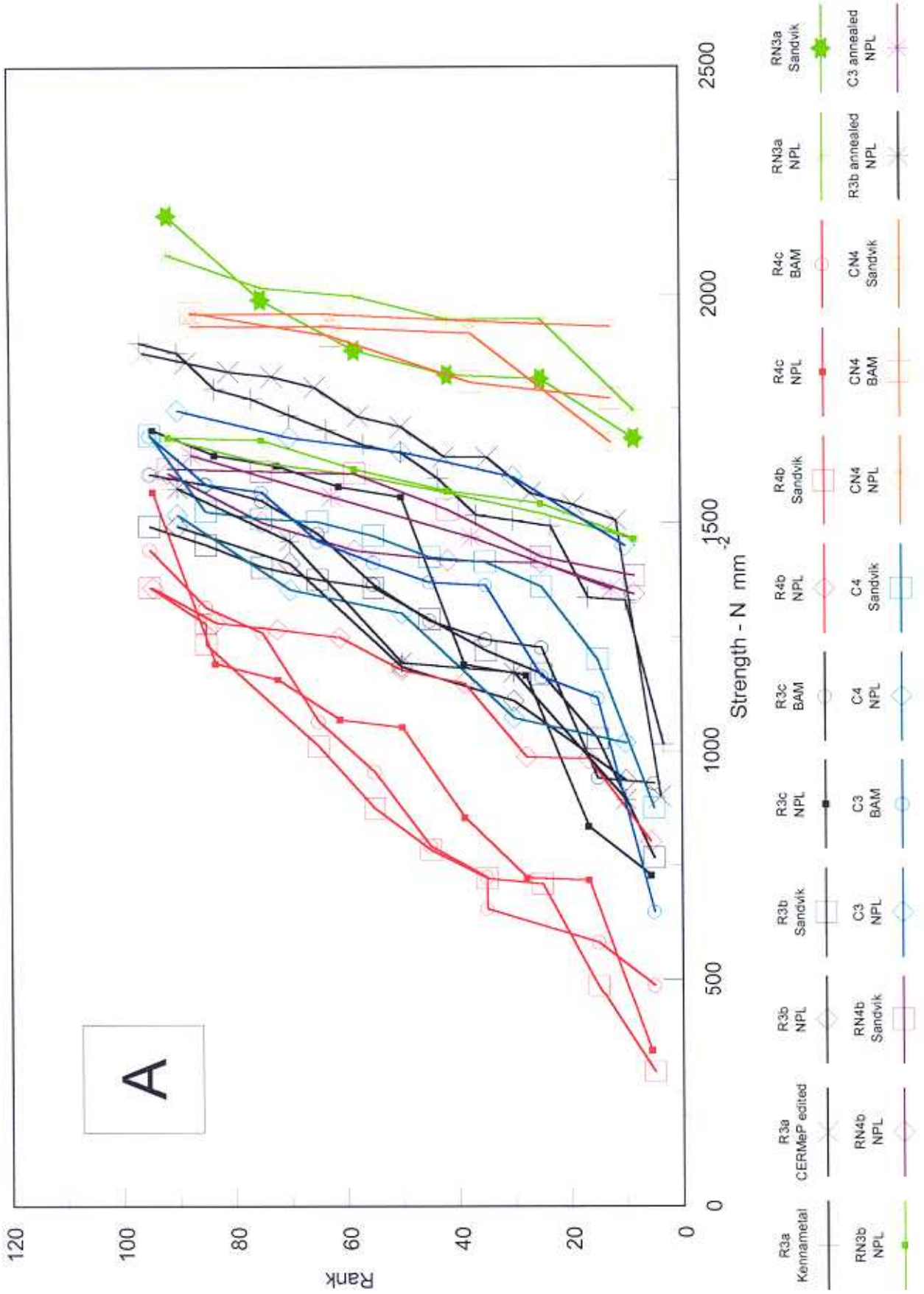
Results Comment Sheet

Sandvik Coromant - Category (5) Ti(C,N) Cermet

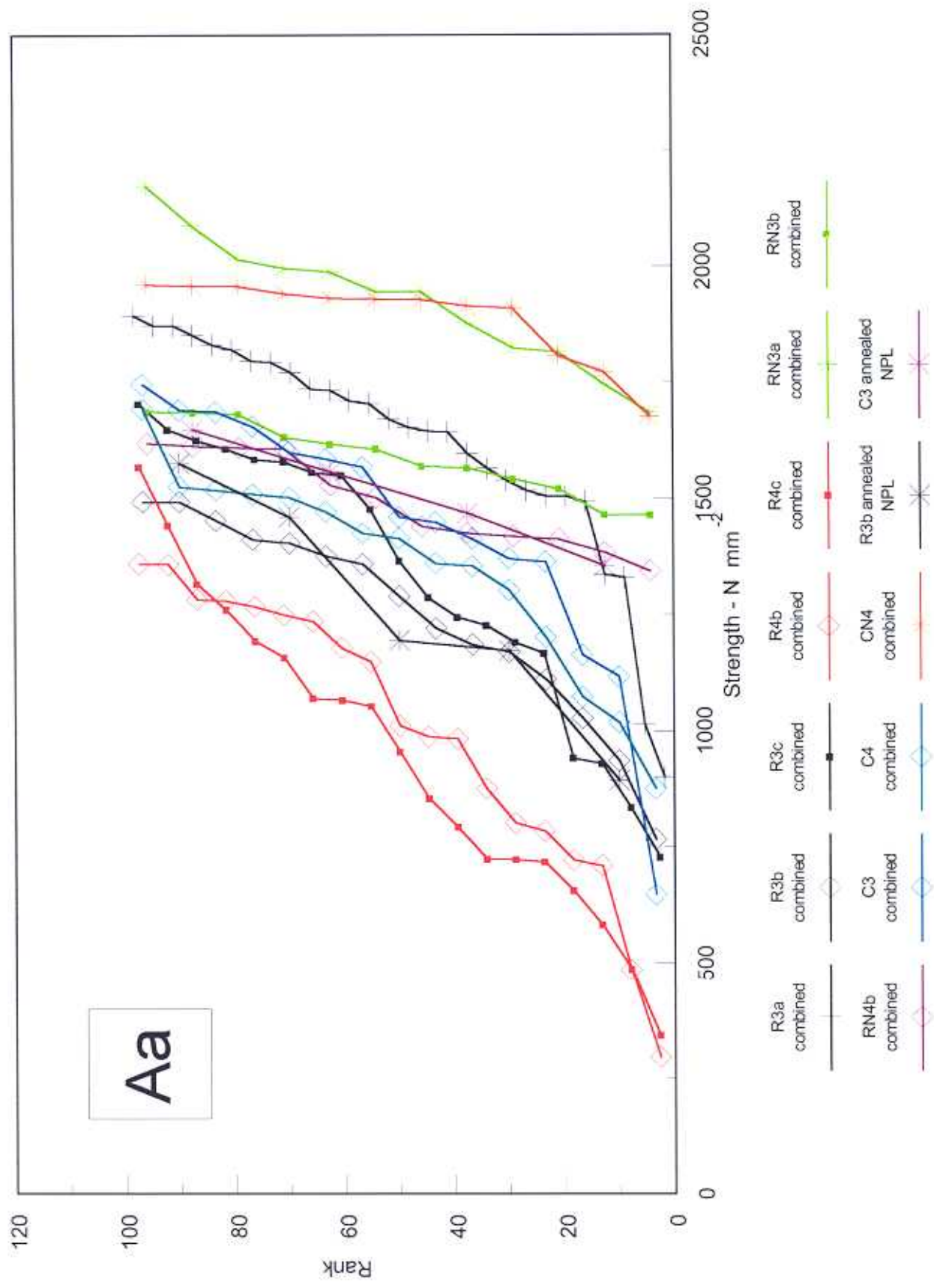
PLOT SEQUENCE

- A - Complete set of all strength values.
- Aa - Complete set, different laboratories combined.
- 1 - Standard tests, ISO type B (R3a).
- 1a - Combined R3a.
- 2 - 3 pt rectangular tests; R3a, R3b, R3c.
- 2a - Combined R3a, R3b and R3c.
- 3 - 4 pt rectangular tests, compared with standard ISO type B; R3a, R4b, R4c.
- 3a - Combined R3a, R4b and R4c.
- 4 - 3 pt vs 4 pt tests; R3b, R3c, R4b, R4c; not including R3a.
- 4a - Combined 3 pt vs 4 pt tests; R3b, R3c, R4b and R4c.
- 5 - Round testpieces, compared with standard R3a; (C3, C4 and R3a).
- 5a - Combined C3, C4 and R3a.
- 6 - 3 pt rectangular and round; R3b, R3c and C3; not including R3a.
- 6a - Combined C3 compared with R3b and R3c combined.
- 7 - 4 pt rectangular and round, R4b, R4c and C4.
- 7a - Combined C4 compared with R4b and R4c.
- 8 - Notched rectangular testpieces; RN3a, RN3b and RN4b.
- 8a - Combined notched testpieces; RN3a, RN3b and RN4b.
- 9 - Notched round compared with combined notched rectangular; CN4 and RN3a, RB3b and RN4b.
- 9a - Combined notched round compared with combined notched rectangular; CN4 and RN3a, RN3b and RN4b.
- 10 - Annealed NPL R3b, C3 and C4 testpieces compared with as-ground testpieces.

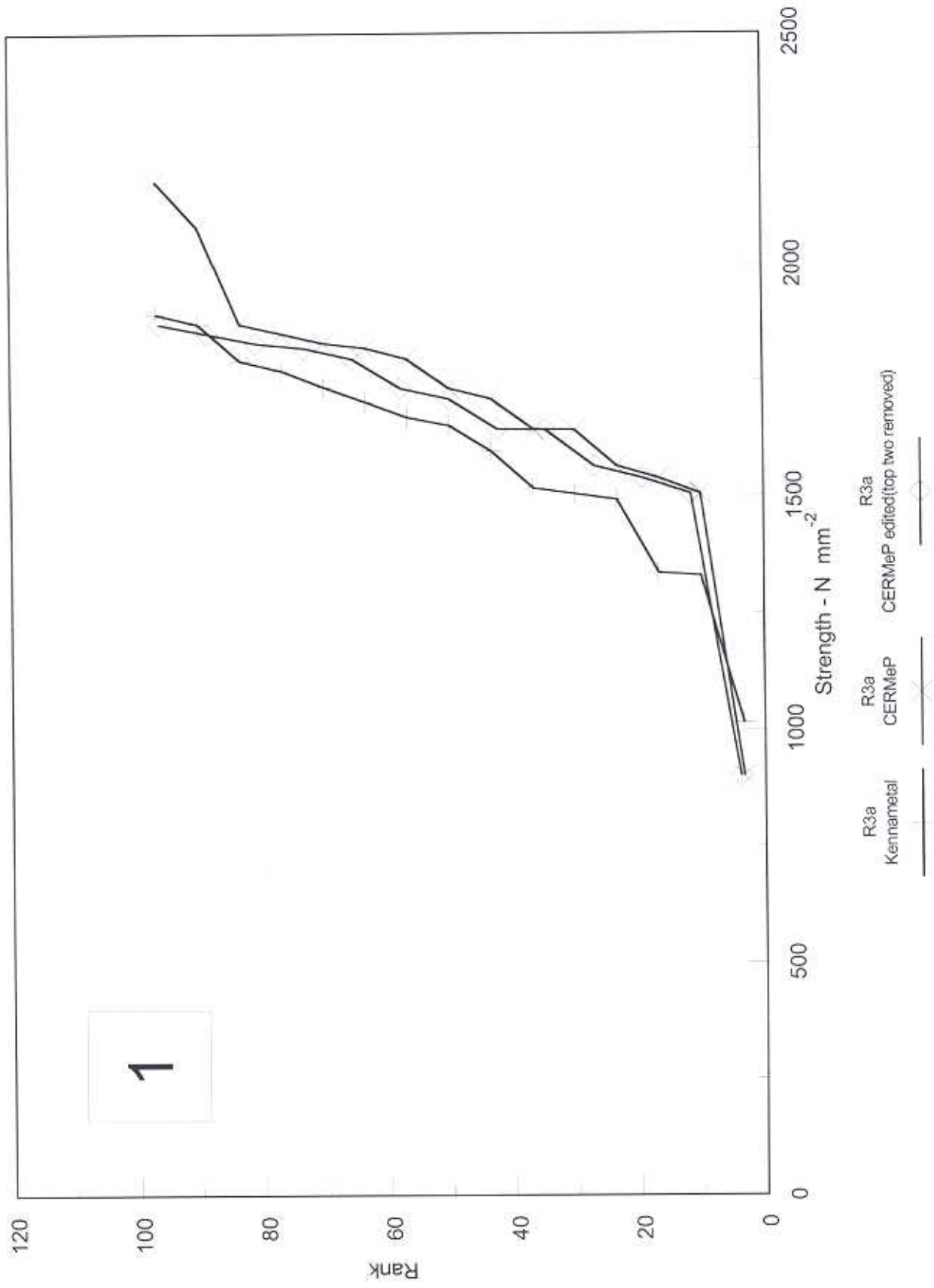
Bend Tests - Sandvik Cermet (4)



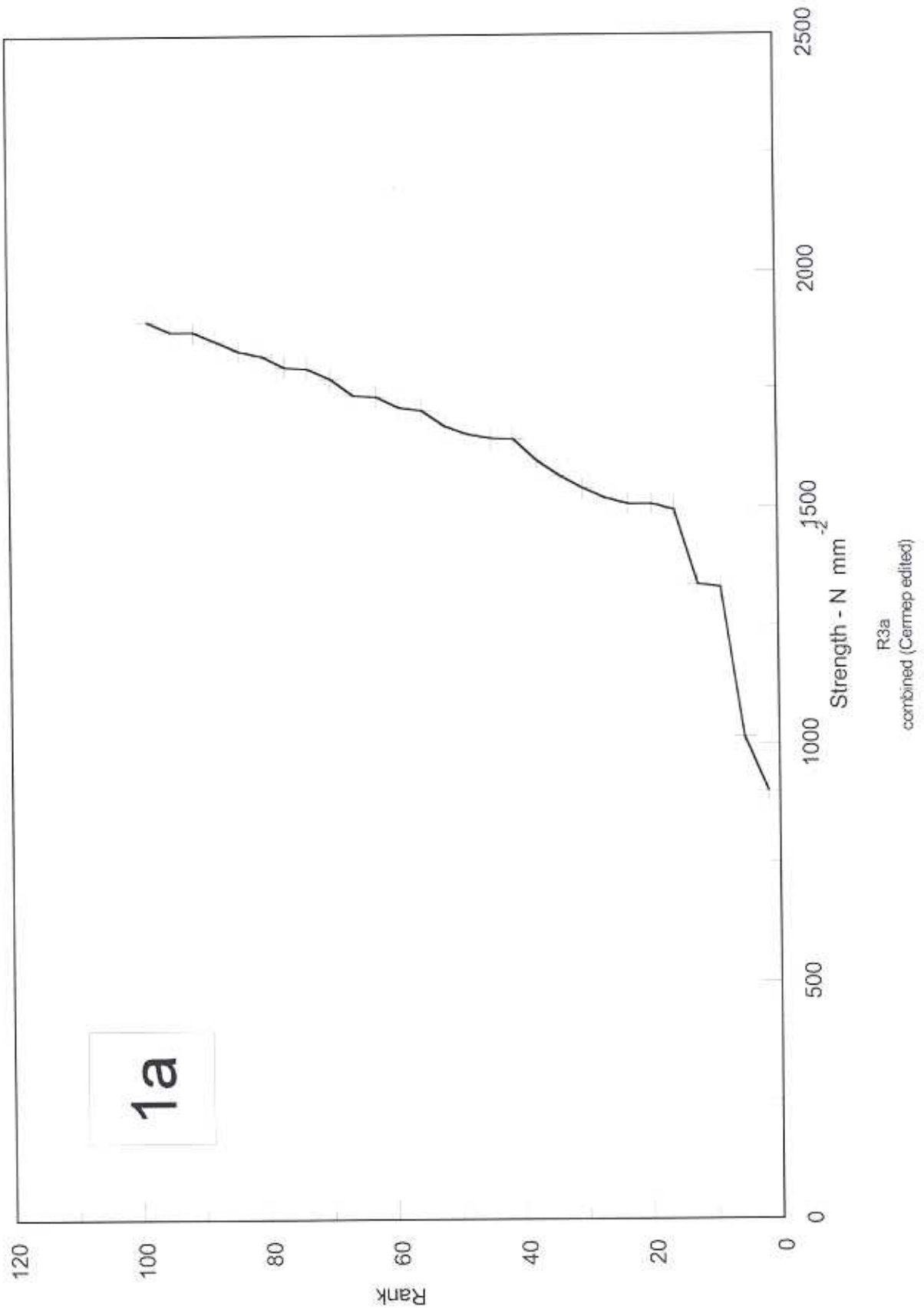
Bend Tests - Sandvik Cermet (4)



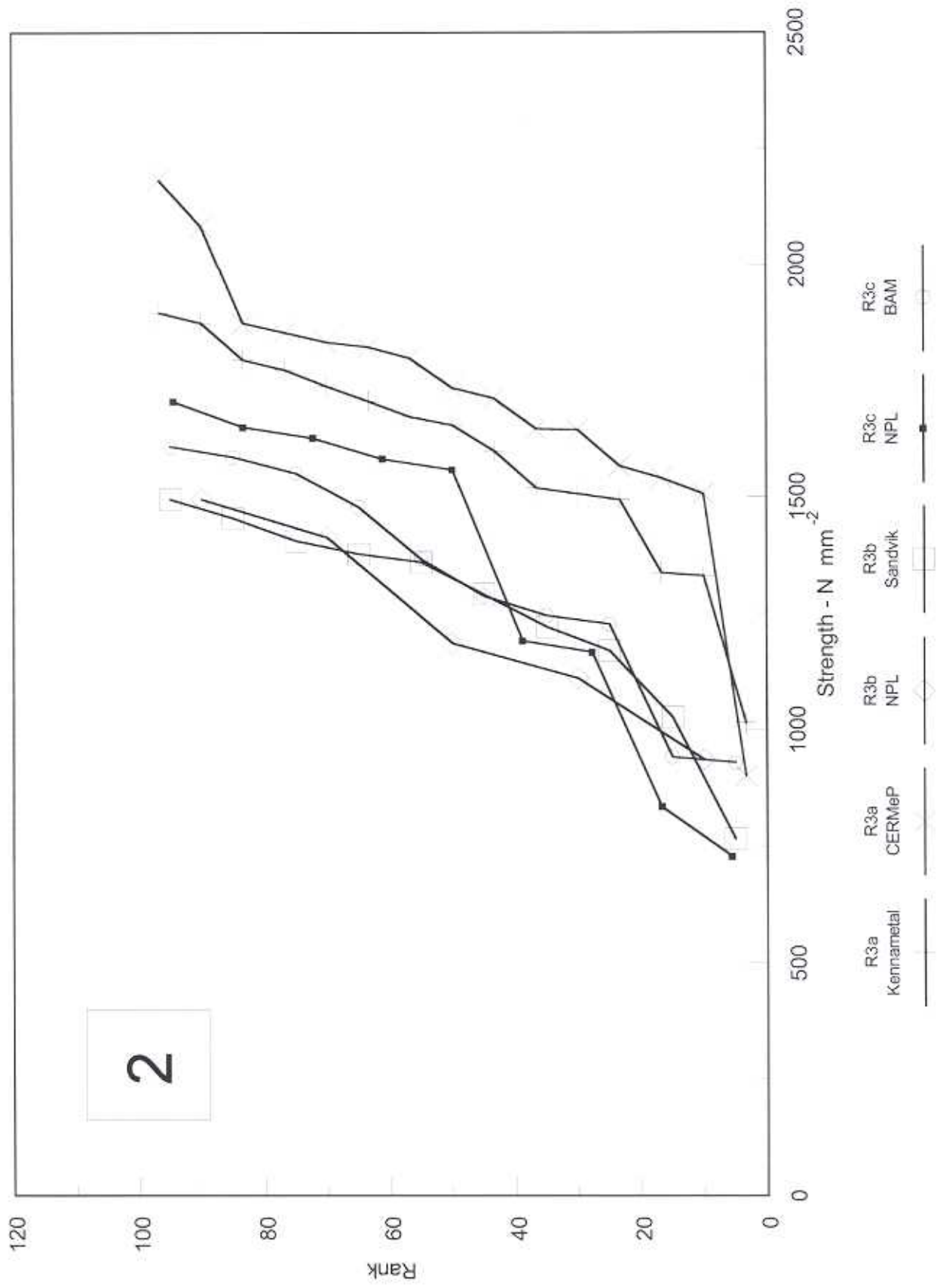
Bend Tests - Sandvik Cermet (4)



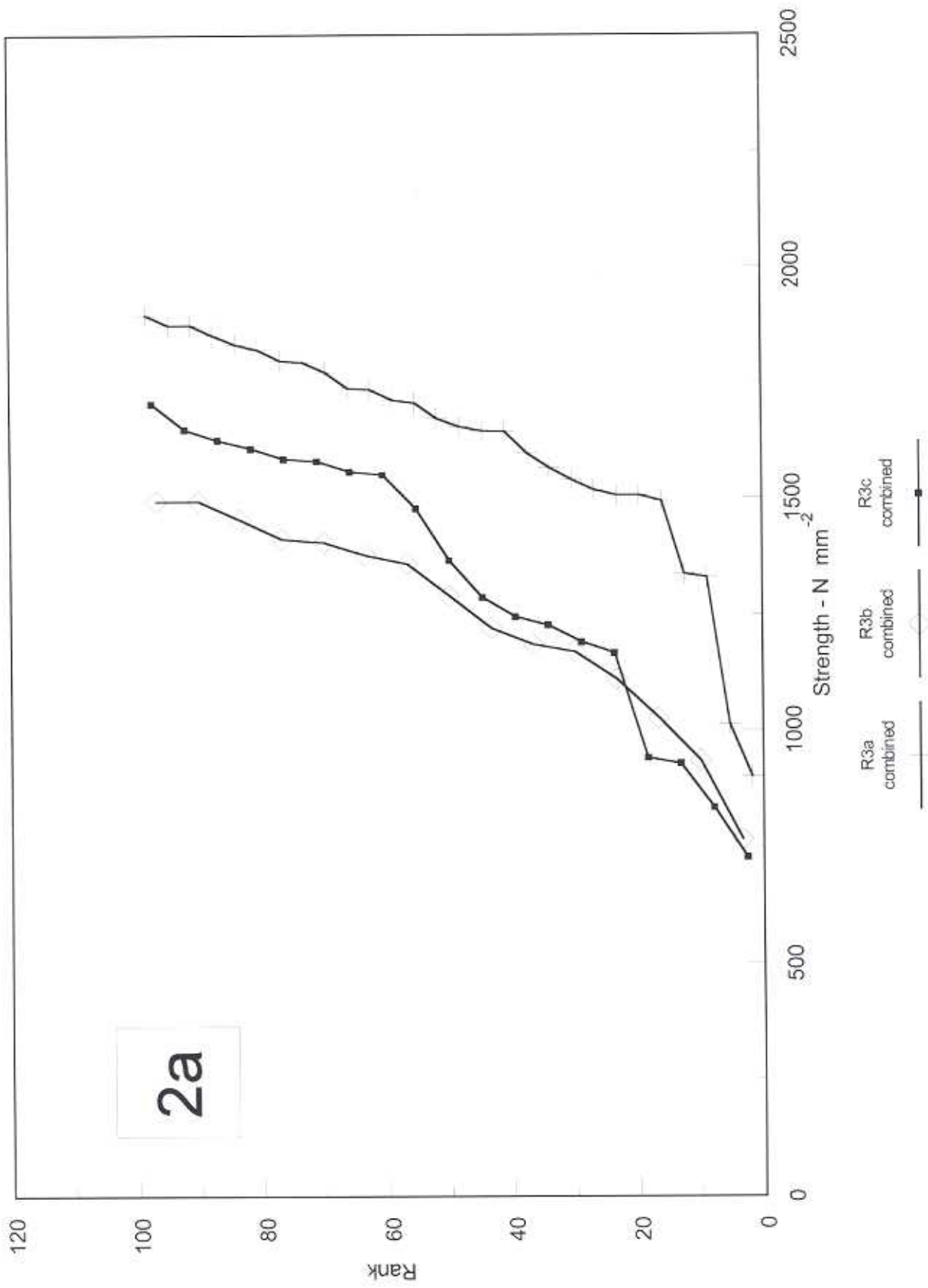
Bend Tests - Sandvik Cermet (4)



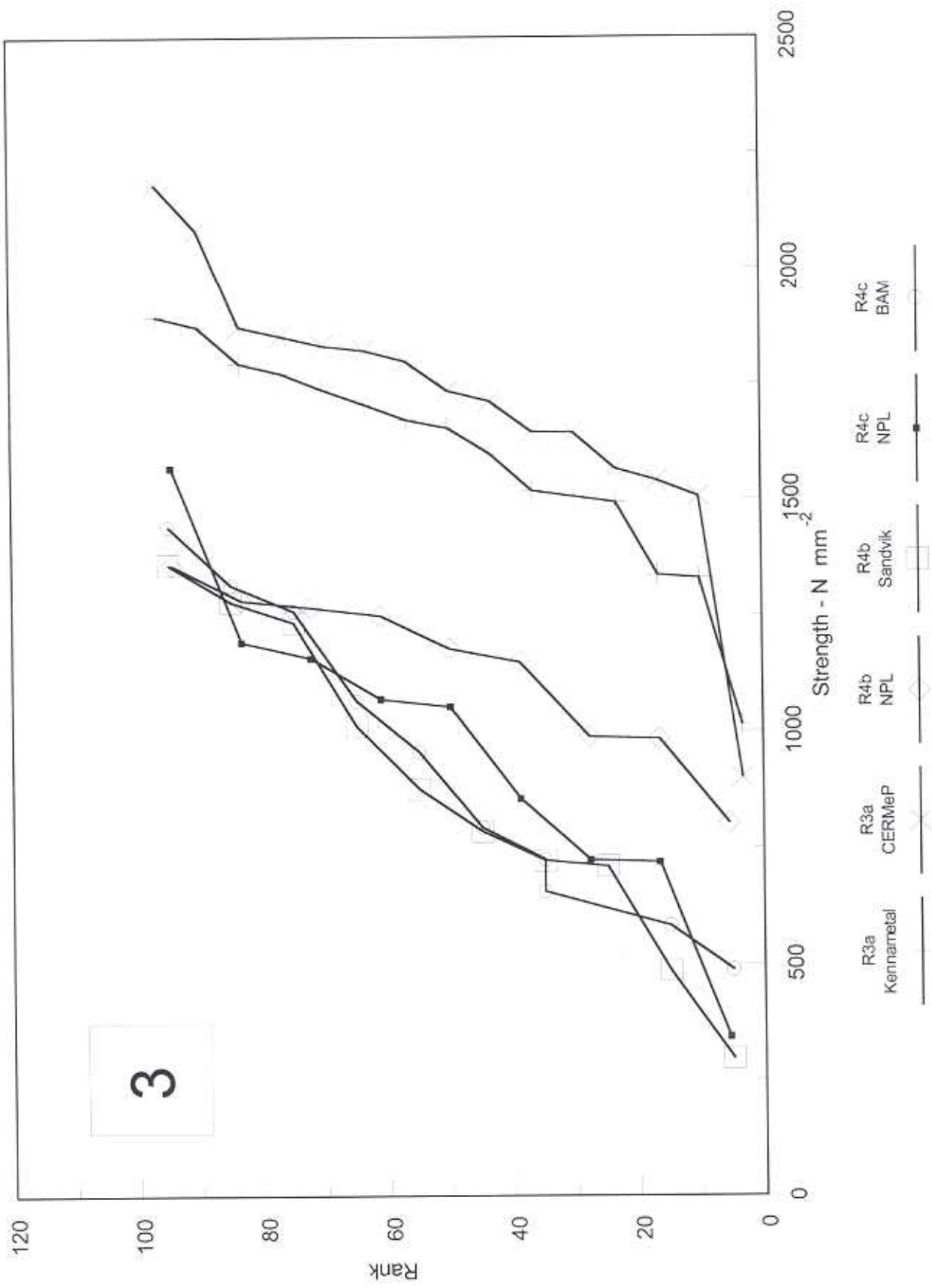
Bend Tests - Sandvik Cermet (4)



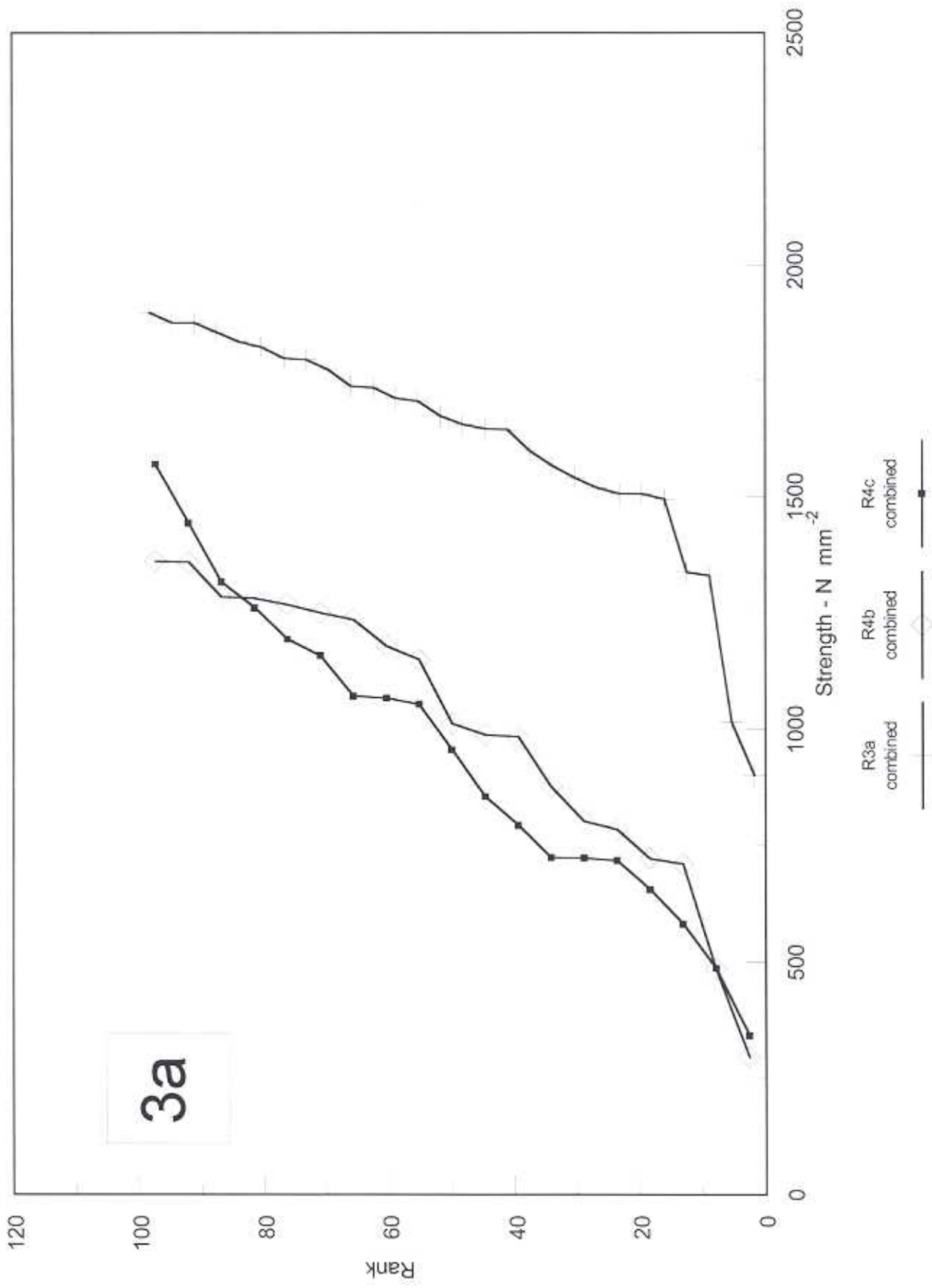
Bend Tests - Sandvik Cermet (4)



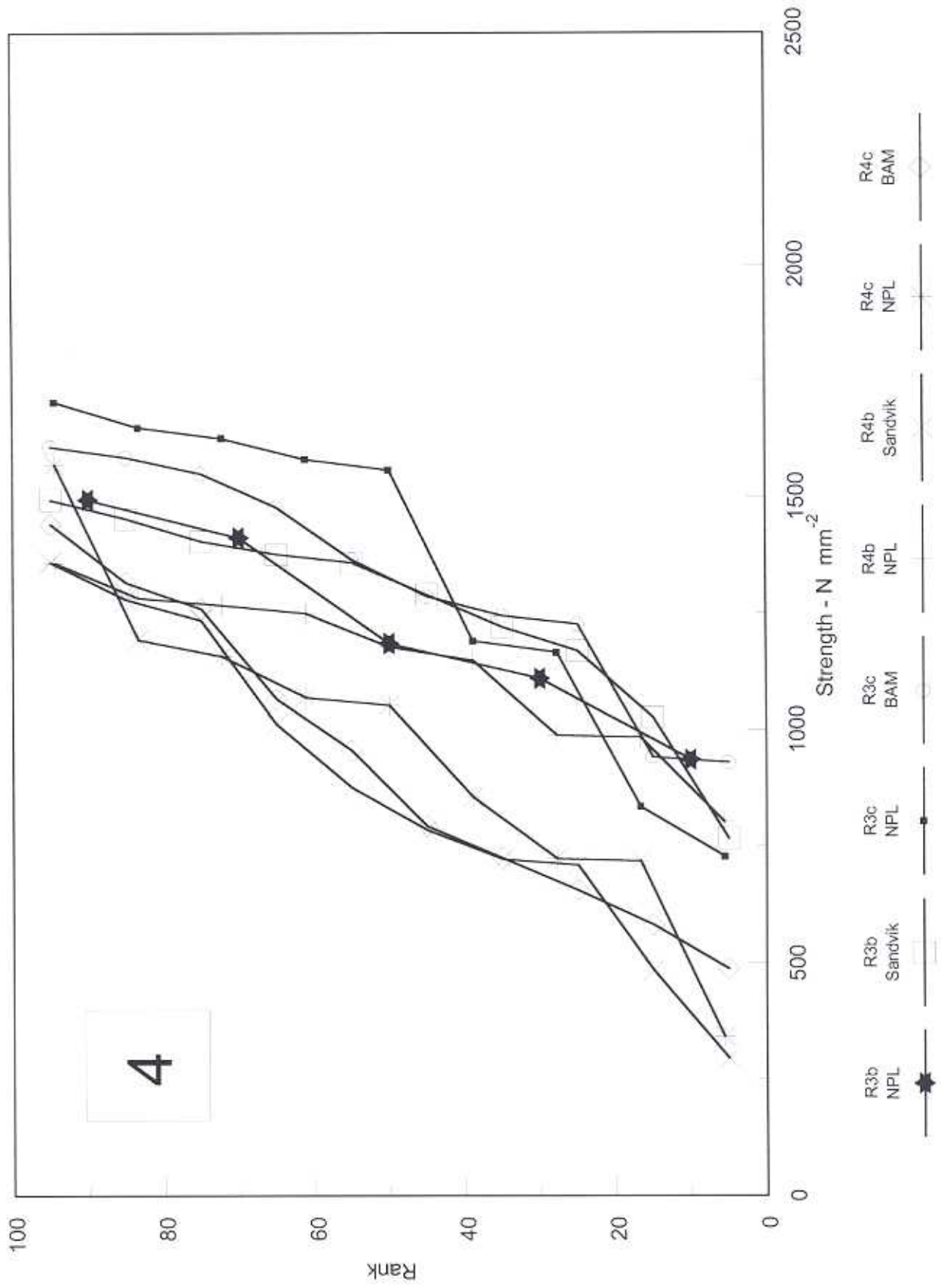
Bend Tests - Sandvik Cermet (4)



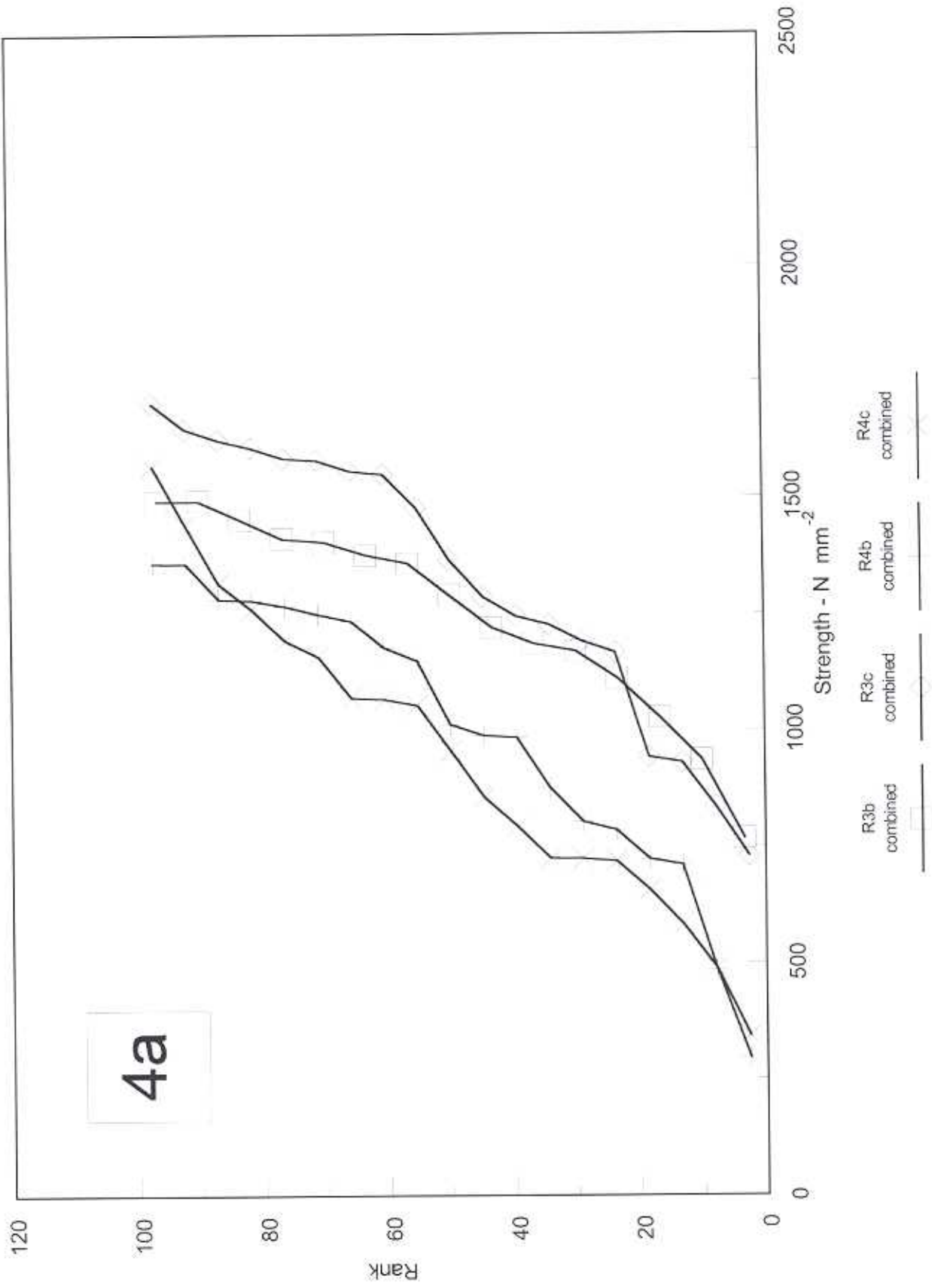
Bend Tests - Sandvik Cermet (4)



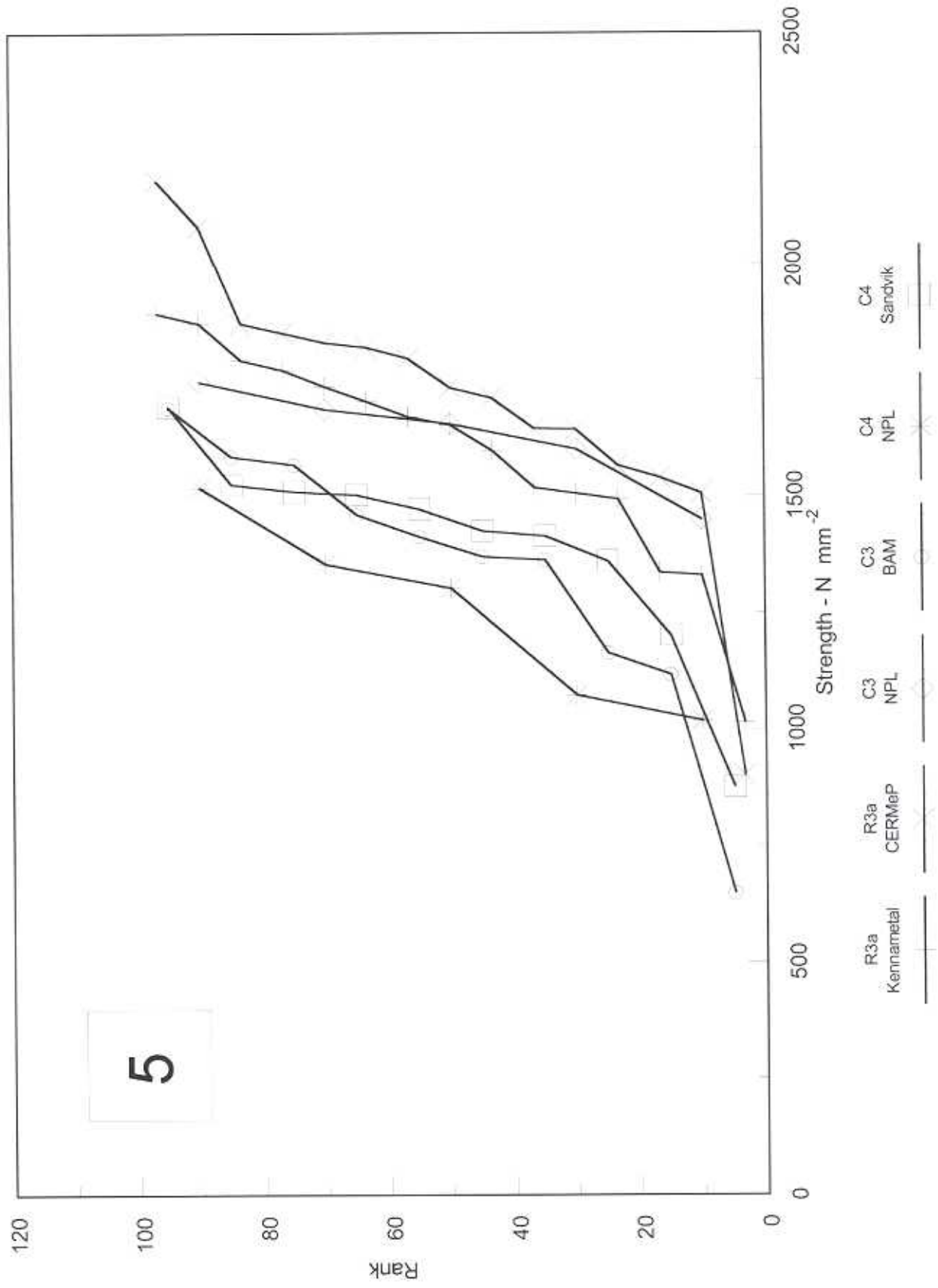
Bend Tests - Sandvik Cermet (4)



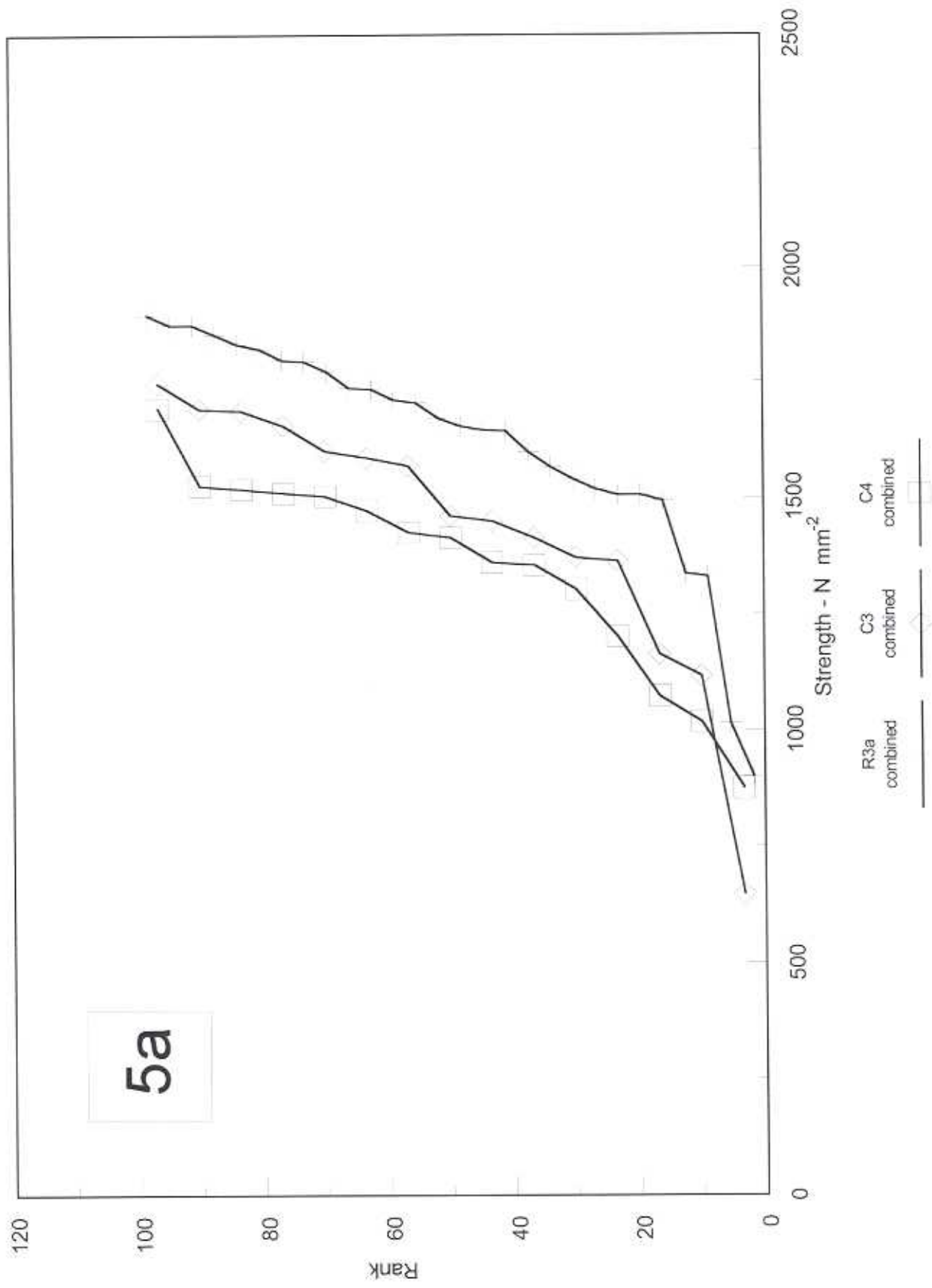
Bend Tests - Sandvik Cermet (4)



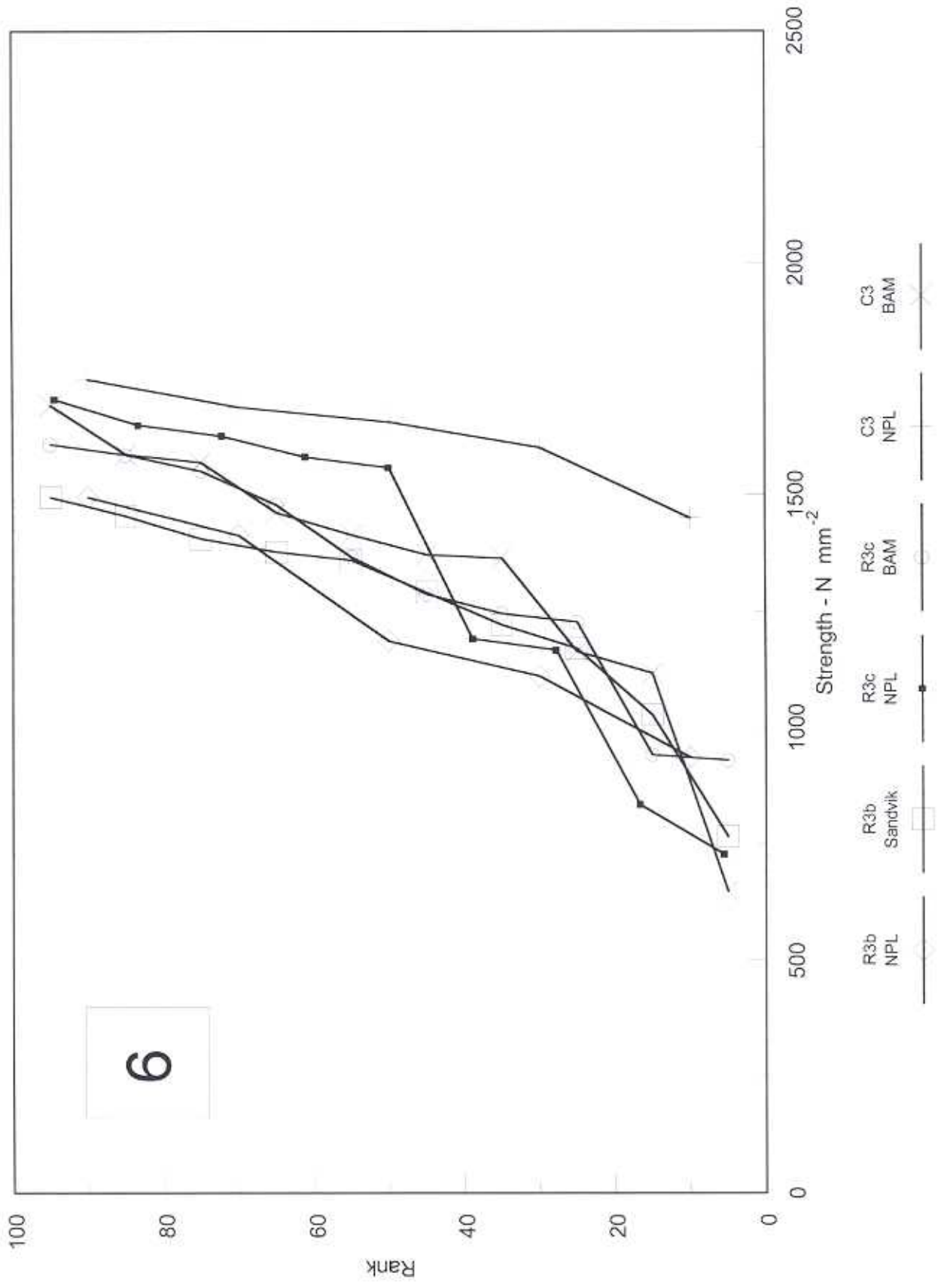
Bend Tests - Sandvik Cermet (4)



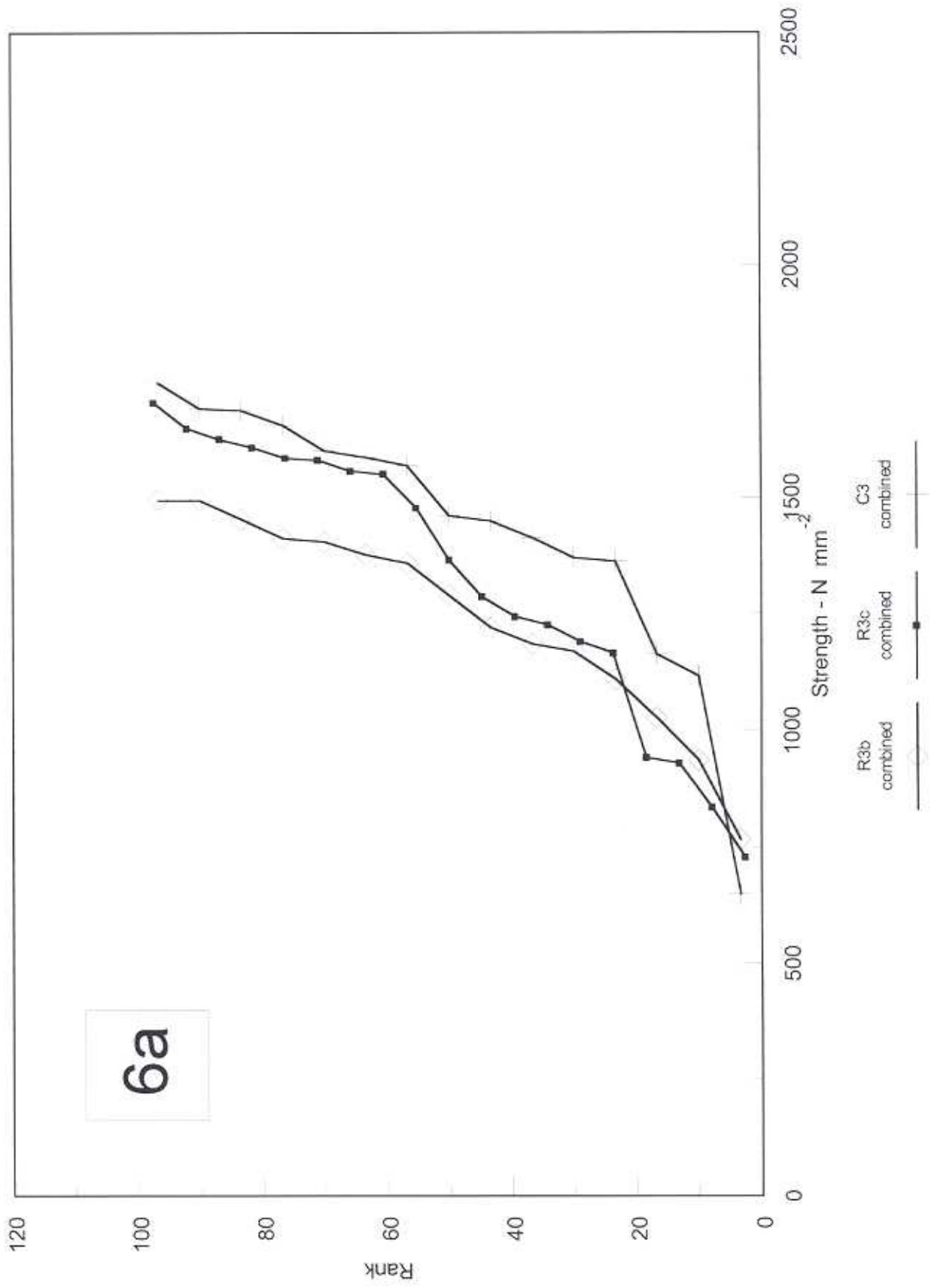
Bend Tests - Sandvik Cermet (4)



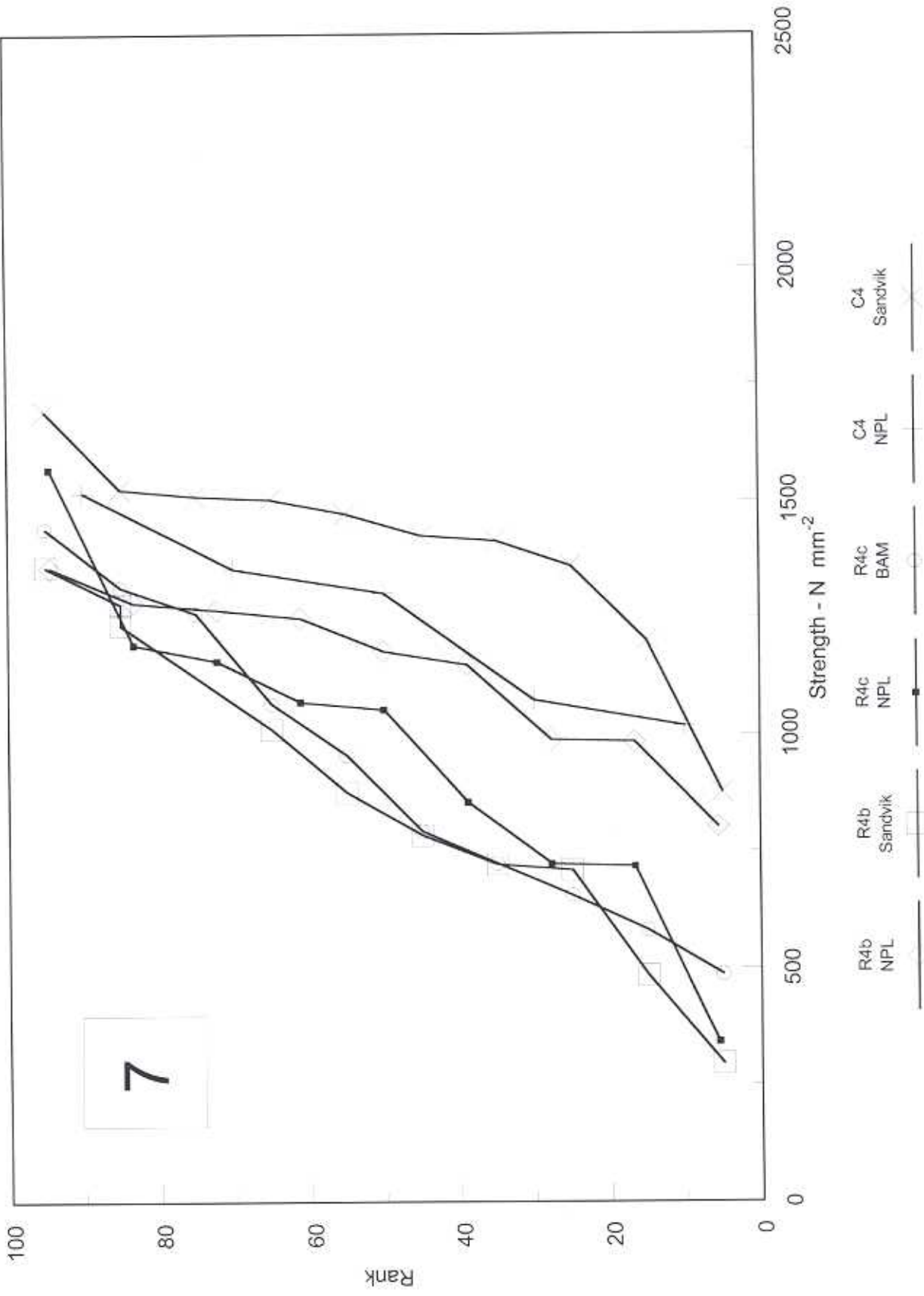
Bend Tests - Sandvik Cermet (4)



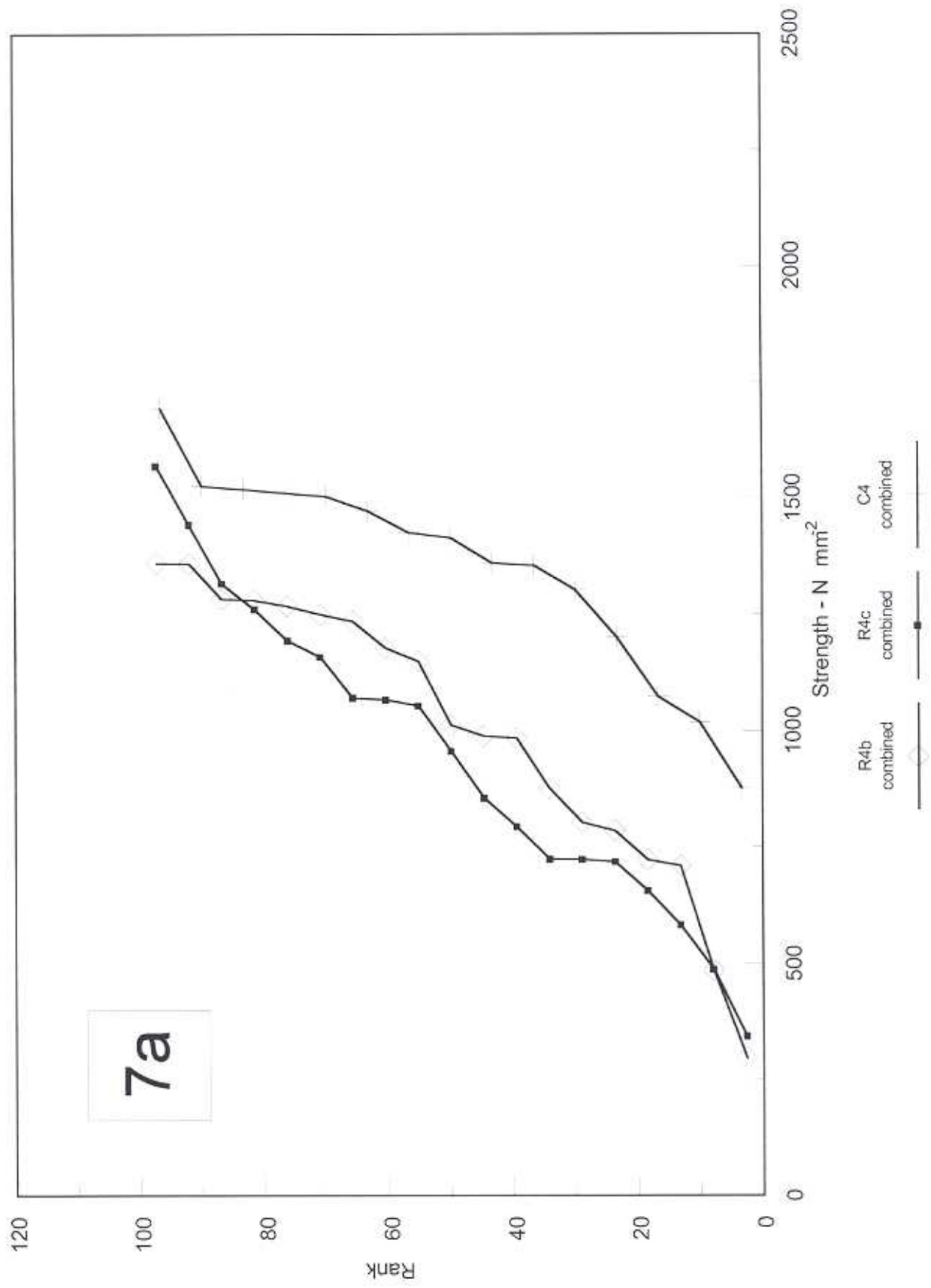
Bend Tests - Sandvik Cermet (4)



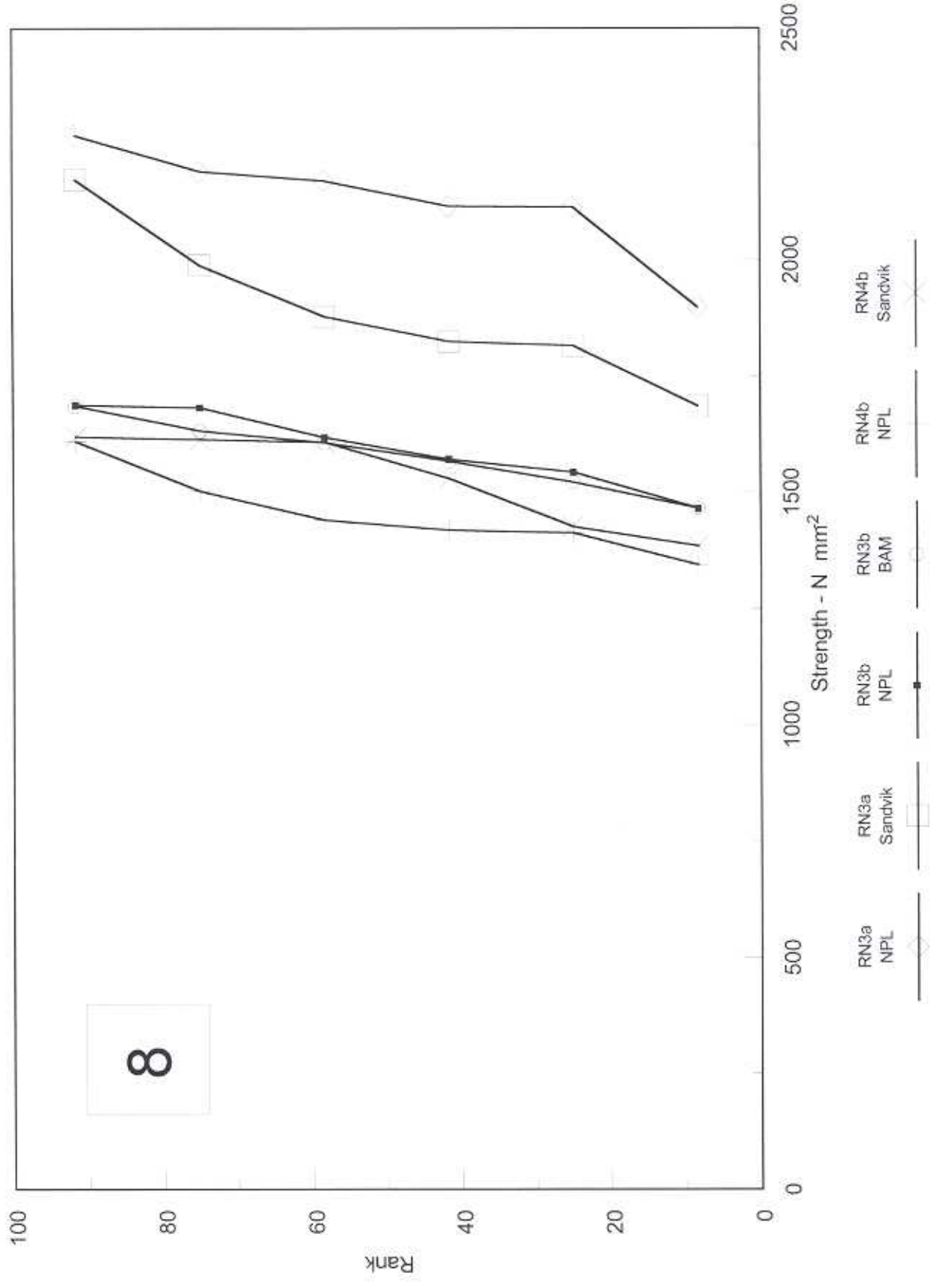
Bend Tests - Sandvik Cermet (4)



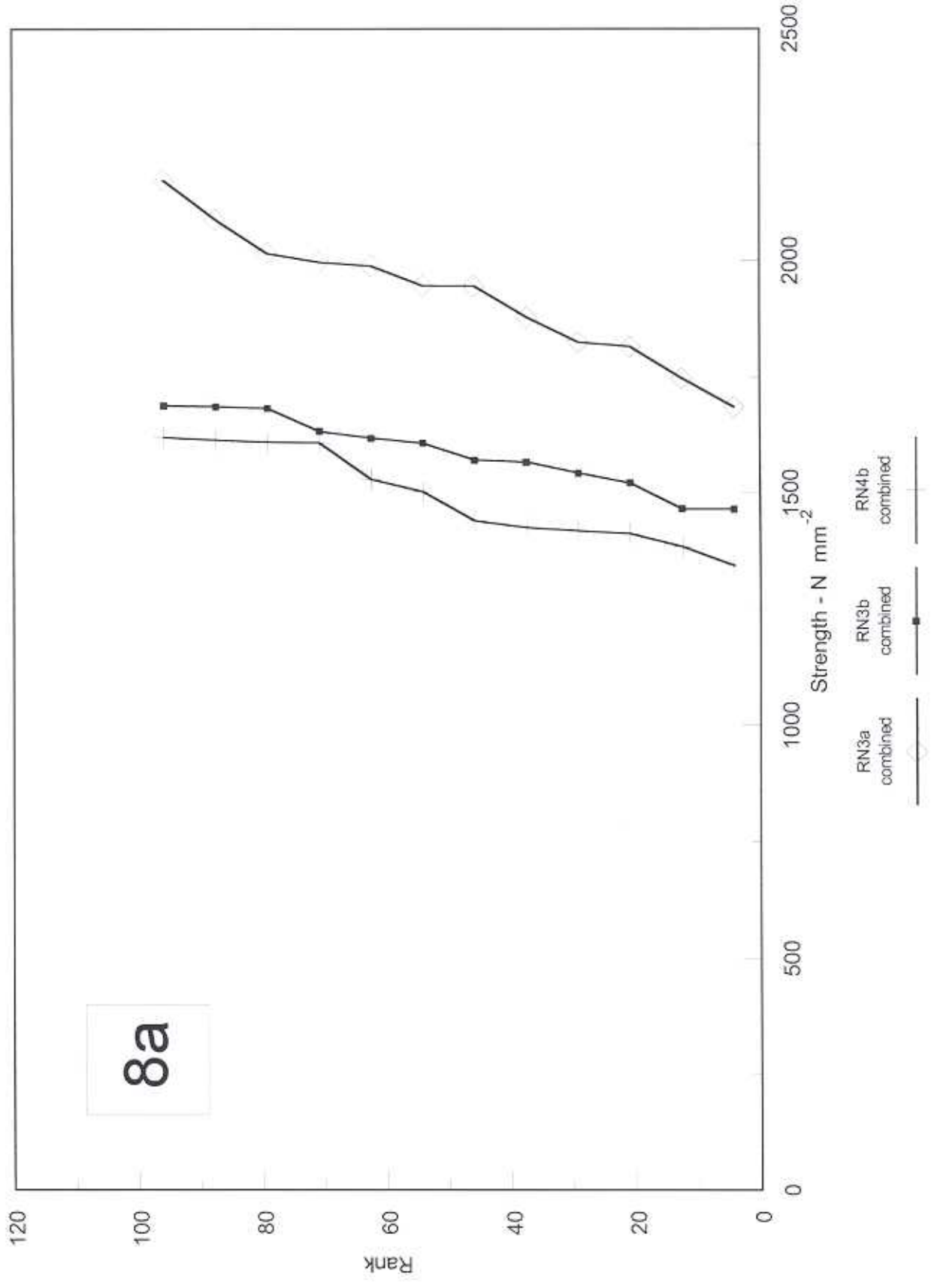
Bend Tests - Sandvik Cermet (4)



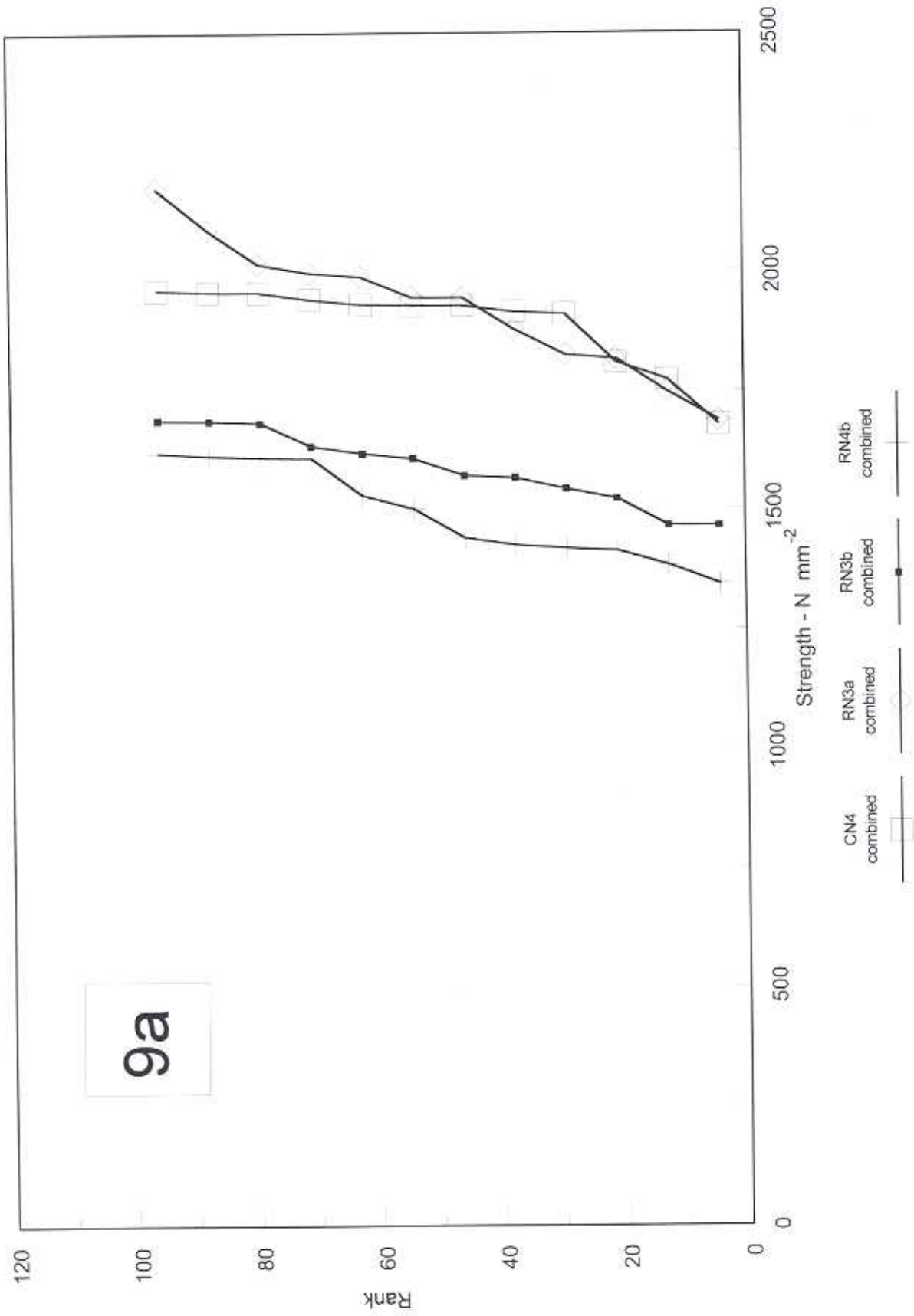
Bend Tests - Sandvik Cermet (4)



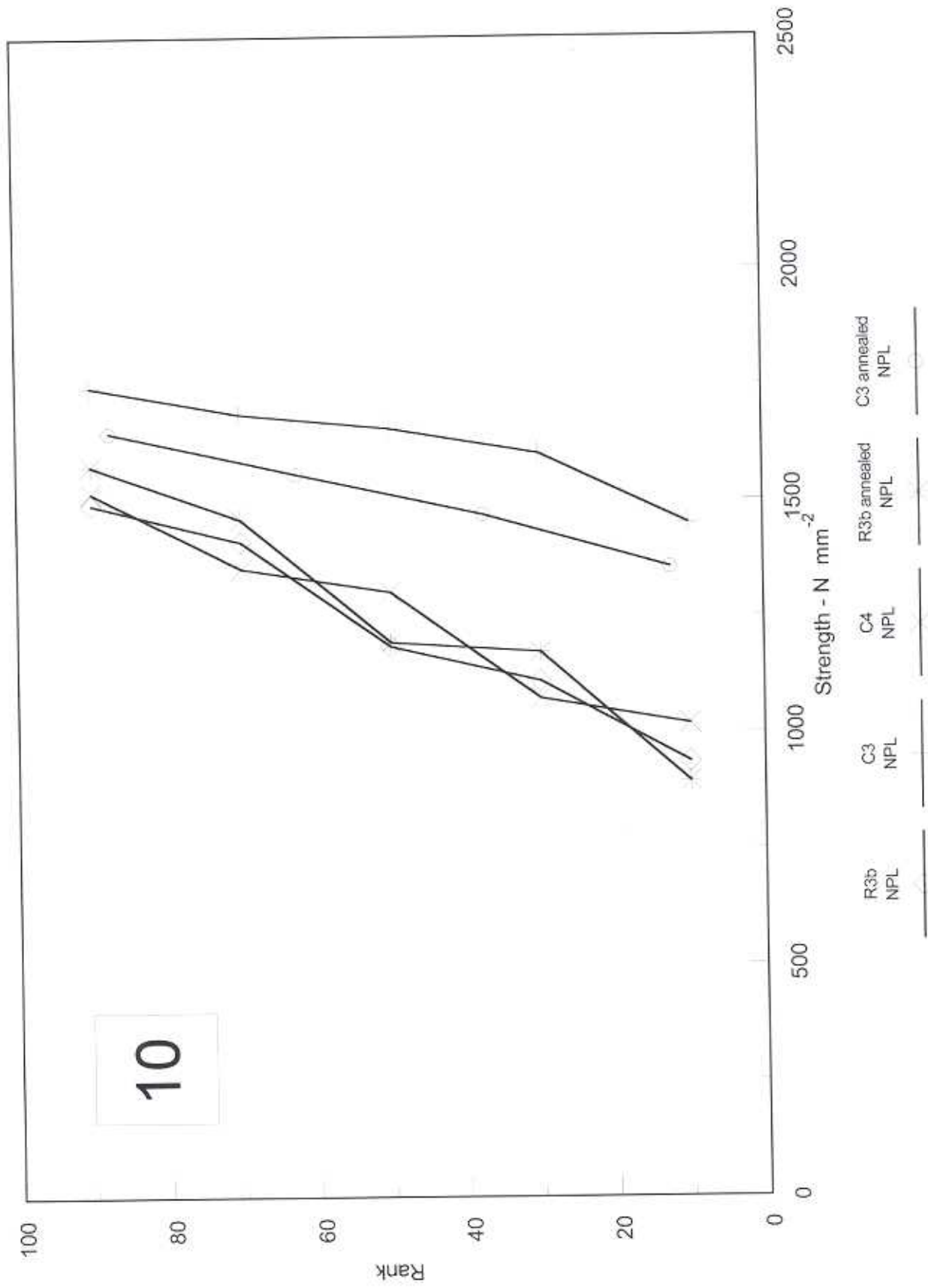
Bend Tests - Sandvik Cermet (4)



Bend Tests - Sandvik Cermet (4)



Bend Tests - Sandvik Cermet (4)



RESULTS SET

(6) SANDVIK COROMANT Medium/Coarse, WC/Co

Data Tables

Supplementary Comments

Data Plots

HARDMETAL BEND TESTS INTERNATIONAL INTERCOMPARISON

TABLES OF RESULTS

SET 6

WC/Co (Med/Coarse grained) - Source: Sandvik

<i>Geometry</i>		<i>Organisation</i>
3 pt TRS	R3a	Standard Tests (Gen Carbide/United Hardmetals)
3,4 pt Rectangular	R3, R4	NPL
3,4 pt Rectangular	R3, R4	EAD
3,4 pt Rectangular	R3, R4	K-Hertel
3,4 pt Rectangular Notched	RN3, RN4	NPL
3,4 pt Rectangular Notched	RN4	EAD
3,4 pt Rectangular Notched	RN3	K-Hertel
Round	C3, C4, CN4	NPL
Round	C4, CN4	EAD
Round	C3, CN4	K-Hertel

**SANDVIK WC/Co(6) - MED/COARSE
STANDARD TRS TESTS - R3a**

Gen Carbide					Span 14.3 mm Rate 1300 N s ⁻¹			
Number	B mm	W mm	Load N20461	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.00	5.00	20461	2926	4	3244	1	96.7
2	6.00	5.00	20572	2942	6	3228	2	90
3	6.00	5.00	18348	2624	10	3180	3	83.3
4	6.00	5.00	22685	3244	15	3133	4	76.7
5	6.00	5.00	20794	2974	12	3117	5	70
6	6.00	5.00	22574	3228	7	3085	6	63.3
7	6.00	5.00	21573	3085	13	3085	6	56.7
8	6.00	5.00	18459	2640	5	2974	8	50
9	6.00	5.00	17570	2513	2	2942	9	43.3
10	6.00	5.00	22240	3180	1	2926	10	36.7
11	6.00	5.00	19238	2751	14	2799	11	30
12	6.00	5.00	21795	3117	11	2751	12	23.3
13	6.00	5.00	21573	3085	8	2640	13	16.7
14	6.00	5.00	19571	2799	3	2624	14	10
15	6.00	5.00	21906	3133	9	2513	15	3.3

United Hardmetals					Span 15 mm Rate 1250 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
16	6.00	5.00	21517	3086	2	3175	1	96.7
17	6.00	5.00	22139	3175	9	3132	2	90
18	6.00	5.00	19679	2822	8	3122	3	83.3
19	6.00	5.00	20792	2982	14	3111	4	76.7
20	6.00	5.00	21545	3090	10	3107	5	70
21	6.00	5.00	21497	3083	5	3090	6	63.3
22	6.00	5.00	20552	2947	1	3086	7	56.7
23	6.00	5.00	21772	3122	6	3083	8	50
24	6.00	5.00	21844	3132	11	3011	9	43.3
25	6.00	5.00	21665	3107	12	2999	10	36.7
26	6.00	5.00	20995	3011	15	2990	11	30
27	6.00	5.00	20911	2999	4	2982	12	23.3
28	6.00	5.00	18782	2693	7	2947	13	16.7
29	6.00	5.01	21784	3111	3	2822	14	10
30	6.00	5.00	20851	2990	13	2693	15	3.3

**SANDVIK WC/Co(6) - MED/COARSE
NPL BEND TESTS (R3b, R3c, R4b, R4c)**

R3b					Span 30 mm Rate 200 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.9	4.9	6684	2557	2	2831	1	90
2	4.9	4.9	7402	2831	4	2815	2	70
3	4.9	4.9	6784	2595	5	2804	3	50
4	4.9	4.9	7359	2815	3	2595	4	30
5	4.9	4.9	7331	2804	1	2557	5	10
6*	4.9	4.9	6620	2532	4	2604	1	90
7*	4.9	4.9	6800	2601	2	2601	2	70
8*	4.9	4.9	6551	2506	5	2591	3	50
9*	4.9	4.9	6809	2604	1	2532	4	30
10*	4.9	4.9	6774	2591	3	2506	5	10

*annealed 800 °C, 1h in vacuum

R3c					Span 40 mm Rate 40 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	3.00	1609	2682	4	2841	1	94.4
2	4.00	3.00	1650	2750	7	2803	2	83.3
3	4.00	3.00	1618	2697	8	2784	3	72.2
4	4.01	3.00	1709	2841	5	2777	4	61.1
5	4.00	3.00	1666	2777	2	2750	5	50
6	3.98	3.00	1633	2735	9	2740	6	38.9
7	4.00	3.00	1682	2803	6	2735	7	27.8
8	3.98	3.00	1662	2784	3	2697	8	16.7
9	4.00	3.00	1644	2740	1	2682	9	5.6
10								

R4b								
Outer Span 10 mm Rate 200 N s ⁻¹								
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.9	4.9	9912	2528	4	2706	1	94.4
2	4.9	4.9	10440	2662	2	2662	2	83.3
3	4.9	4.9	10120	2581	8	2588	3	72.2
4	4.9	4.9	10610	2706	7	2586	4	61.1
5	4.9	4.9	10110	2578	3	2581	5	50
6	4.9	4.9	9639	2458	5	2578	6	38.9
7	4.9	4.9	10140	2586	9	2563	7	27.8
8	4.9	4.9	10150	2588	1	2528	8	16.7
9	4.9	4.9	10050	2563	6	2458	9	5.6
10								

R4c								
Outer Span 10 mm Rate 100 N s ⁻¹								
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	3.00	2383	1986	4	2656	1	94.4
2	4.00	3.00	3168	2640	2	2640	2	83.3
3	4.00	3.00	3131	2609	3	2609	3	72.2
4	4.00	3.00	3187	2656	9	2597	4	61.1
5	4.00	3.00	3089	2574	5	2574	5	50
6	4.00	3.00	3007	2506	6	2506	6	38.9
7	3.98	3.00	2712	2271	8	2462	7	27.8
8	4.00	3.00	2954	2462	7	2271	8	16.7
9	4.00	3.00	3116	2597	1	1986	9	5.6
10								

**SANDVIK WC/Co(6) - MED/COARSE
EAD BEND TESTS (R3b, R4b)**

R3b					Span 30 mm Rate 0.5 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4.9	4.9	7110	2720	16	2791	1	95
12	4.9	4.9	6816	2607	20	2780	2	85
13	4.9	4.9	6963	2663	14	2768	3	75
14	4.9	4.9	7237	2768	15	2763	4	65
15	4.91	4.91	7268	2763	18	2757	5	55
16	4.9	4.9	7296	2791	11	2720	6	45
17	4.9	4.9	7022	2686	19	2712	7	35
18	4.9	4.9	7208	2757	17	2686	8	25
19	4.9	4.9	7090	2712	13	2663	9	15
20	4.9	4.9	7267	2780	12	2607	10	5

R4b					Outer Span 10 mm Rate 0.5 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
11	4.9	4.9	9532	2431	18	2613	1	95
12	4.9	4.9	10062	2566	15	2603	2	85
13	4.9	4.9	10091	2573	17	2601	3	75
14	4.9	4.9	10042	2561	13	2573	4	65
15	4.9	4.9	10209	2603	12	2566	5	55
16	4.9	4.9	9375	2391	14	2561	6	45
17	4.9	4.9	10199	2601	20	2501	7	35
18	4.9	4.9	10248	2613	11	2431	8	25
19	4.9	4.9	9071	2313	16	2391	9	15
20	4.9	4.9	9807	2501	19	2313	10	5

**SANDVIK WC/Co(6) - MED/COARSE
K-HERTEL BEND TESTS (R3c, R4c)**

R3c					Span 30 mm Rate 0.7 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	3.00	1750	2917	9	2974	1	95
2	4.00	3.00	1660	2767	6	2957	2	85
3	3.99	3.00	1760	2941	3	2941	3	75
4	4.01	3.00	1700	2826	1	2917	4	65
5	3.99	3.00	1660	2774	8	2883	5	55
6	3.99	3.00	1770	2957	4	2826	6	45
7	3.99	3.01	1490	2473	10	2800	7	25
8	4.00	3.00	1730	2883	5	2774	8	25
9	3.99	3.00	1780	2974	2	2767	9	15
10	4.00	3.00	1680	2800	7	2473	10	5

R4c					Outer Span 10 mm Rate 0.7 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	3.00	3170	2642	6	2725	1	95
2	4.00	3.00	2760	2300	4	2700	2	85
3	3.98	3.00	2870	2404	1	2642	3	75
4	4.00	3.00	3240	2700	10	2625	4	65
5	4.00	3.00	3010	2508	8	2598	5	55
6	4.00	3.00	3270	2725	5	2508	6	45
7	3.99	3.00	2650	2214	3	2404	7	35
8	3.99	3.00	3110	2598	9	2383	8	25
9	4.00	3.00	2860	2383	2	2300	9	15
10	4.00	3.00	3150	2625	7	2214	10	5

**SANDVIK WC/Co(6) - MED/COARSE
NPL BEND TESTS (RN3a, RN3b, RN4b)**

RN3a				Span 13.8 mm Rate 200 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.00	5.00	1849	2392	5	2656	1	91.7
2	2.00	5.00	1855	2400	4	2612	2	75
3	2.00	5.00	1822	2357	6	2419	3	58.3
4	2.00	5.00	2019	2612	2	2400	4	41.7
5	2.00	5.00	2053	2656	1	2392	5	25
6	2.00	5.00	1870	2419	3	2357	6	8.3

RN3b				Span 30 mm Rate 80 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.90	5.00	749	2410	2	2646	1	91.7
2	1.89	5.00	818	2646	4	2567	2	75
3	1.90	5.00	744	2394	6	2487	3	58.3
4	1.90	5.00	798	2567	5	2464	4	41.7
5	1.90	5.00	766	2464	1	2410	5	25
6	1.90	5.00	773	2487	3	2394	6	8.3

RN4b				Outer Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.90	5.00	1188	2466	1	2466	1	91.7
2	1.90	5.00	1049	2177	3	2439	2	75
3	1.90	5.00	1175	2439	5	2337	3	58.3
4	1.90	5.00	1083	2248	4	2248	4	41.7
5	1.90	5.00	1126	2337	2	2177	5	25
6	1.91	5.00	975	2013	6	2013	6	8.3

**SANDVIK WC/Co(6) - MED/COARSE
EAD BEND TESTS (RN4b)**

RN4b				Span 10 mm Rate 0.5 mm min ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.91	5	1128	2329	3	2341	1	91.7
2	1.9	5.01	1098	2268	1	2329	2	75
3	1.9	5	1128	2341	6	2300	3	58.3
4	1.89	5	981	2047	2	2268	4	41.7
5	1.9	5	1079	2240	5	2240	5	25
6	1.9	5	1108	2300	4	2047	6	8.3

**SANDVIK WC/Co(6) - MED/COARSE
K-HERTEL BEND TESTS (RN3a, RN3b)**

RN3a					Span mm Rate 0.7 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.00	5.00	1760	2393	3	2800	1	91.7
2	2.00	5.00	1960	2664	2	2664	2	75
3	2.00	5.00	2060	2800	6	2610	3	58.3
4	2.00	5.00	1790	2433	4	2433	4	41.7
5	2.00	5.00	1790	2433	5	2433	4	25
6	2.00	5.00	1920	2610	1	2393	6	8.3

RN3b					Span 30 mm Rate 0.7 mm min ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	1.90	5.00	900	2895	3	2942	1	91.7
2	1.90	4.99	880	2845	5	2910	2	75
3	1.90	4.99	910	2942	1	2895	3	58.3
4	1.89	5.00	840	2717	2	2845	4	41.7
5	1.90	4.99	900	2910	6	2767	5	25
6	1.90	5.00	860	2767	4	2717	6	8.3

SANDVIK WC/Co(6) - MED/COARSE
NPL BEND TESTS (C3, C4, CN4)

C3				Span 30 mm Rate 200 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	4731	2874	3	3072	1	90
2	5.01	4938	3000	5	3012	2	70
3	5.01	5057	3072	4	3008	3	50
4	5.01	4951	3008	2	3000	4	30
5	5.01	4958	3012	1	2874	5	10
6*	5.01	4479	2721	5	2889	1	90
7*	5.01	4598	2793	3	2815	2	70
8*	5.01	4634	2815	4	2804	3	50
9*	5.01	4616	2804	2	2793	4	30
10*	5.01	4755	2889	1	2721	5	10

*annealed, 1h 8000 °C in vacuum

C4				Outer Span 10 mm Rate 150 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	6953	2833	3	2850	1	90
2	5.00	6891	2808	1	2833	2	70
3	5.00	6994	2850	2	2808	3	50
4	5.00	6842	2788	4	2788	4	30
5	5.00	6798	2770	5	2770	5	10
6*	5.00	6253	2548	5	2629	1	90
7*	5.00	6243	2544	4	2604	2	70
8*	5.00	6337	2582	3	2582	3	50
9*	5.00	6391	2604	1	2548	4	30
10*	5.00	6453	2629	2	2544	5	10

*annealed, 1h 800 °C in vacuum

CN4				Outer Span 10 mm Rate 125 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.01	1929	2776	1	2776	1	87.5
2	5.01	1928	2775	2	2775	2	62.5
3	5.00	1898	2748	3	2748	3	37.5
4	5.01	1825	2627	4	2627	4	12.5

**SANDVIK WC/Co(6) - MED/COARSE
EAD BEND TESTS (C4, CN4)**

C4				Outer Span 10 mm Rate 0.5 mm min ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
11	5	7061	2877	15	2893	1	95
12	5	7080	2885	12	2885	2	85
13	5	6708	2733	11	2877	3	75
14	5	6629	2701	18	2853	4	65
15	5	7100	2893	19	2853	5	55
16	5	5933	2417	13	2733	6	45
17	5	6312	2572	14	2701	7	35
18	5	7002	2853	20	2619	8	25
19	5	7002	2853	17	2572	9	15
20	5	6428	2619	16	2417	10	5

CN4				Outer Span 10 mm Rate 0.5 mm min ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5	2010	2910	1	2910	1	87.5
2	5	1912	2769	2	2769	2	62.5
3	5	1814	2627	3	2727	3	37.5
4	5	1883	2727	4	2627	4	12.5

**SANDVIK WC/Co(6) - MED/COARSE
K-HERTEL BEND TESTS - (C3, CN4)**

C3				Span 30 mm Rate 0.7 mm min ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	4930	3013	8	3129	1	95
2	5.00	5080	3105	2	3105	2	85
3	5.00	5050	3086	3	3086	3	75
4	5.00	5010	3062	4	3062	4	65
5	5.00	4900	2995	7	3050	5	55
6	5.00	3410	2084	10	3031	6	45
7	5.00	4990	3050	1	3013	7	35
8	5.00	5120	3129	9	3007	8	25
9	5.00	4920	3007	5	2995	9	15
10	5.00	4960	3031	6	2084	10	5

CN4				Outer Span 10 mm Rate 0.7 mm min ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	2000	2896	4	2968	1	87.5
2	5.00	2000	2896	3	2925	2	62.5
3	5.00	2020	2925	1	2896	3	37.5
4	5.00	2050	2968	2	2896	4	12.5

HARDMETAL BEND TESTS

Results Comment Sheet

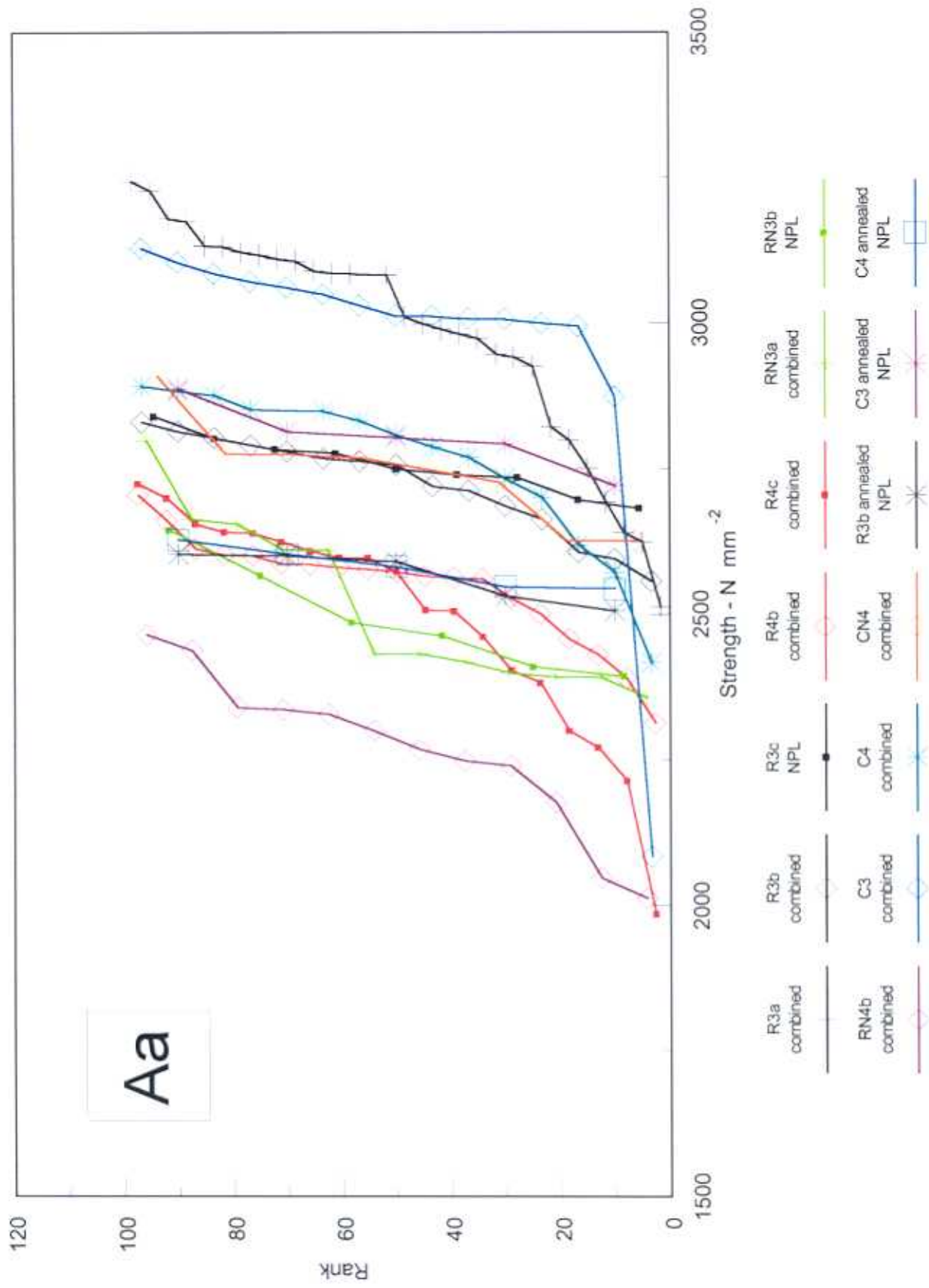
Sandvik Coromant - Category (6) Med/Coarse WC/Co Hardmetal

PLOT SEQUENCE

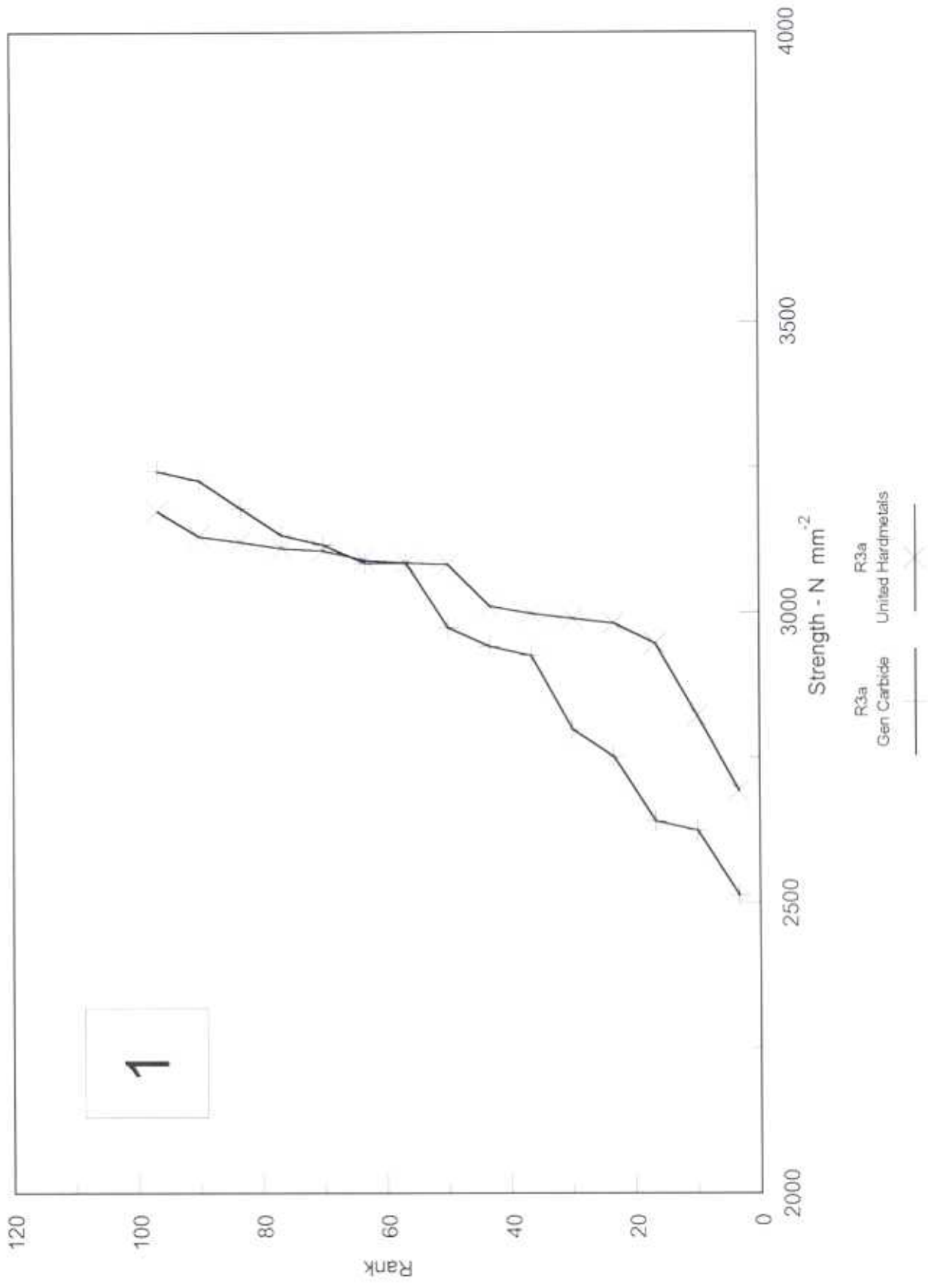
- A - Complete set of all strength values.
- Aa - Complete set, different laboratories combined.
- 1 - Standard tests, ISO type B (R3a).
- 1a - Combined R3a.
- 2 - 3 pt rectangular tests; R3a, R3b, R3c.
- 2a - Combined R3a, R3b and R3c.
- 3 - 4 pt rectangular tests, compared with standard ISO type B; R3a, R4b, R4c.
- 3a - Combined R3a, R4b and R4c.
- 4 - 3 pt vs 4 pt tests; R3b, R3c, R4b, R4c; not including R3a.
- 4a - Combined R3b, R3c, R4b and R4c.
- 5 - Round testpieces, compared with standard R3a, C3, C4 and R3a.
- 5a - Combined C3, C4 and R3a.
- 6 - 3 pt rectangular and round; R3b, R3c and C3; not including R3a.
- 6a - Combined C3 compared with R3b and R3c combined.
- 7 - 4 pt rectangular and round R4b, R4c and C4.
- 7a - Combined C4 compared with R4b and R4c.
- 8 - Notched rectangular testpieces, RN3a, RN3b and RN4b.
- 8a - Combined notched testpieces; RN3a, RN3b and RN4b.
- 9 - Notched round compared with combined notched rectangular; CN4 and RN3a, RB3b and RN4b.
- 9a - Combined notched round compared with combined notched rectangular; CN4 and RN3a, RN3b and RN4b.
- 10 - Annealed NPL R3b, C3 and C4 testpieces compared with as-ground testpieces.

*NB *There was good agreement between laboratories except for the R3c, CN4 and RN3b K-Hertel results which were high. These have been excluded from the combined plots.*

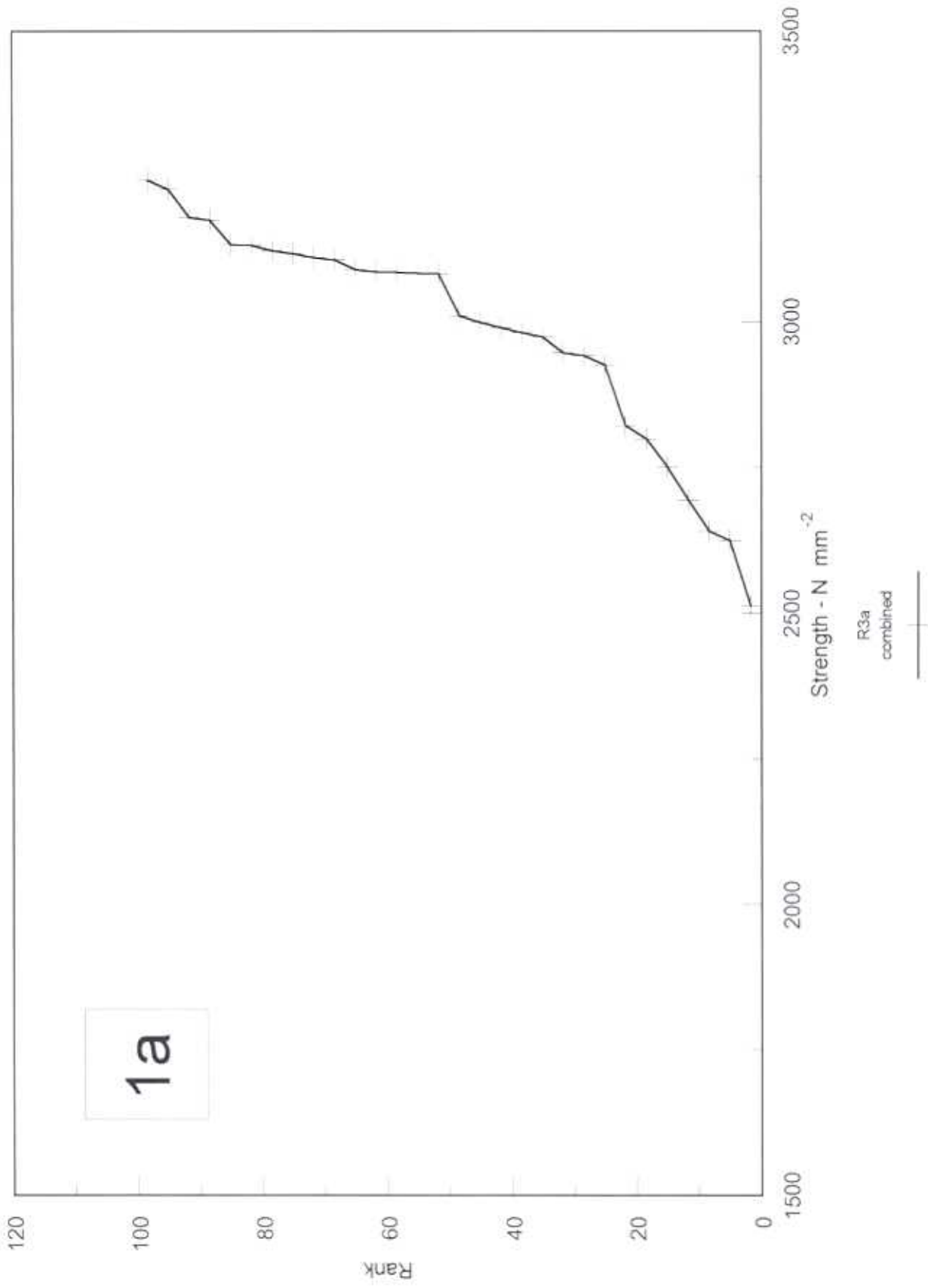
Bend Tests - Sandvik Med/Coarse WC/Co (5)



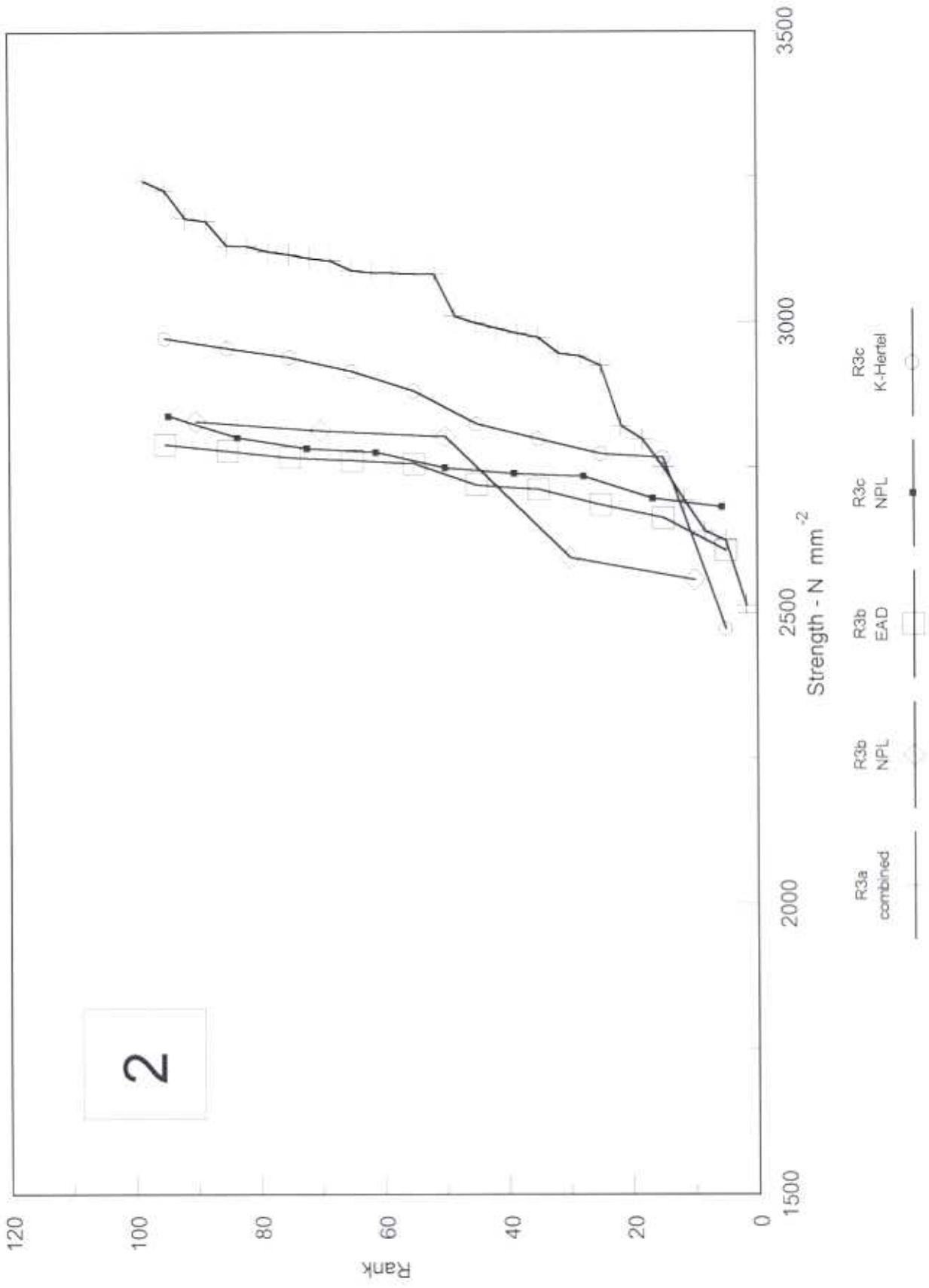
Bend Tests - Sandvik Med/Coarse WC/Co (5)



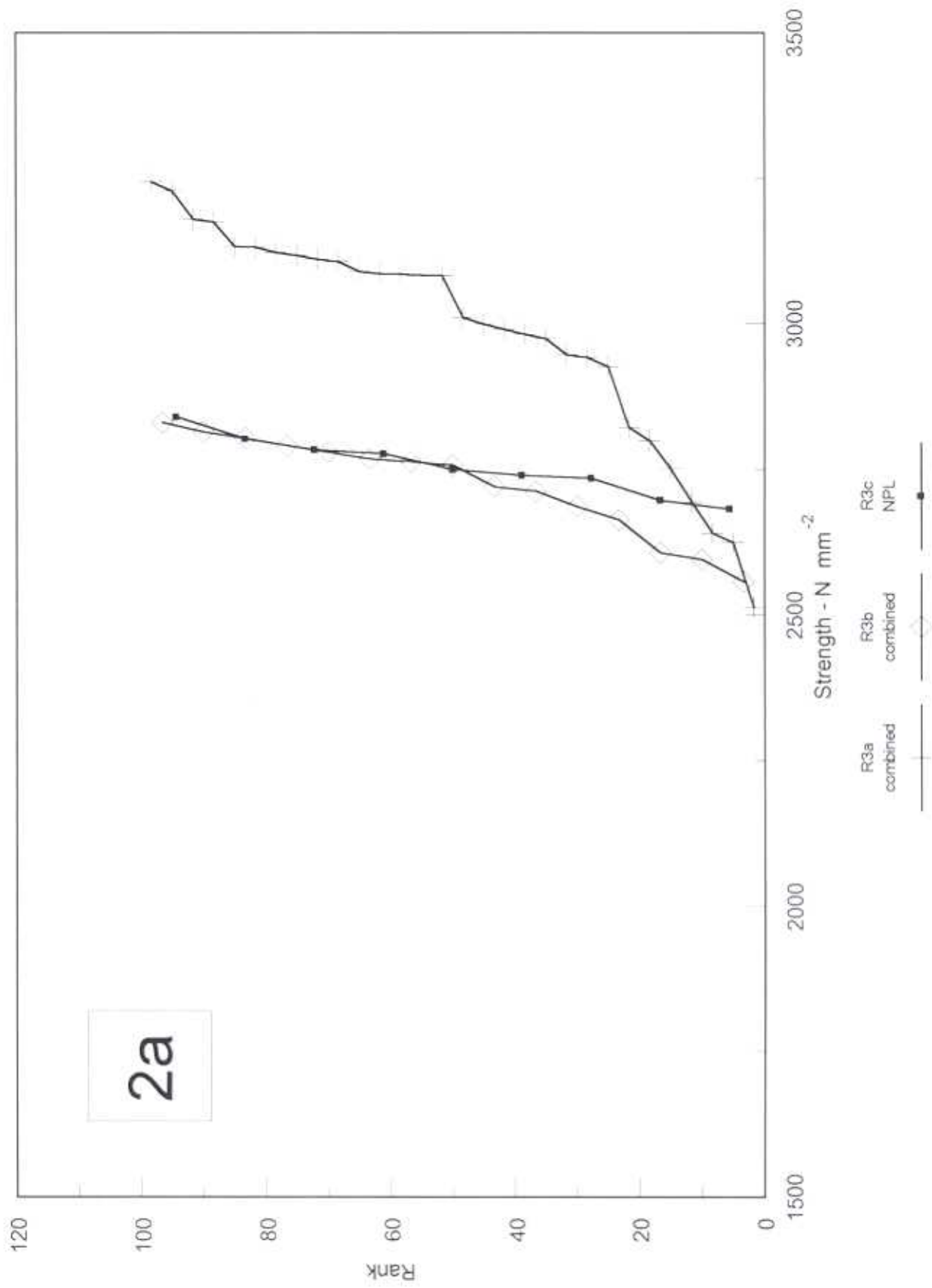
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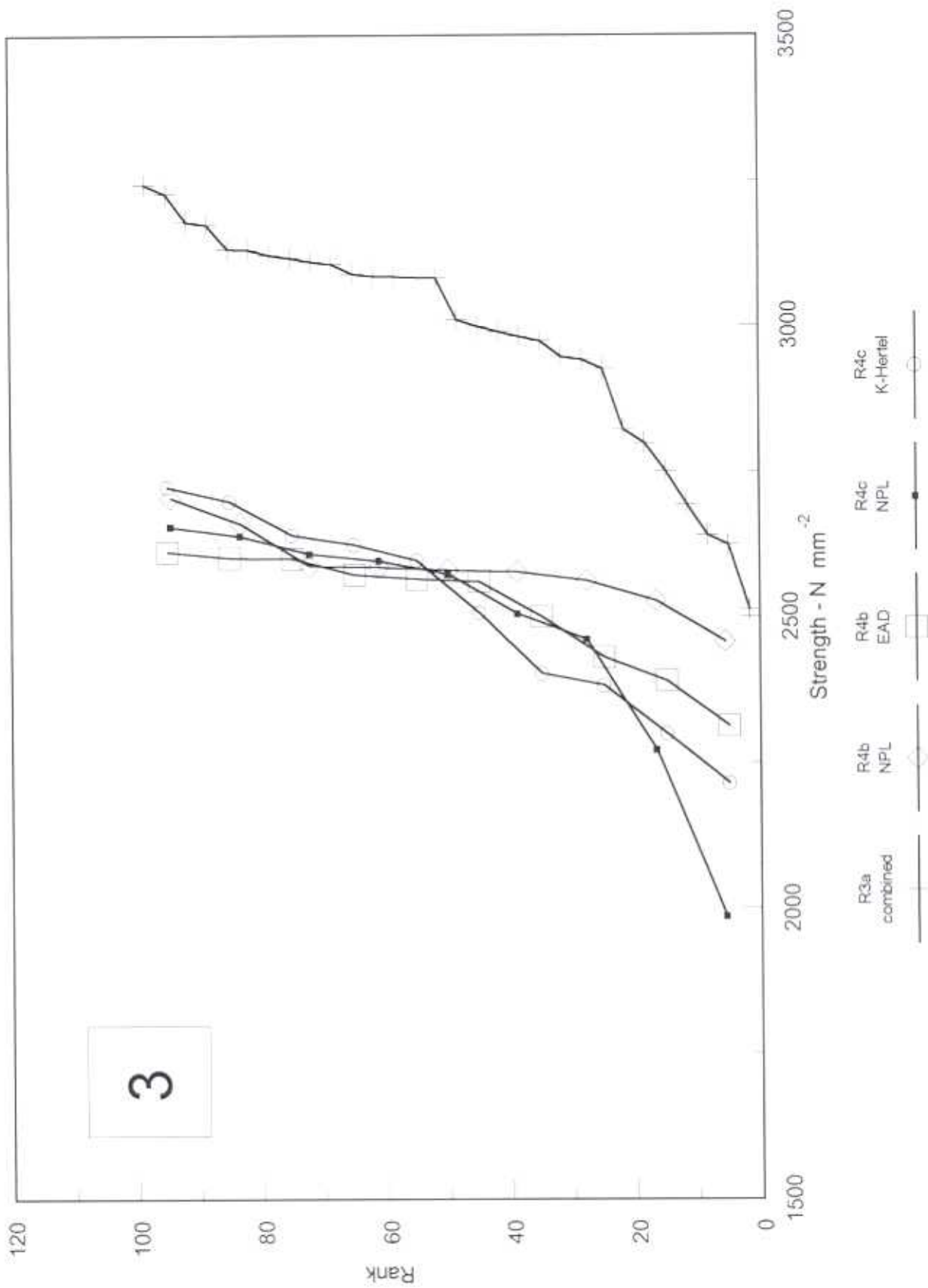
Bend Tests - Sandvik Med/Coarse WC/Co (5)



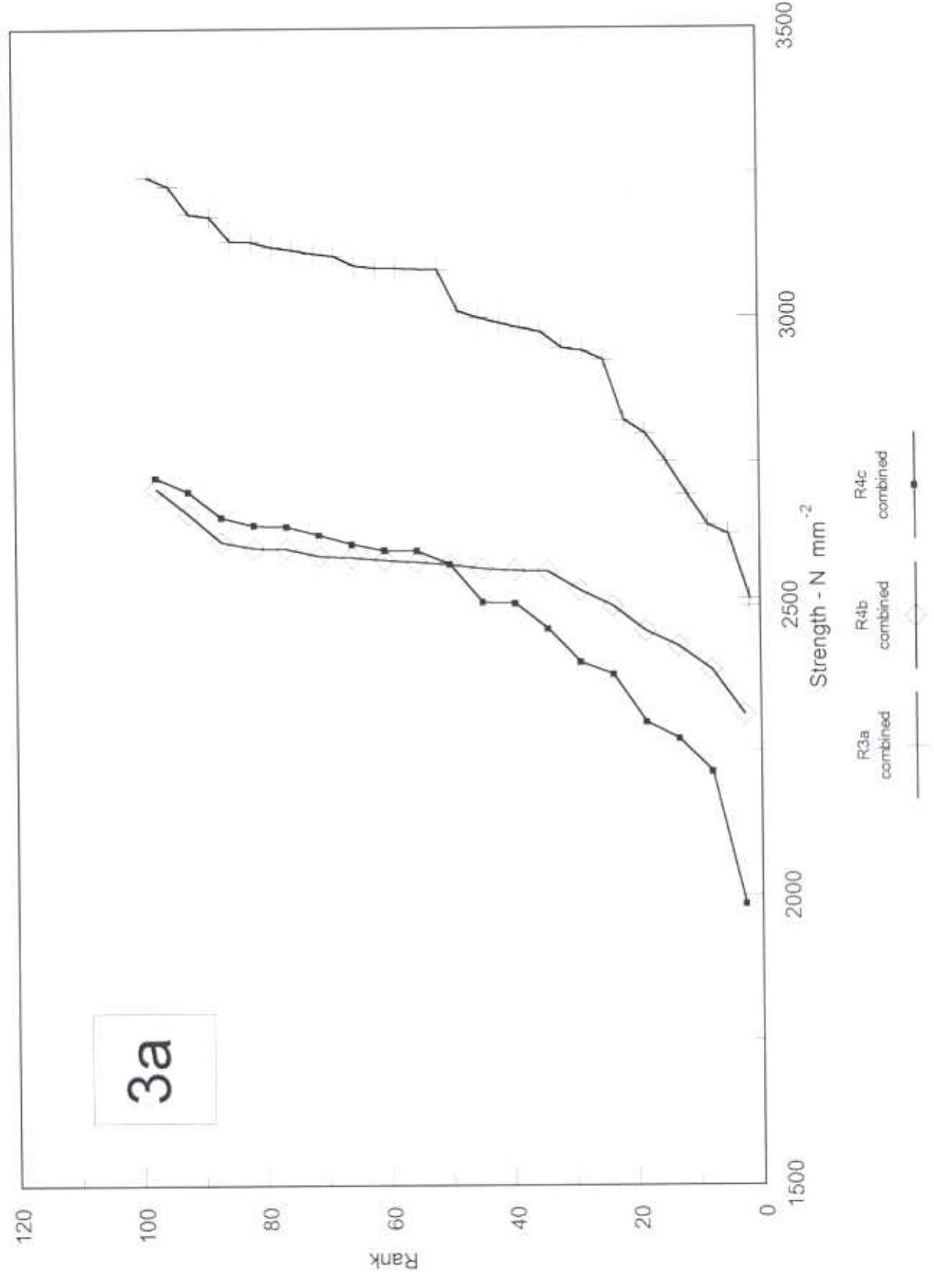
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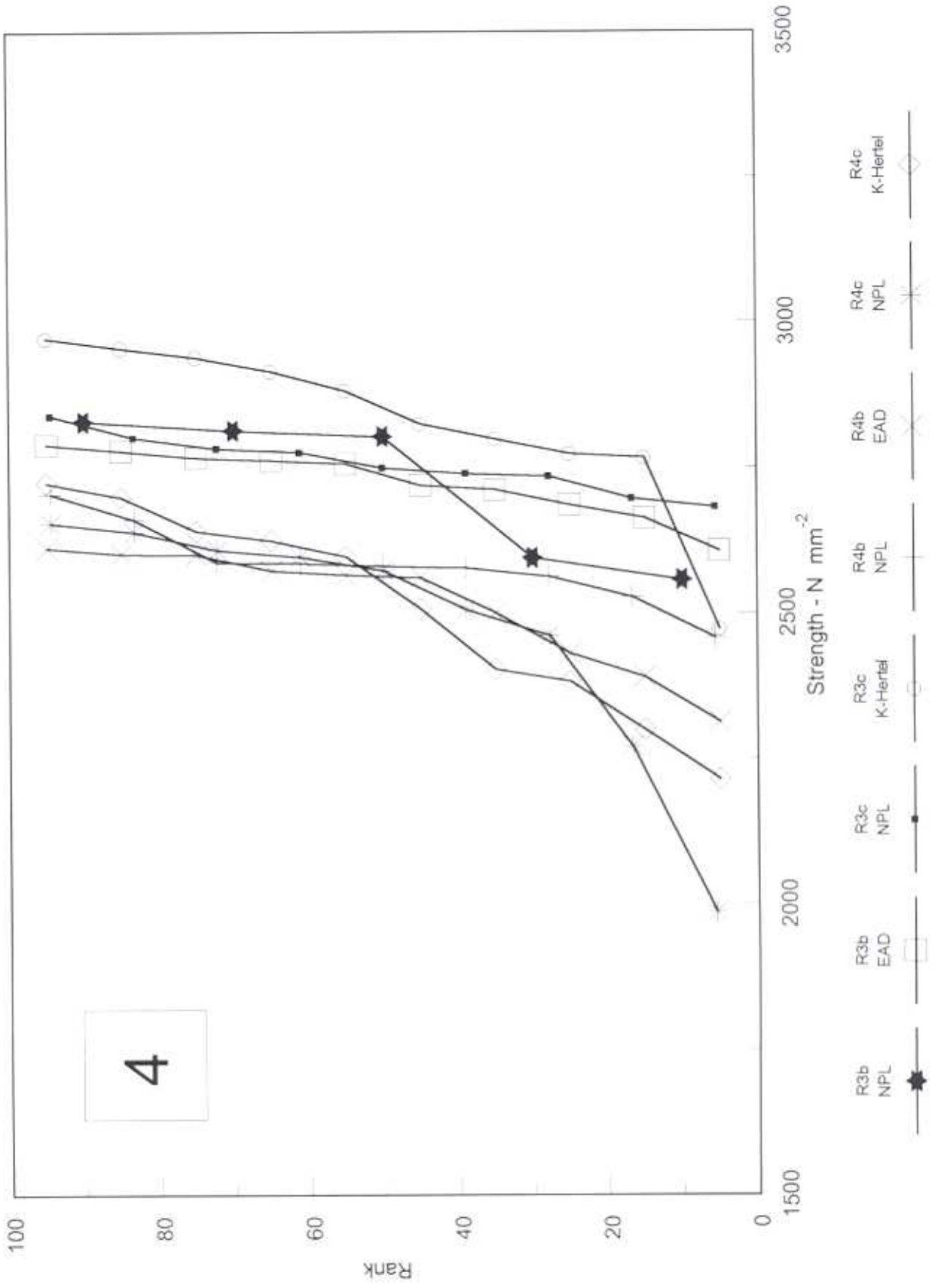
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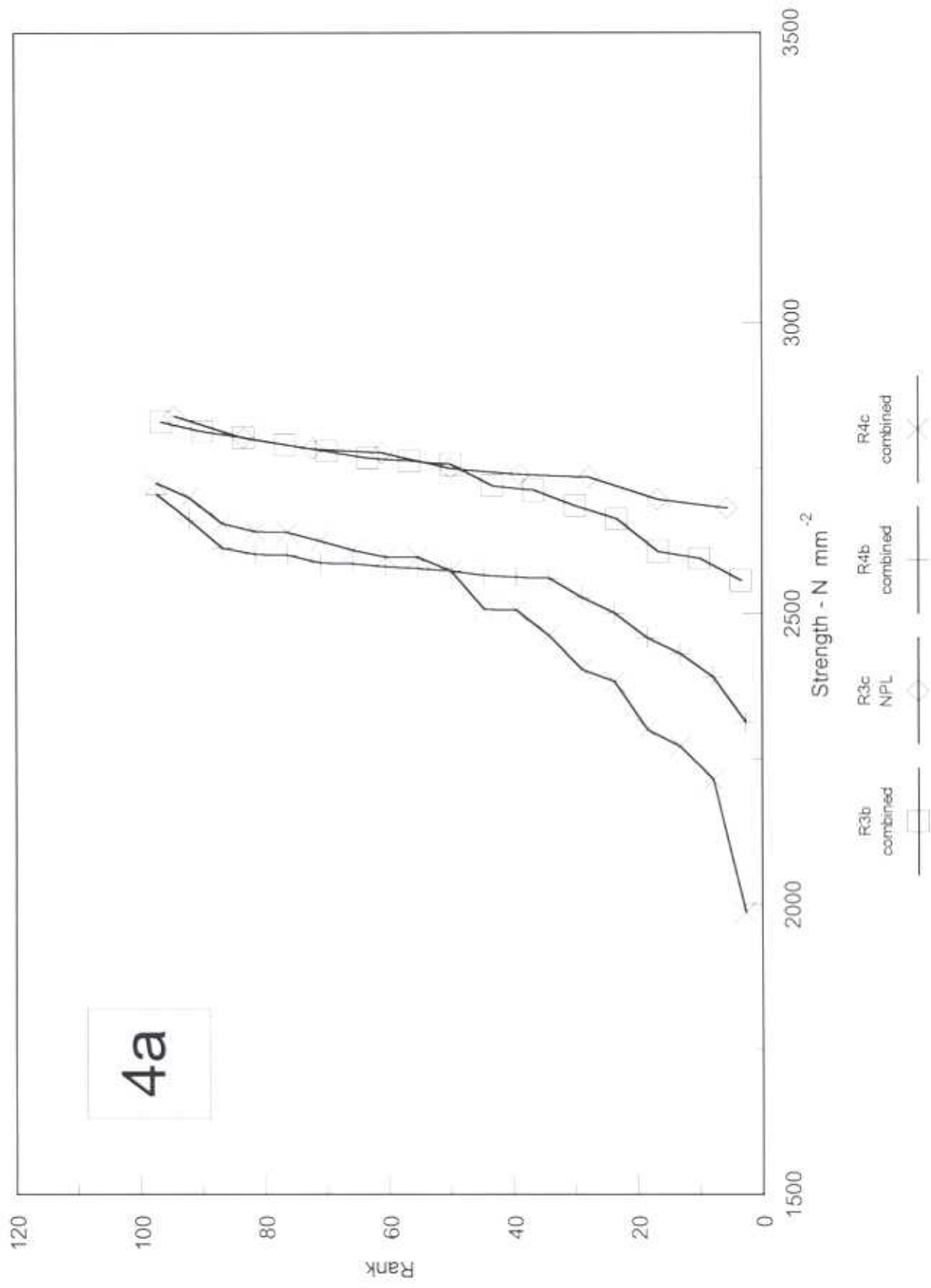
Bend Tests - Sandvik Med/Coarse WC/Co (5)



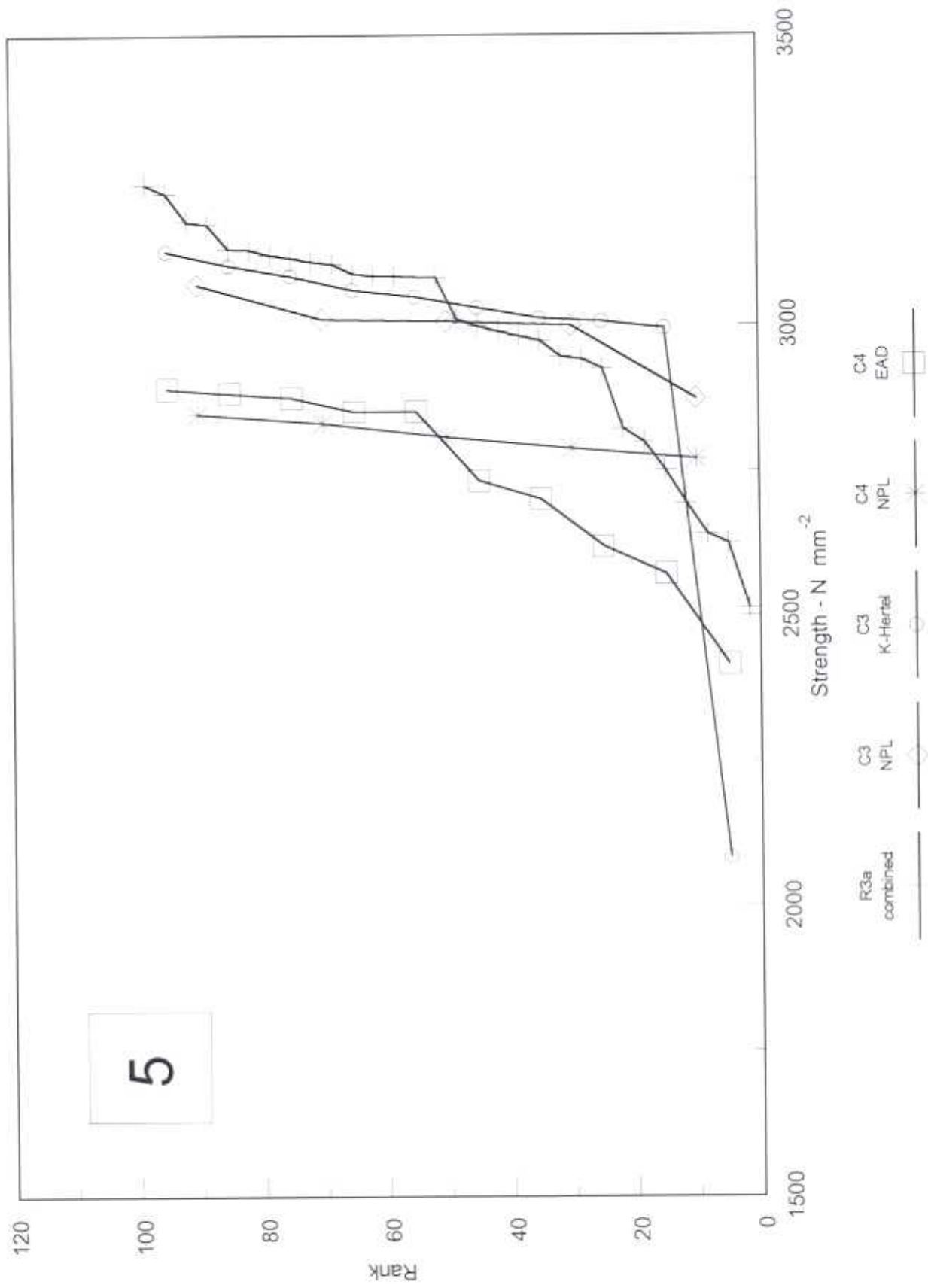
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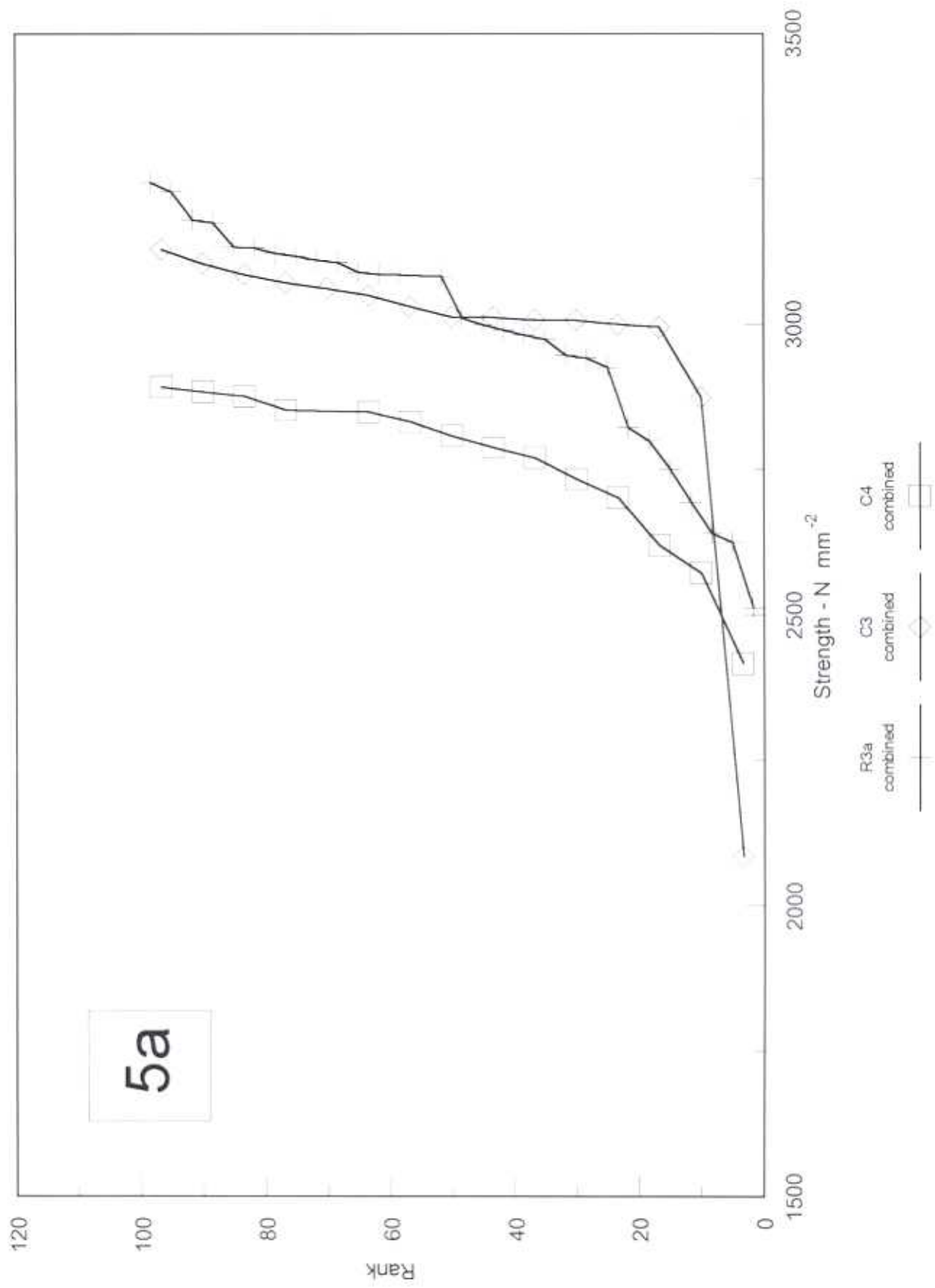
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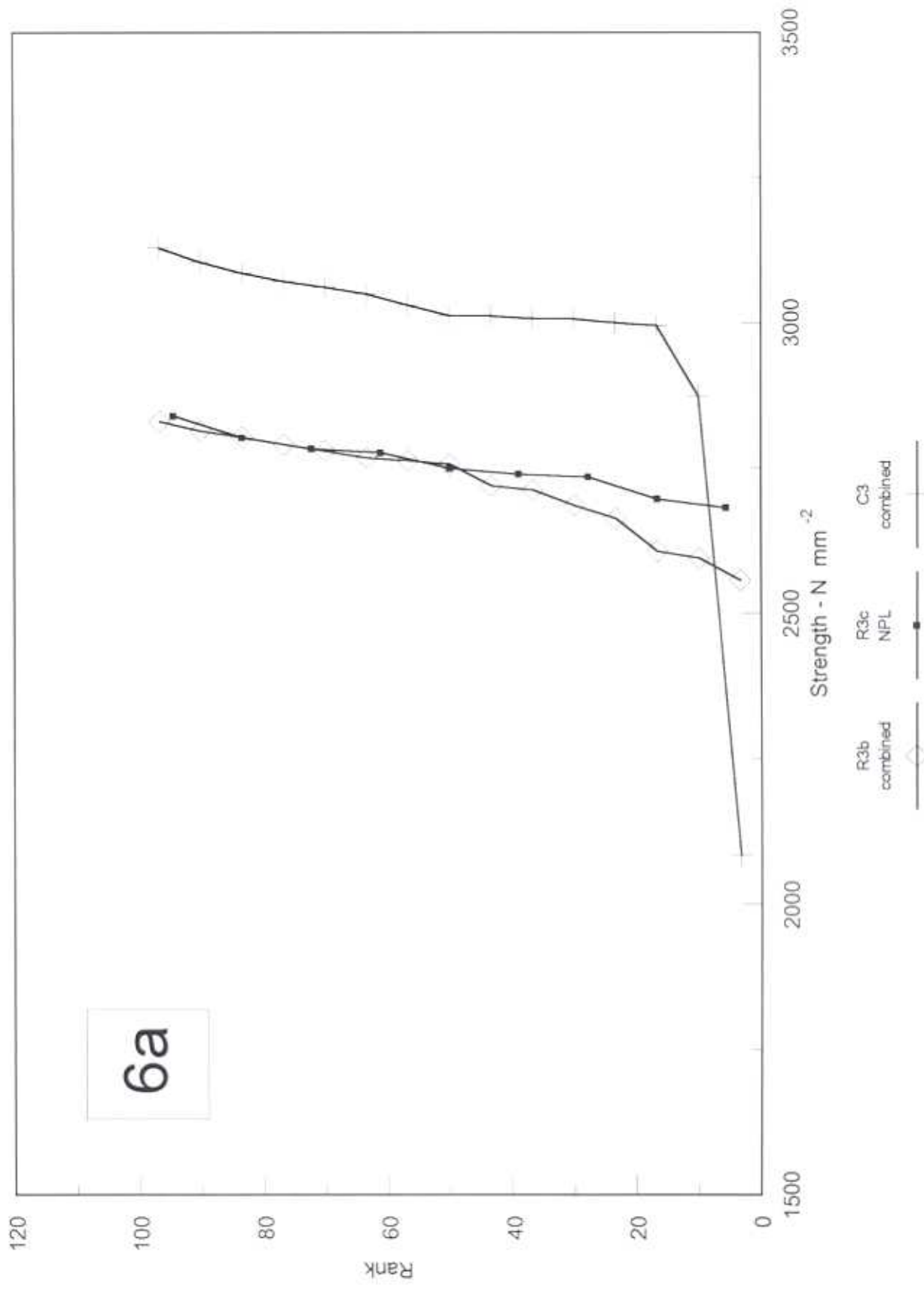
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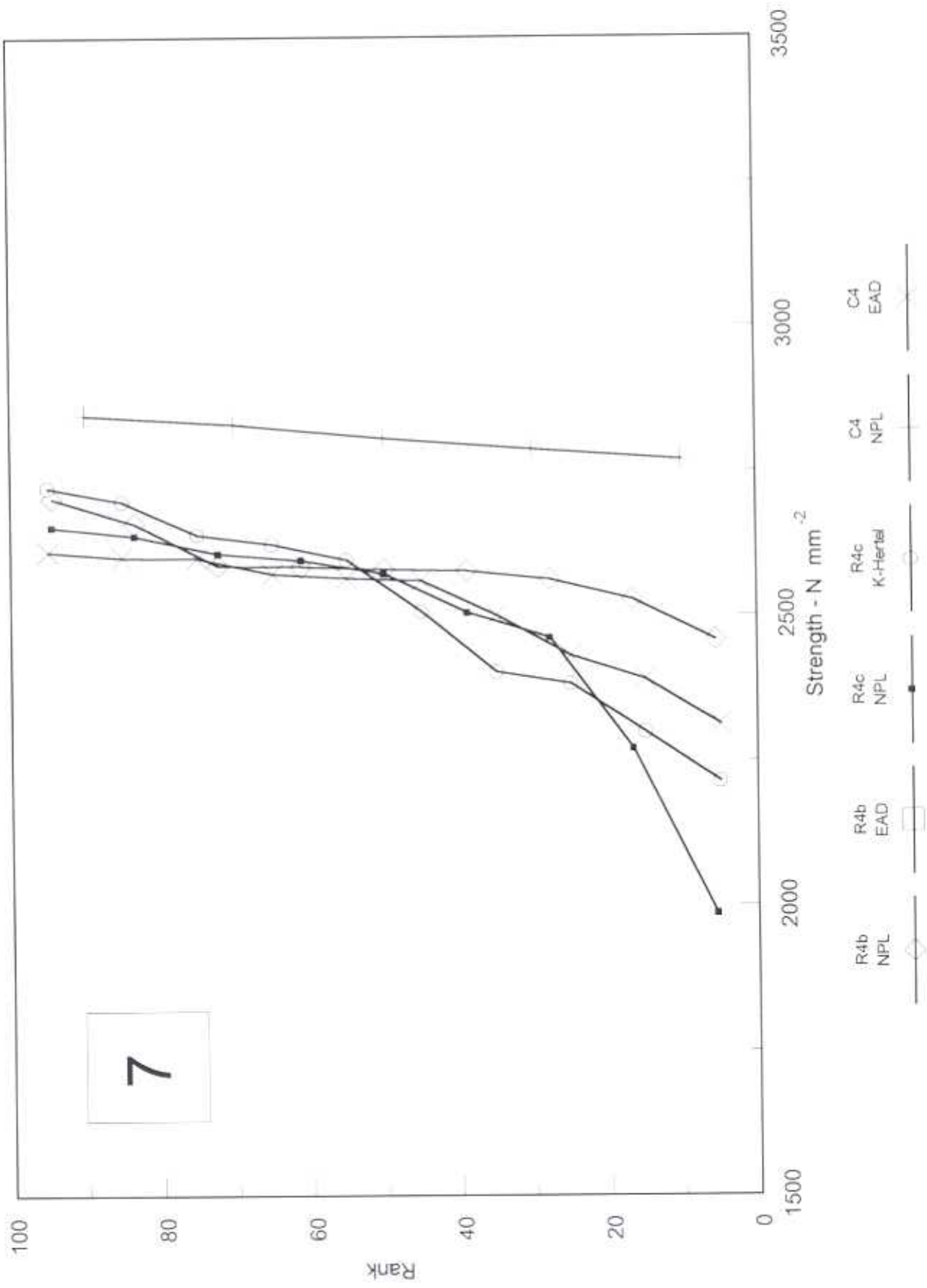
Bend Tests - Sandvik Med/Coarse WC/Co (5)



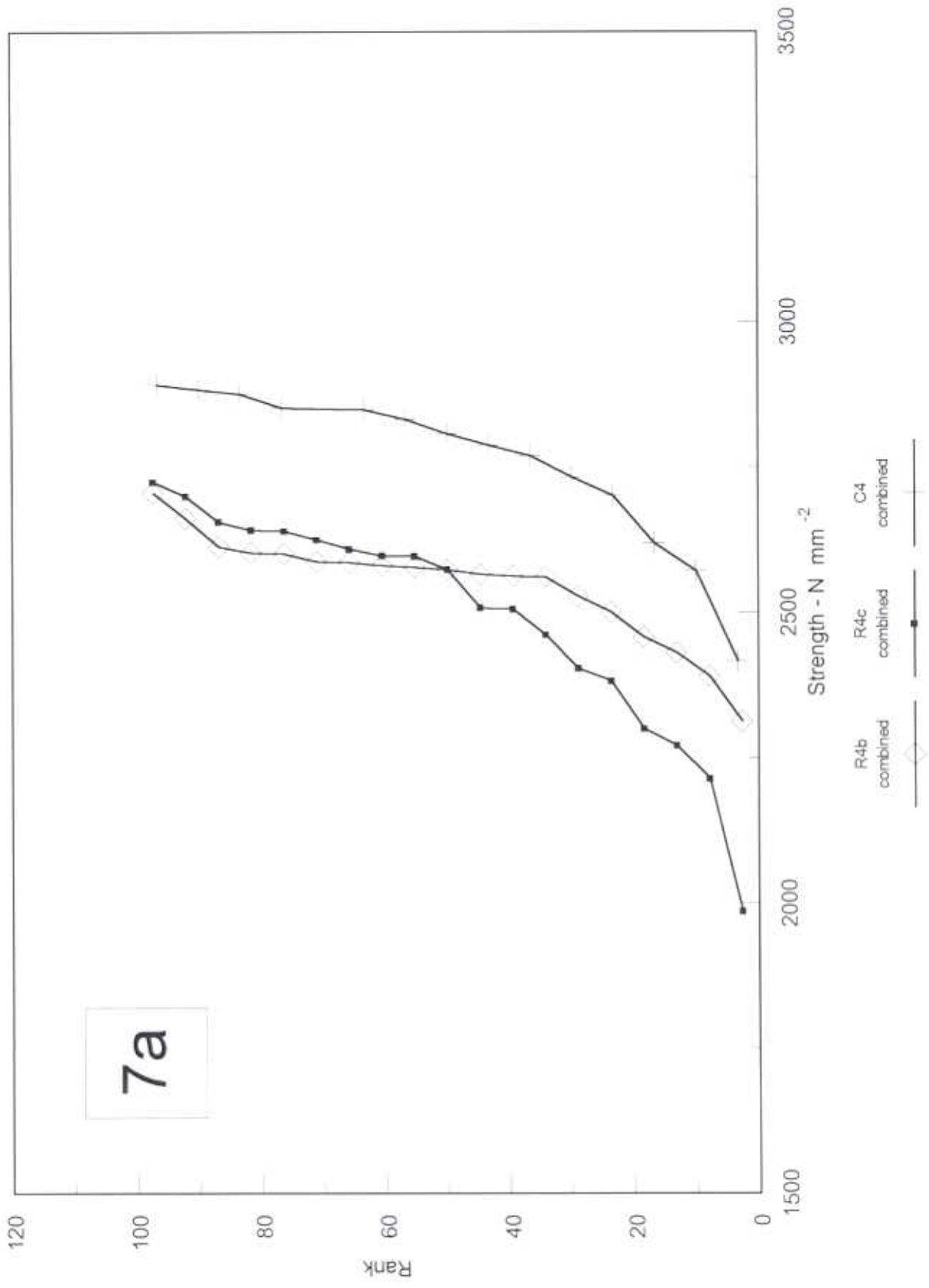
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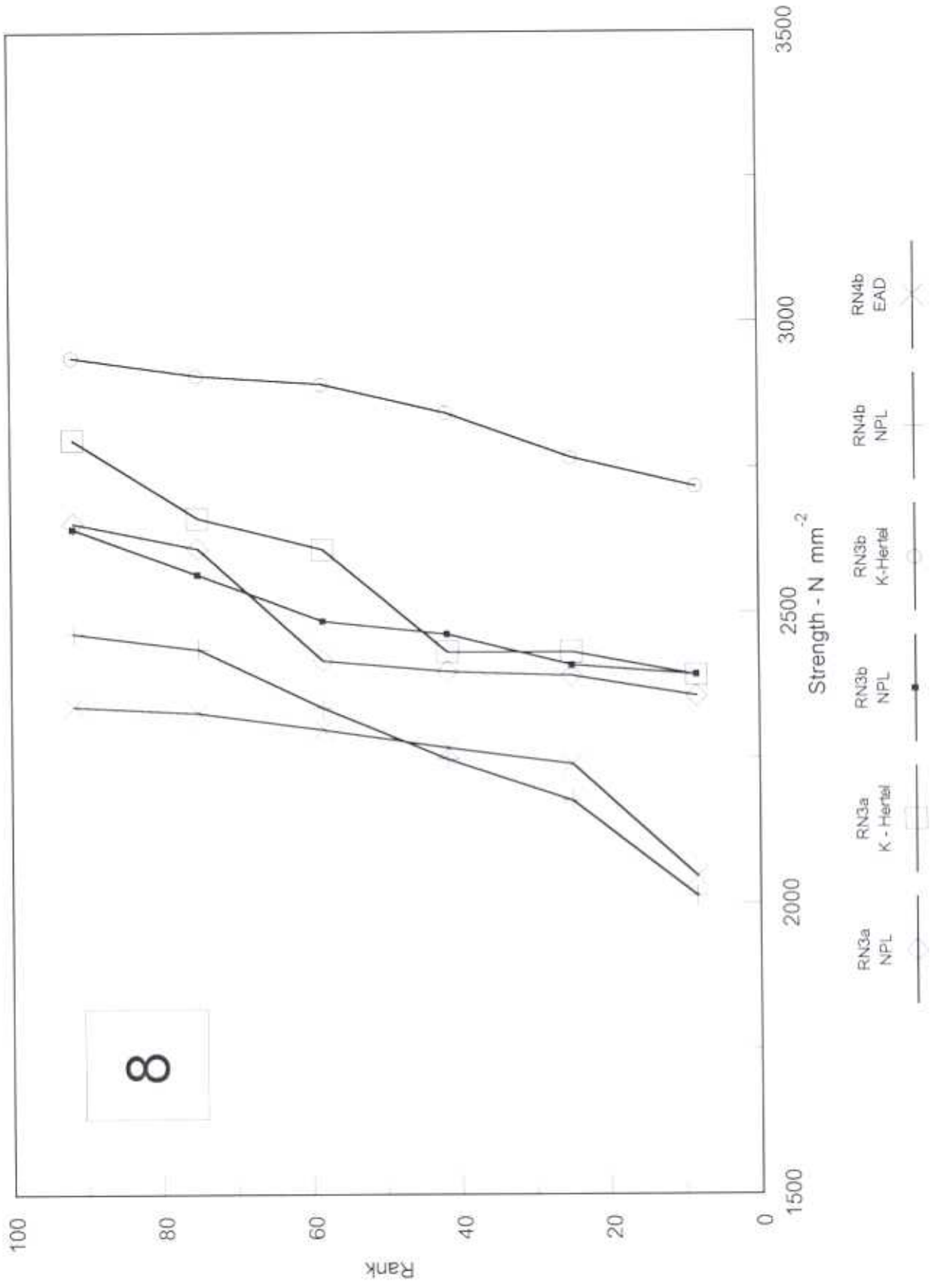
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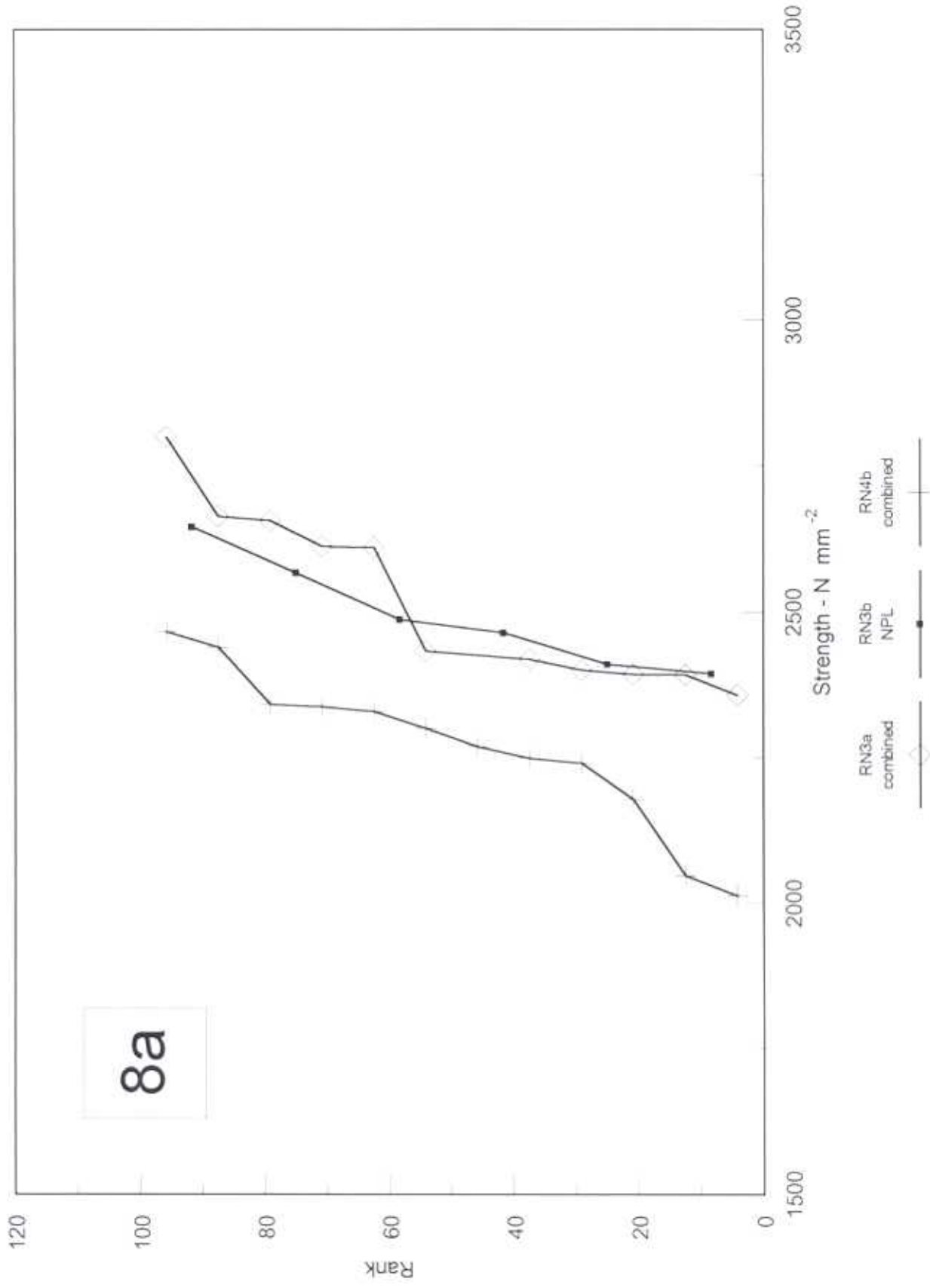
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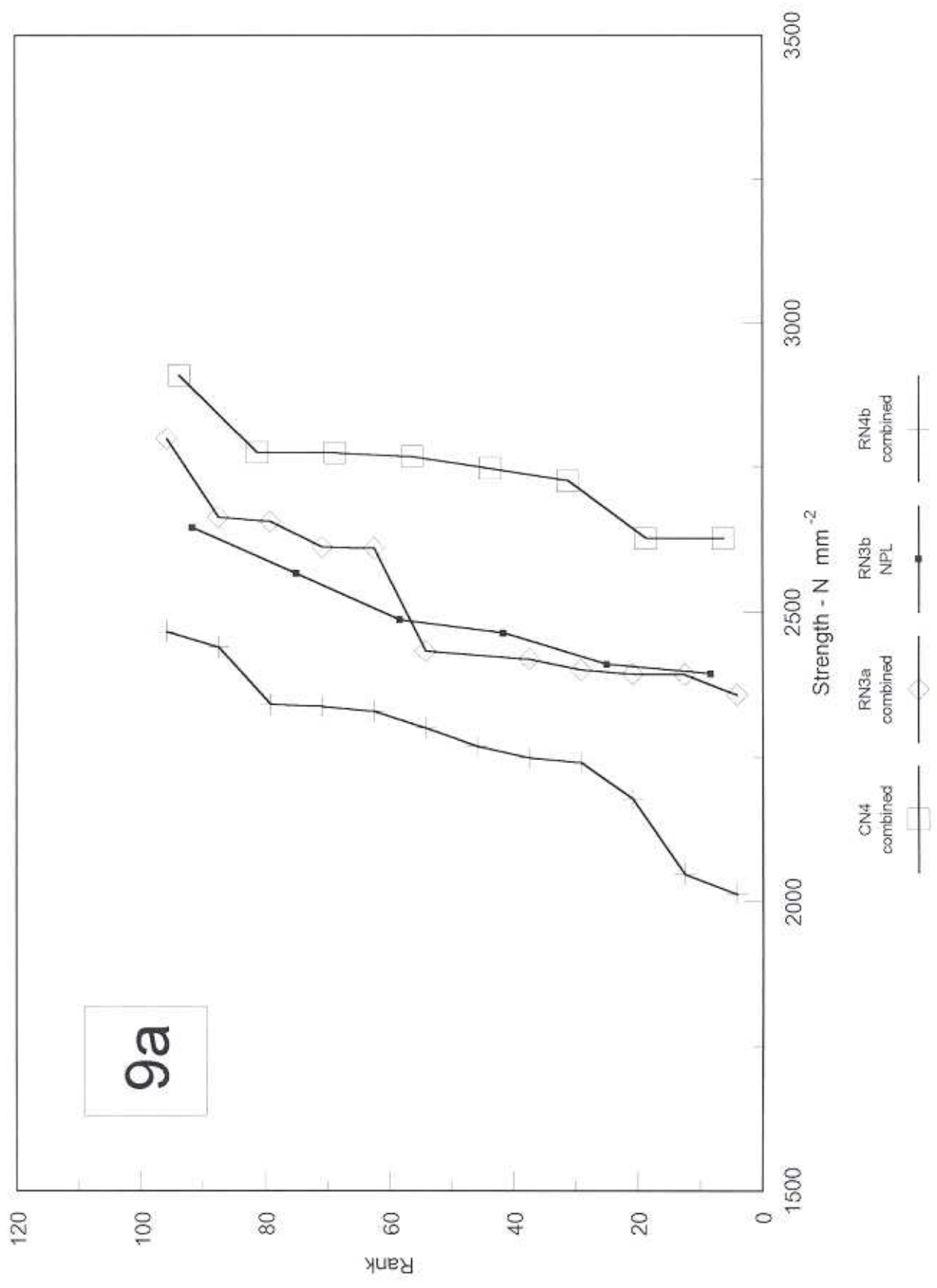
Bend Tests - Sandvik Med/Coarse WC/Co (5)



Bend Tests - Sandvik Med/Coarse WC/Co (5)



Bend Tests - Sandvik Med/Coarse WC/Co (5)



RESULTS SET

(7) BOART LONGYEAR

Coarse, WC/Co

Data Tables

Supplementary Comments

Data Plots

HARDMETAL BEND TESTS INTERNATIONAL INTERCOMPARISON

TABLES OF RESULTS

SET 7

WC/Co (Coarse grained) - Source: Boart Longyear

<i>Geometry</i>		<i>Organisation</i>
3 pt TRS	R3a	Standard Tests (NPL)
3,4 pt Rectangular	R3, R4	NPL
3,4 pt Rectangular Notched	RN3, RN4	NPL
Round	C3, C4, CN4	NPL

BOART LONGYEAR WC/Co(7) - COARSE
NPL STANDARD TRS TESTS - R3a

NPL					Span 13.8 mm Rate 600 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	6.51	5.25	18720	2238	1	2238	1	96.4
2	6.5	5.24	16760	2014	12	2233	2	89.3
3	6.5	5.25	15390	1843	13	2204	3	82.1
4	6.5	5.25	16960	2031	11	2187	4	75
5	6.5	5.23	17960	2167	10	2186	5	67.9
6	6.5	5.25	17260	2067	5	2167	6	60.7
7	6.5	5.25	17640	2112	7	2112	7	53.6
8	6.51	5.23	15690	1890	6	2067	8	46.4
10	6.5	5.24	18190	2186	14	2064	9	39.3
11	6.5	5.25	18270	2187	4	2031	10	32.1
12	6.5	5.25	18650	2233	15	2026	11	25
13	6.5	5.25	18410	2204	2	2014	12	17.9
14	6.5	5.24	17170	2064	8	1890	13	10.7
15	6.5	5.25	16920	2026	3	1843	14	3.6

**BOART LONGYEAR WC/Co(7) - COARSE
NPL BEND TESTS (R3b, R3c, R4b, R4c)**

R3b				Span 30 mm Rate 200 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	5.01	4.99	4830	1742	3	1913	1	94.4
2	4.95	4.99	5153	1881	2	1881	2	83.3
3	5.00	5.01	5334	1913	8	1874	3	72.2
4	5.00	5.00	5041	1815	6	1827	4	61.1
5	4.99	5.01	4549	1634	4	1815	5	50
6	5.00	5.00	5075	1827	7	1772	6	38.9
7	4.99	5.00	4912	1772	1	1742	7	27.8
8	4.99	5.00	5194	1874	9	1692	8	16.7
9	5.01	5.00	4709	1692	5	1634	9	5.6
10								

R3c				Span 40 mm Rate 35 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.00	2.98	1133	1914	1	1914	1	95
2	4.01	3.00	1140	1895	2	1895	2	85
3	4.01	3.00	1028	1709	9	1879	3	75
4	4.00	2.96	1083	1854	8	1859	4	65
5	4.01	2.99	1082	1811	4	1854	5	55
6	4.01	3.00	1051	1747	5	1811	6	45
7	4.01	2.99	1035	1732	6	1747	7	35
8	4.01	3.00	1118	1859	7	1732	8	25
9	4.01	3.01	1138	1879	3	1709	9	15
10	4.01	2.97	1005	1705	10	1705	10	5

R4b				Outer Span 10 mm Rate 200 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.99	5.00	6490	1561	3	1736	1	94.4
2	5.00	4.95	6539	1601	8	1711	2	83.3
3	5.01	5.00	7247	1736	6	1695	3	72.2
4	4.98	5.01	6940	1666	4	1666	4	61.1
5	5.01	5.00	6924	1658	9	1662	5	50
6	5.00	4.98	7008	1695	5	1658	6	38.9
7	5.00	5.01	6863	1641	7	1641	7	27.8
8	4.98	5.01	7130	1711	2	1601	8	16.7
9	5.00	5.00	6924	1662	1	1561	9	5.6
10								

R4c				Outer Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ⁻²	Number	Stress N mm ⁻²	Rank	%
1	4.01	2.99	1946	1628	9	1760	1	95
2	4.01	2.99	1848	1546	10	1751	2	85
3	4.01	2.98	1903	1603	4	1742	3	75
4	4.00	3.00	2090	1742	6	1682	4	65
5	4.01	3.01	2002	1653	8	1677	5	55
6	4.01	3.00	2024	1682	7	1661	6	45
7	4.01	2.99	1985	1661	5	1653	7	35
8	4.00	3.01	2026	1677	1	1628	8	25
9	4.01	3.00	2117	1760	3	1603	9	15
10	4.01	2.98	2078	1751	2	1546	10	5

**BOART LONGYEAR WC/Co(7) - COARSE
NPL TESTS - (R3b, R4b) ANNEALED**

R3b annealed					Span 30 mm Rate 200 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	5.01	4581	1643	9	1740	1	94.4
2	5.01	5.01	4733	1694	2	1694	2	83.3
3	5.00	5.00	4631	1667	8	1674	3	72.2
4	5.01	4.97	4593	1670	4	1670	4	61.1
5	5.01	5.00	4596	1651	3	1667	5	50
6	5.00	4.98	4423	1605	7	1662	6	38.9
7	5.00	5.00	4618	1662	5	1651	7	27.8
8	5.01	4.99	4641	1674	1	1643	8	16.7
9	5.01	5.00	4842	1740	6	1605	9	5.6

R4b annealed					Outer Span 10 mm Rate 100 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	5.01	6593	1576	9	1629	1	94.4
2	5.00	4.96	6083	1484	6	1580	2	83.3
3	5.00	4.99	6142	1480	5	1579	3	72.2
4	5.00	5.00	6515	1564	1	1576	4	61.1
5	5.00	5.00	6579	1579	7	1564	5	50
6	5.00	4.95	6452	1580	4	1564	6	38.9
7	5.00	5.00	6516	1564	8	1541	7	27.8
8	5.00	5.00	6420	1541	2	1484	8	16.7
9	5.00	5.00	6787	1629	3	1480	9	5.6

**BOART LONGYEAR WC/Co(7) - COARSE
NPL BEND TESTS (RN3a, RN3b, RN4b)**

RN3a				Span 13.8 mm Rate 200 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.00	5.00	1455	1882	6	1903	1	91.7
2	2.00	5.00	1452	1879	3	1895	2	75
3	2.00	5.00	1465	1895	1	1882	3	58.3
4	2.00	5.00	1404	1816	2	1879	4	41.7
5	2.00	5.00	1345	1740	4	1816	5	25
6	2.00	5.00	1471	1903	5	1740	6	8.3

RN3b				Span 30 mm Rate 80 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.00	5.00	661	2020	1	2020	1	91.7
2	2.00	5.00	597	1825	6	1901	2	75
3	2.00	5.00	619	1892	3	1892	3	58.3
4	2.00	5.00	577	1763	5	1849	4	41.7
5	2.00	5.00	605	1849	2	1825	5	25
6	2.00	5.00	622	1901	4	1763	6	8.3

RN4b				Outer Span 10 mm Rate 100 N s ⁻¹				
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	2.00	5.01	855	1678	6	1846	1	91.7
2	2.00	5.01	878	1723	5	1755	2	75
3	2.00	5.01	864	1695	2	1723	3	58.3
4	1.99	5.00	867	1718	4	1718	4	41.7
5	2.00	5.00	890	1755	3	1695	5	25
6	2.00	5.01	941	1846	1	1678	6	8.3

**BOART LONGYEAR WC/Co(7) - COARSE
NPL BEND TESTS (C3, C4, CN4)**

C3				Span 30 mm Rate 100 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	5.00	3278	2003	9	2223	1	94.4
2	5.00	3285	2008	5	2076	2	83.3
3	5.00	3097	1893	8	2069	3	72.2
4	5.00	3260	1992	7	2026	4	61.1
5	5.00	3397	2076	2	2008	5	50
6	5.00	3195	1953	1	2003	6	38.9
7	5.00	3315	2026	4	1992	7	27.8
8	5.00	3386	2069	6	1953	8	16.7
9	5.00	3638	2223	3	1893	9	5.6
10							

C4				Outer Span 10 mm Rate 100 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	5.00	4833	1969	1	1969	1	94.4
2	5.00	4678	1906	6	1943	2	83.3
3	5.00	4741	1932	3	1932	3	72.2
4	5.00	4701	1915	4	1915	4	61.1
5	5.00	4170	1699	2	1906	5	50
6	5.00	4768	1943	7	1877	6	38.9
7	5.00	4608	1877	8	1789	7	27.8
8	5.00	4390	1789	9	1700	8	16.7
9	5.00	4173	1700	5	1699	9	5.6
10							

CN4				Outer Span 10 mm Rate 100 N s ⁻¹			
Number	diameter, d mm	Load N	Stress N mm ²	Number	Stress N mm ²	Rank	%
1	5.00	1491	2159	6	2366	1	91.7
2	5.00	1538	2227	5	2337	2	75.0
3	5.00	1547	2240	3	2240	3	58.3
4	5.00	1516	2195	2	2227	4	41.7
5	5.00	1614	2337	4	2195	5	25
6	5.00	1634	2366	1	2159	6	8.3

**BOART LONGYEAR WC/Co(7) - COARSE
NPL TESTS - (C3, C4) ANNEALED**

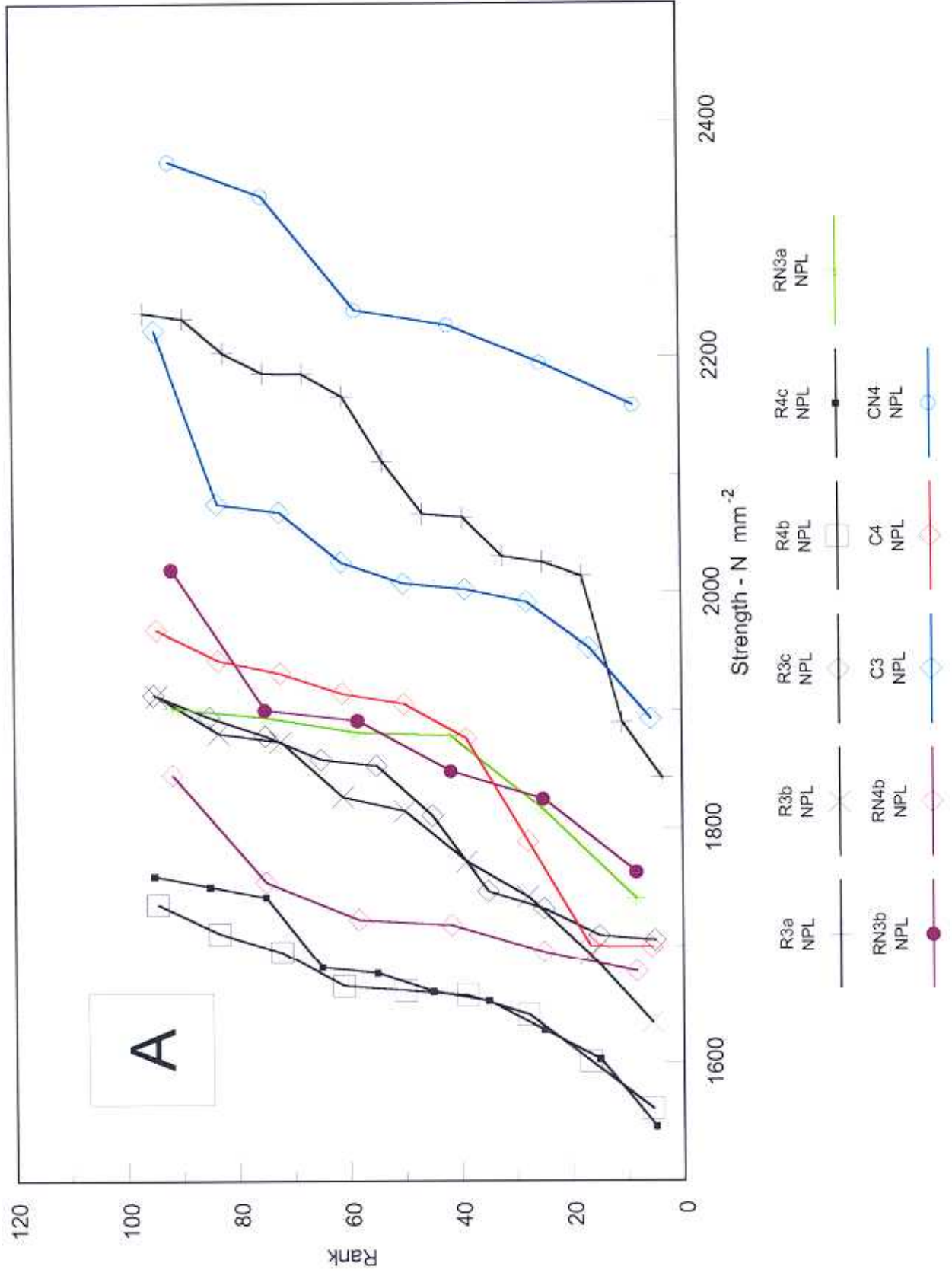
C3 annealed					Span 30 mm Rate 100 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	2821	1724	1552	4	1866	1	94.4
2	5.00	3150	1925	1733	8	1778	2	83.3
3	5.00	2661	1626	1464	7	1738	3	72.2
4	5.00	3392	2073	1866	2	1733	4	61.1
5	5.00	2835	1733	1559	9	1697	5	50
6	5.00	3054	1866	1680	6	1680	6	38.9
7	5.00	3160	1931	1738	5	1559	7	27.8
8	5.00	3232	1975	1778	1	1552	8	16.7
9	5.00	3086	1886	1697	3	1464	9	5.6

C4 annealed					Outer Span 10 mm Rate 100 N s ⁻¹			
Number	B mm	W mm	Load N	Stress N mm ²	Number	Stress N mm ⁻²	Rank	%
1	5.00	4244	4244	1729	2	1796	1	94.4
2	5.00	4408	4408	1796	6	1755	2	83.3
3	5.00	4154	4154	1692	8	1744	3	72.2
4	5.00	4040	4040	1646	1	1729	4	61.1
5	5.00	4241	4241	1728	5	1728	5	50
6	5.00	4308	4308	1755	7	1701	6	38.9
7	5.00	4174	4174	1701	3	1692	7	27.8
8	5.00	4281	4281	1744	4	1646	8	16.7
9	5.00	3867	3867	1576	9	1576	9	5.6

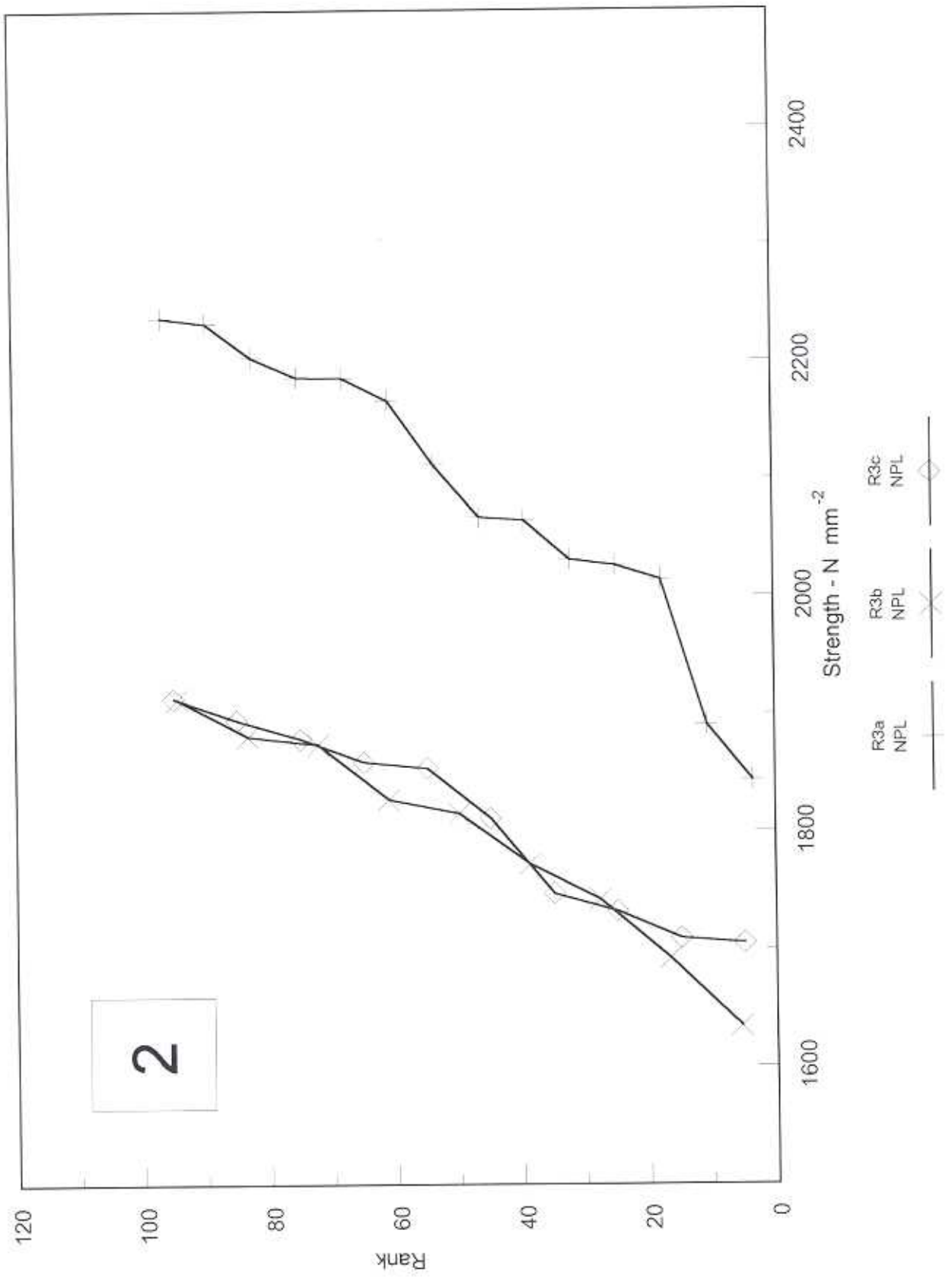
HARDMETAL BEND TESTS**Results Comment Sheet****Boart Longyear Category (7) Coarse WC/Co Hardmetal****PLOT SEQUENCE**

- A - Complete set of all strength values.
- 2 - 3 pt rectangular tests, compared with ISO Type B, R3a, R3b, R3c.
- 3 - 4 pt rectangular tests, compared with standard ISO type B; R3a, R4b and R4c.
- 4 - 3 pt vs 4 pt tests; not including R3a, R3b, R3c, R4b, R4c.
- 5 - Round testpieces, compared with standard R3a, C3, C4 and R3a.
- 6 - 3 pt rectangular and round, R3b, R3c and C3; not including R3a..
- 7 - 4 pt rectangular and round, R4b, R4c and C4.
- 8 - Notched rectangular testpieces, RN3a, RN3b and RN4b.
- 9 - Notched round compared with notched rectangular; CN4 and RN3a, RB3b and RN4b.
- 10 - Annealed testpieces compared with as-ground testpieces, R3b, R4b, C3 and C4.

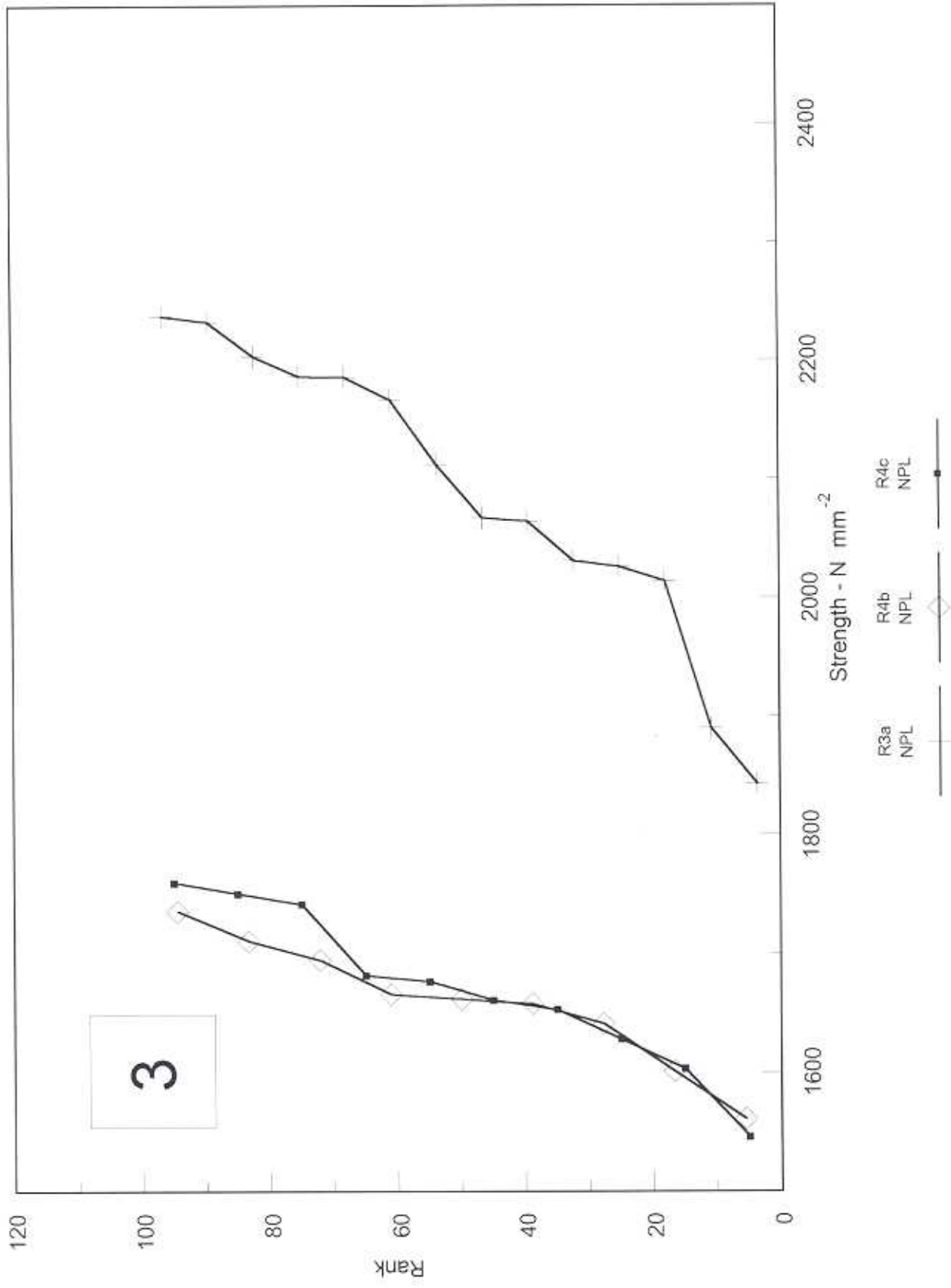
Bend Tests - Boart WC/Co (2)



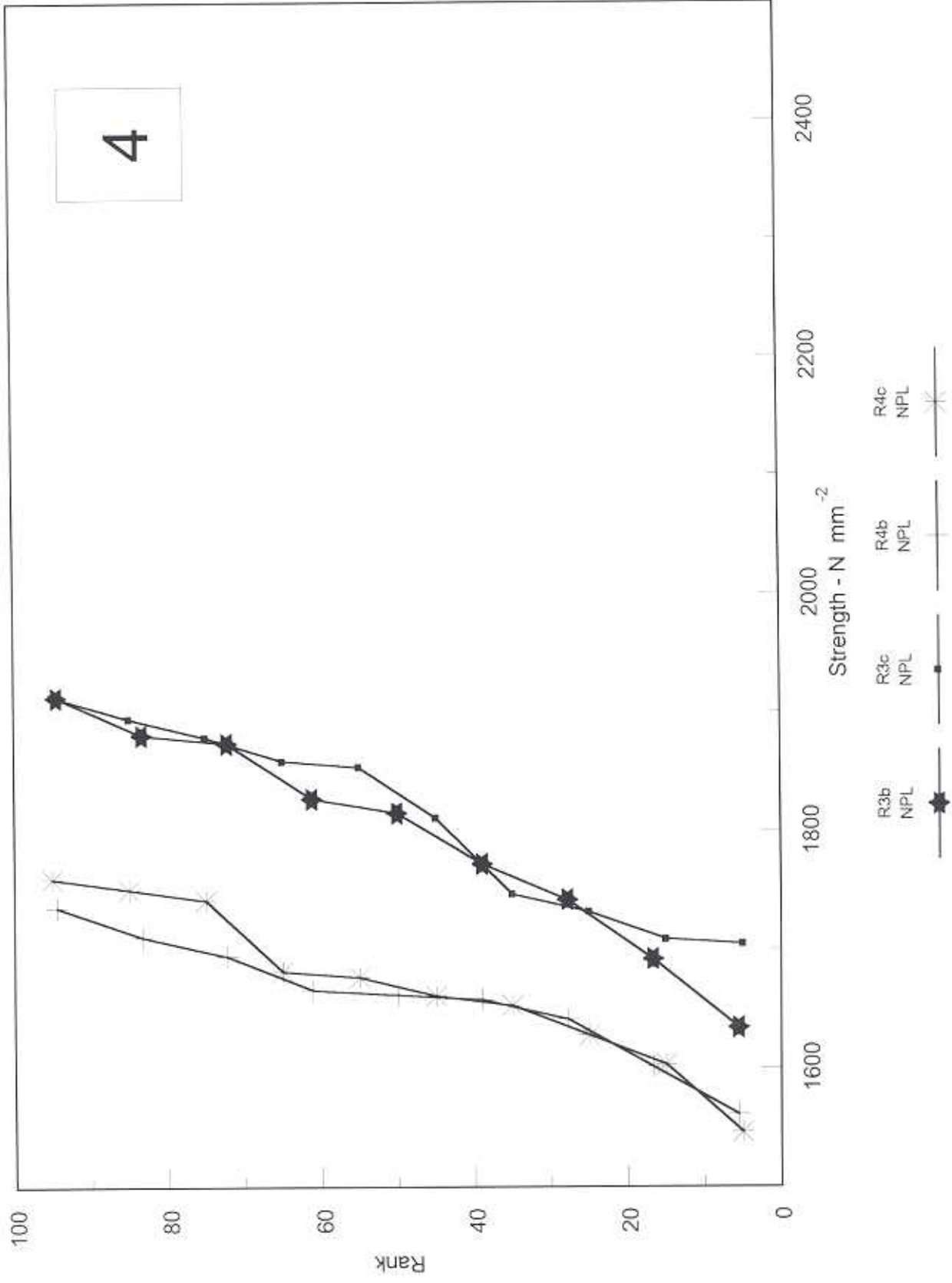
Bend Tests - Boart Coarse WC/Co (7)



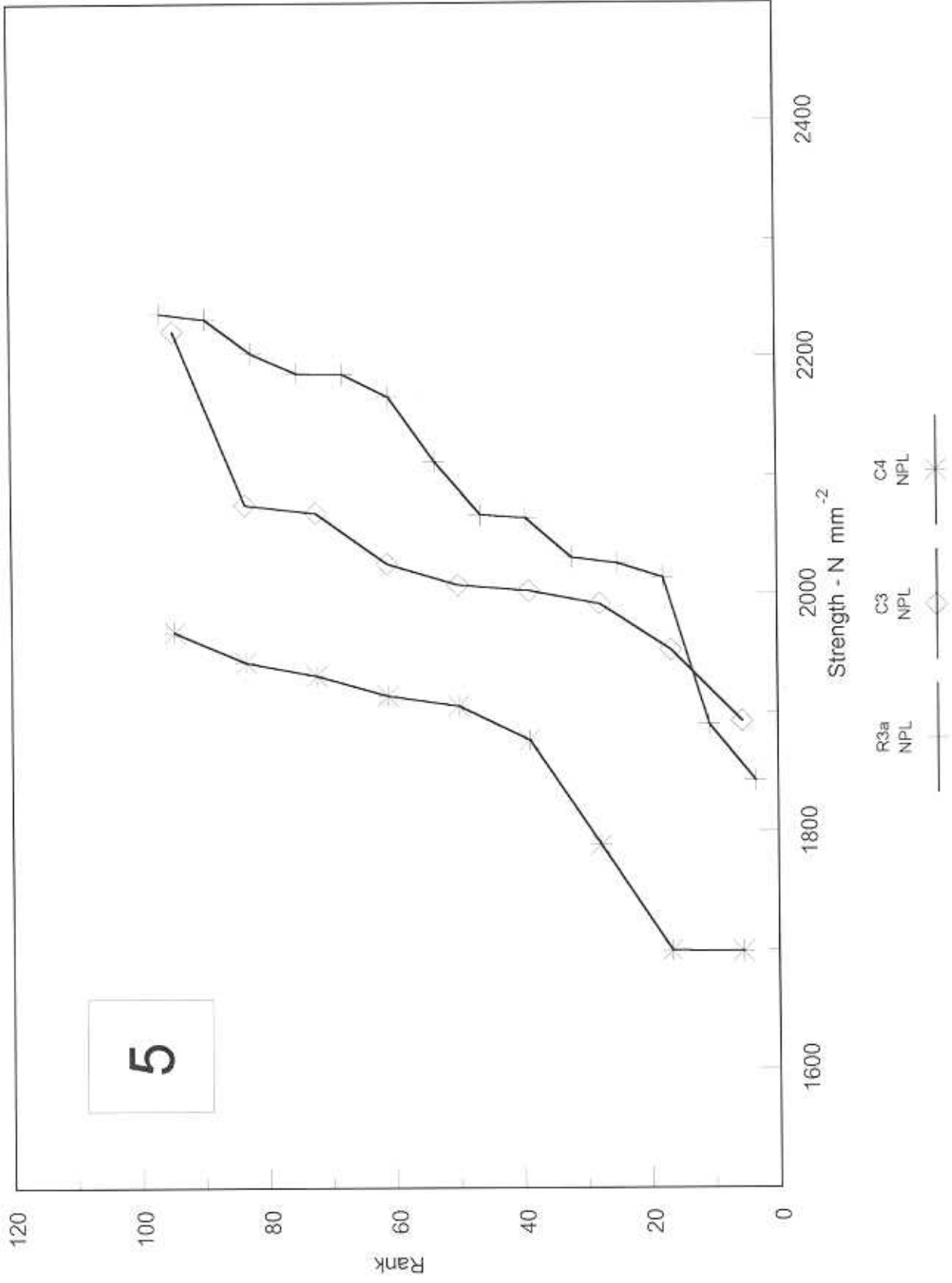
Bend Tests - Boart Coarse WC/Co (7)



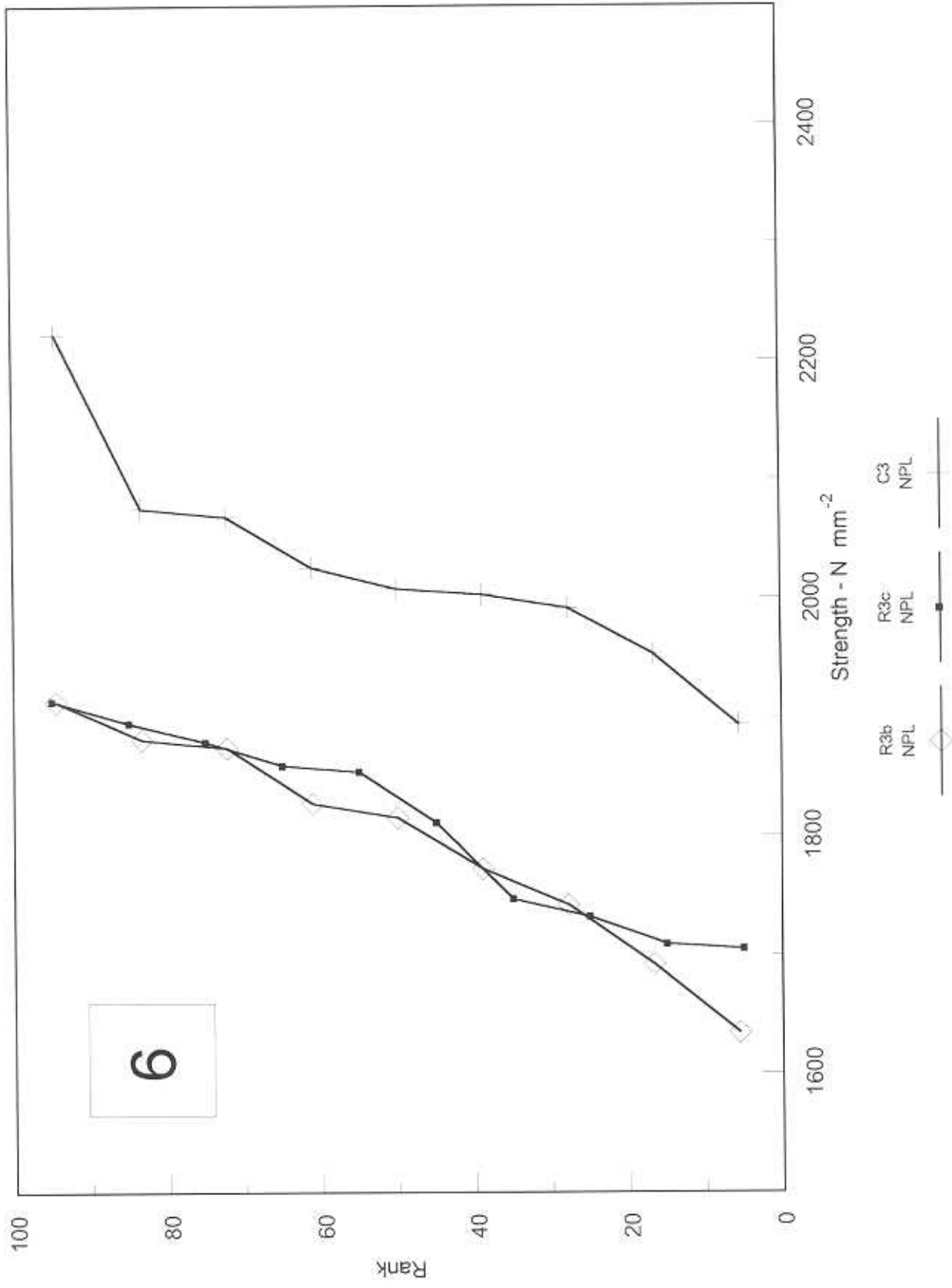
Bend Tests - Boart Coarse WC/Co (7)



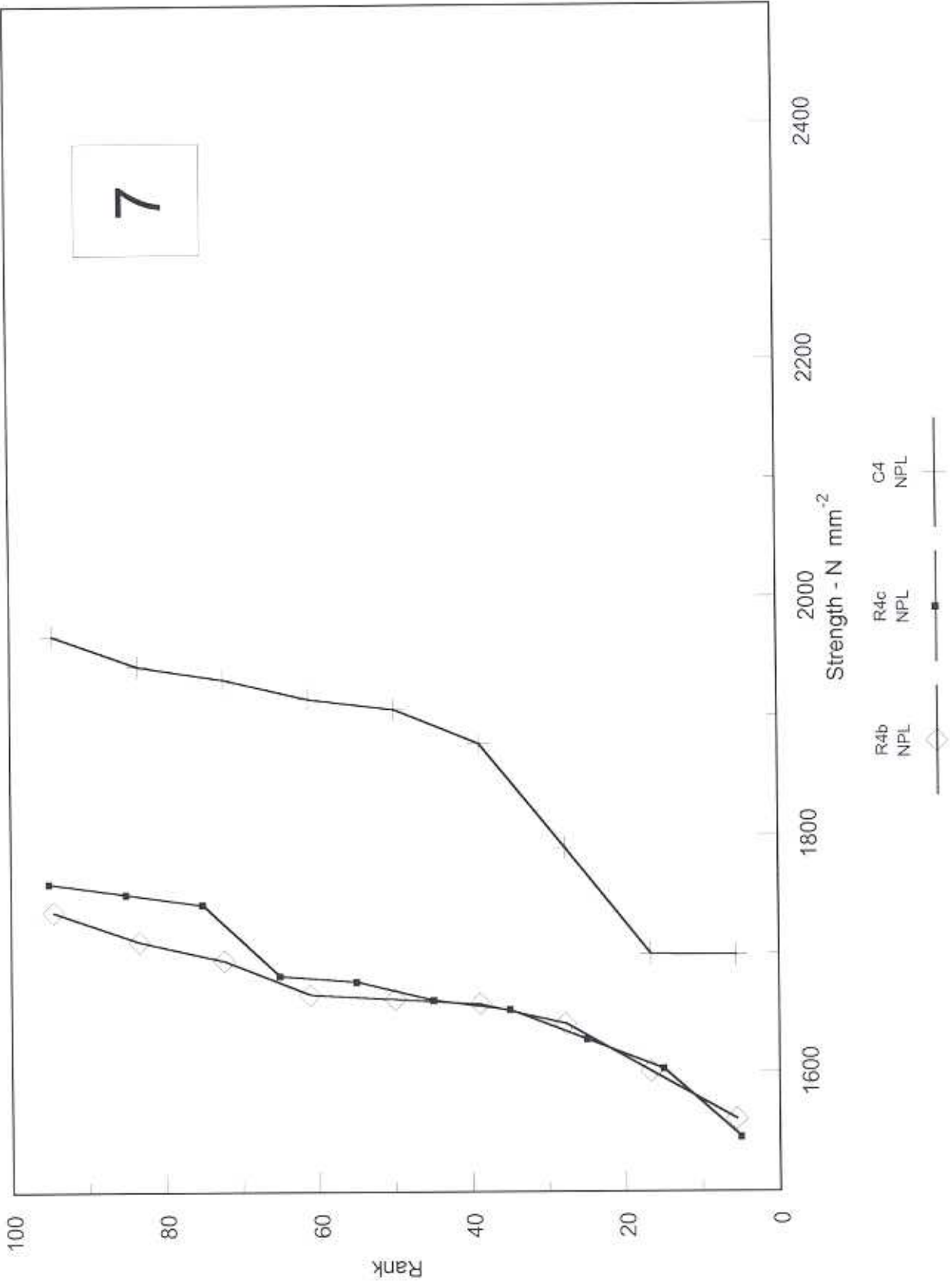
Bend Tests - Boart Coarse WC/Co (7)



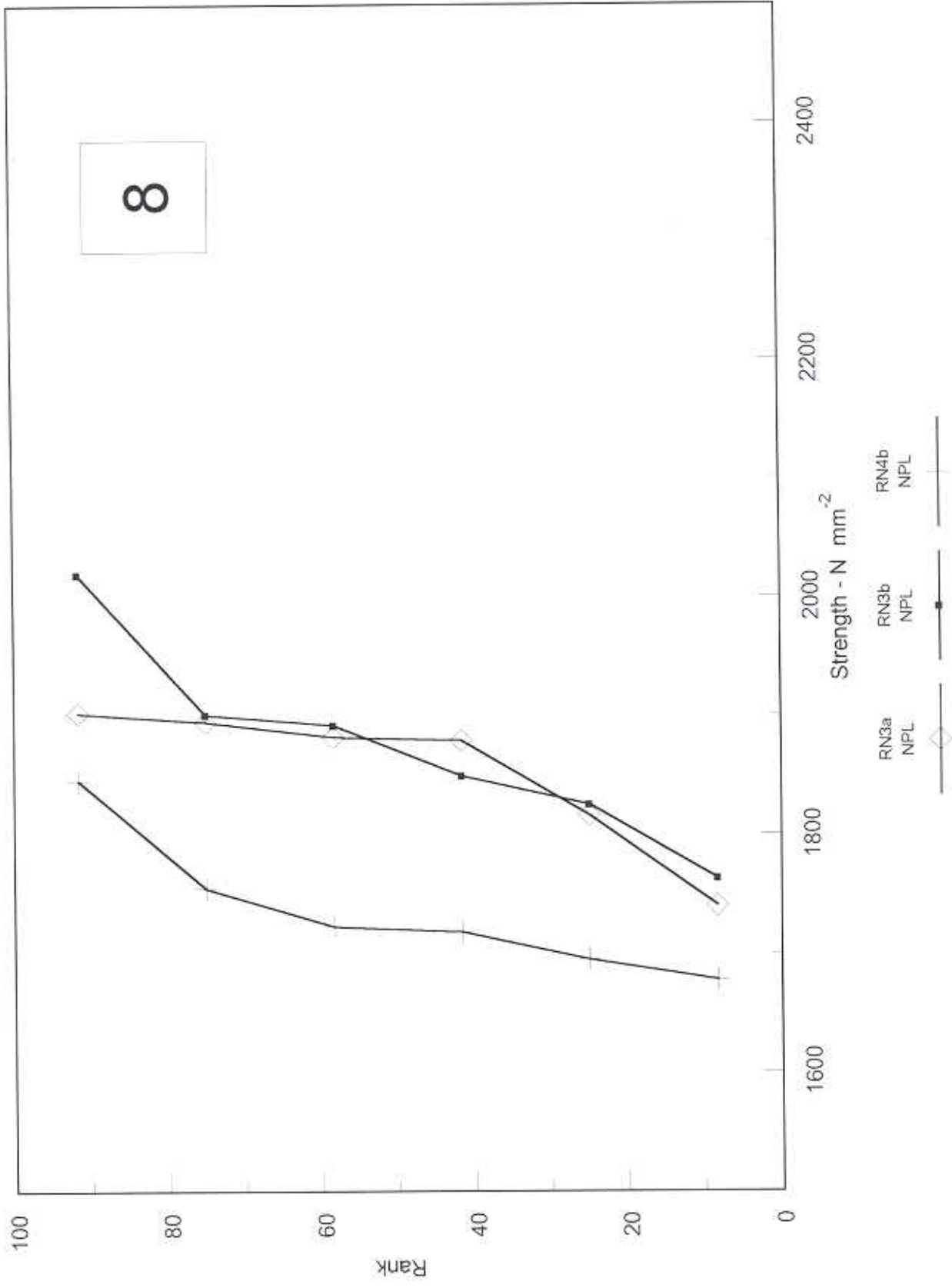
Bend Tests - Boart Coarse WC/Co (7)



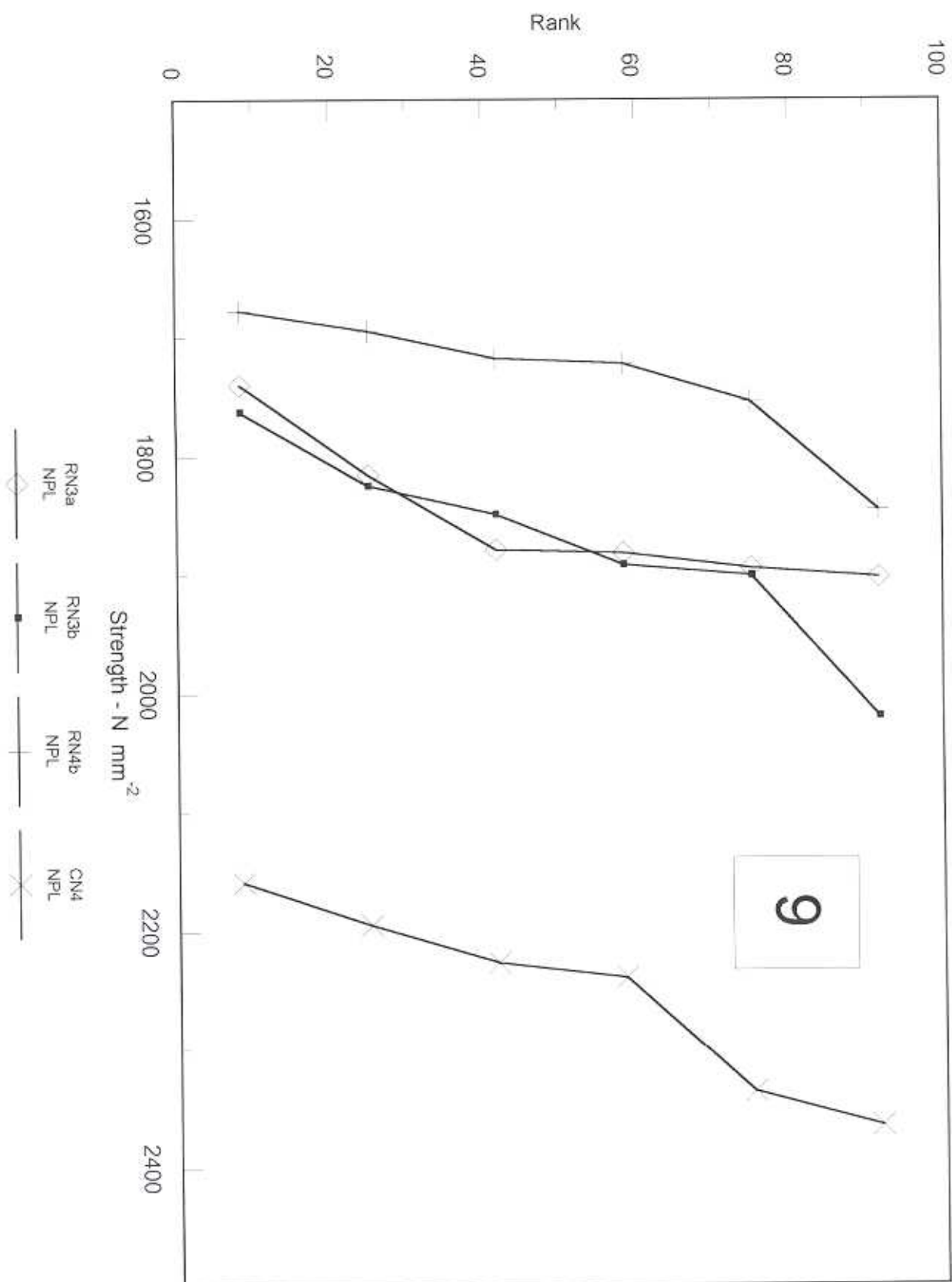
Bend Tests - Boart Coarse WC/Co (7)



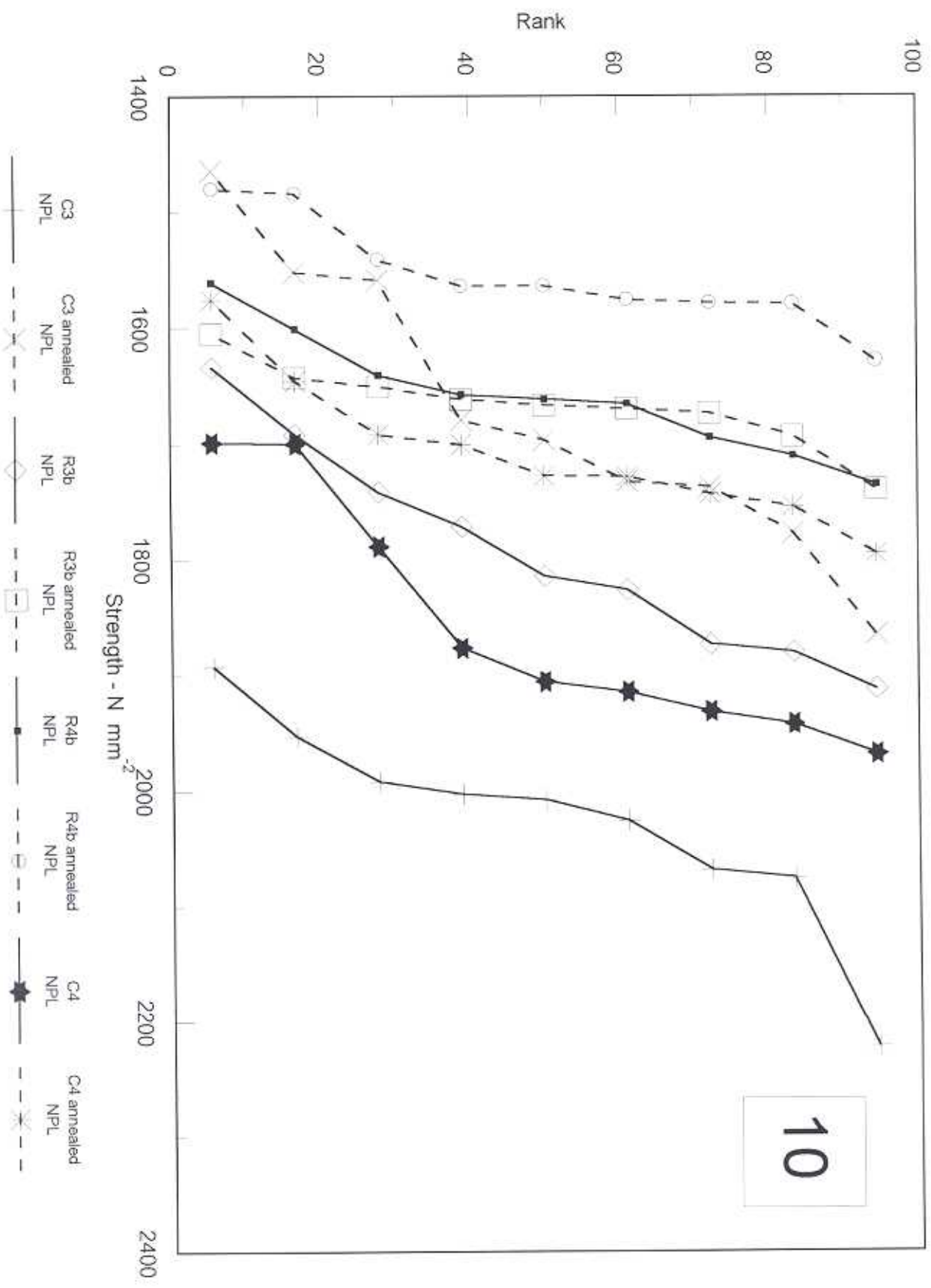
Bend Tests - Boart Coarse WC/Co (7)



Bend Tests - Boart Coarse WC/Co (7)



Bend Tests - Boart Coarse WC/Co (7)



APPENDIX A
ACTIVITY RATIONALE

Publication in International Journal of Refractory Metals and Hard Materials

Announcement

Bend Strength Measurements for Hardmetals — International Prestandardisation Collaborative Activity

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INTRODUCTION

There is a need to re-evaluate the current standard for Transverse Rupture Tests (bend tests) for Hardmetals, ISO 3327, to take account of developments in the understanding of strength measurements, the increasing desire for more relevant data to material quality and design, and not least, to work towards a test which can give results comparable to test data obtained on competing materials, such as ceramics and cermets. Following an initial assessment an agreement has been reached to perform an international inter-laboratory exercise, the purpose being to examine a number of alternative methods of bend tests for hardmetals to that specified in ISO 3327, to include geometries which compare with standards for ceramics (3 and 4 pt), to include tests on small specimens, to include unconventional geometries (round and notched) and possibly to include methods of specimen preparation. The final outcome will be an independent report with analysis of the results of the test programme for input to the appropriate standardisation bodies.

Specimens and testpieces are due to arrive at NPL in early 1994. Rigs and testpieces will be circulated for testing throughout the rest of 1994

and early 1995, with a final report due in autumn 1995.

Background

In North America a military standard MIL-STD-1942A for flexure tests on ceramics has been adopted by the ASTM. In Europe a new CEN standard for bend tests on ceramics is in draft. In Japan there is a relevant standard JIS R 1601. The geometries associated with these standards are summarised in Table 1. None of these geometries are compatible with ISO 3327.

Recent correspondence with Kennametal USA and the US ASTM committee for tests on hardmetals, regarding the relative merits of 3 and 4 pt bend tests, has indicated a renewed interest in a more relevant test method. In addition, Sandvik Hard Materials, UK, have expressed views regarding the usefulness of testing round specimens. Work at NPL has indicated that notched bend tests can give useful data. Furthermore, communication with colleagues in Japan, where they test different geometries again, has indicated puzzling data obtained in bend tests on ultra-fine grained hardmetals. Clearly there is considerable scope for examining these issues on an interna-

Table 1. Standard geometries for bend testing

Standard	Type	Width <i>b</i> (mm)	Thickness <i>h</i> (mm)	Total span 3 pt, 4 pt (mm)	Inner span 4 pt (between central rollers) (mm)
MIL STD 1942A = ASTM C1161-1990	A	2	1.5	20	10
	B	4	3	40	20
	C	8	6	80	40
JIS 1601	—	3	3	30	10
CEN	A	2	2.5	20	10
	B	4	3	40	20

tional basis, in order to generate a widely agreed test procedure, which, because of the harmonised approach, would provide the basis for validated recommended methods of testing. Following these preliminary discussions, questionnaires were sent to various organisations around the world for comments on the suitability of an international prestandardisation collaborative activity. The responses are summarised in Table 2. From these responses a plan was proposed which is outlined in the next section.

Outline plan

The outline plan consists of three parts:

- comparison of relevant standards,
- a matrix of testing options,
- materials and sources.

A large series of tests are envisaged to take account of the widespread interest in participation. Some of the tests will involve jigs being circulated between several organisations. Consequently it is planned that about nine–twelve months will be required to complete the tests. A draft report outlining the basic results but without any detailed analysis will be produced by mid-1995 for all participants to debate.

Testpieces and procedure

All test pieces horizontally ground to ISO 3327, 0.2 mm chamfer (45°), out of squareness $\leq 2^\circ$, ± 0.01 mm tolerance, cylindrical load supports and load points with loading rate of ≥ 1500 N s⁻¹. Load measured to $\pm 1\%$.

Standards

3 pt testing, rectangular testpieces

The information in Table 3 is taken from four standards documents which contain information

of relevance: EN843 pt 1 (flexure testing of ceramics), ISO 3327 (TRS of hardmetals), ASTM B406 (TRS of cemented carbides) and CIS 026-1983 (TRS of cemented carbides — CCTMAS, Japan). The information in this table relates only to ground testpieces.

4 pt testing, rectangular testpieces

The standards for testing hardmetals do not include the option of 4 pt tests. However, the ASTM conducted a comparative exercise in the 1980s and the EN standard for ceramics will allow 4 pt tests. Table 4 contains some information of a comparative nature from these sources, used to assist in planning the current interlaboratory exercise. Testpiece preparation is essentially the same as that given in Table 3 for 3 pt test comparisons.

Additional comments

The following comments taken from the ASTM B09.06 exercise (courtesy of J. J. Oakes, Teledyne Advanced Materials and ASTM) on 3 pt vs 4 pt tests, and additional notes from the Japanese standards document CIS 026-1983 must be taken into account.

ASTM B09.06: (a) 4 pt TRS results are significantly lower than those measured by 3 pt tests; (b) the use of 4 pt test gave no improvement in test data scatter compared with 3 pt tests; (c) no significant difference was noted between 3 pt tests using a 10 mm diameter cemented carbide ball or a 6.35 mm diameter cemented carbide roll for the central loading point.

CIS 026-1983: The document indicates that preliminary tests were conducted to compare the Japanese testpiece design (24 × 8 × 4) with the ISO type A design (35 × 5 × 5) and type B design (20 × 6.5 × 5.25). The following comments have been selected (the full document can be obtained

Table 2. Bend tests for hardmetals
(i) Questionnaire response

<i>Organisation (contact)</i>	<i>Agreement with objectives^a</i>	<i>Participation desire^a</i>
Kennametal, USA/UK, Europe (B. North/J. Vankirk/J. Ashley)	H	H
General Carbide Corporation, USA (P. J. Pappafava)	M	M
Fansteel Hydro Carbide, USA (J. E. Campbell)	M	M
Teledyne Advanced Materials, USA (J. J. Oakes)	H	H
Sandvik Hard Materials, UK (V. Thompson)	H	H
Hydra Tools, UK (J. Haddock)	H	M
Hertel AG, Germany (Dr Görting)	H	H
Hoybide, UK (C. Fletcher)	M	M
Boart Research Centre, South Africa (I. Northrop)	H	H
NPL, Teddington, UK (B. Roebuck)	H	H
Sandvik AB, Sweden (B. Aronsson, C. Chatfield)	H	H
Duramet Corporation, USA (C. James)	H	H
Refractory/Hard Metals Research Institute, Russia (K. S. Cherniavsky)	H	H
Boart Hardmetals, South Africa (R. Cooper)	H	H
BAM, Berlin, Germany (E. Rudolph)	H	H
CCMA, Japan (H. Negishi, Mitsubishi)	H-2 M-2 L-3	H-0 M-3 L-4
Dymet Alloys Ltd, UK (B. Richardson)	H	M
Danite Hard Metals Ltd, UK (S. Mosely)	H	H
Plansee Tizit Ltd, UK/Austria (R. Edwards/E. Garber)	H	H
American National Carbide, USA (J. E. Peters)	H	M
Marshalls Hard Metals Ltd, UK (W. Coles)	M	M
Neepsend Tools Ltd, UK (E. Darlow)	H	M
CERMeP, Grenoble, France (H. Pastor)	H	H
United Hardmetal, Germany TU, Darmstadt, Germany (Professor H. E. Exner)	H M	H L/H*
CW Carbides, UK (Ceramental — Dr S. S. Saini)	H	M

Table 2. *contd.*
(ii) Supplementary comments

Organisation	Comment
Kennametal, USA Sandvik Hard Metals, UK	Leaning towards 'B' geometry in CEN and ASTM MIL STD. High confidence that tests on small diameter round test pieces give results which reflect material quality.
Sandvik, AB, Sweden	Characterisation of defects is necessary for a proper interpretation of bend test data. Make own 3 and 4 pt specimens for bend testing.
Fansteel, USA Teledyne Firth Sterling, USA	Particularly interested in testing round specimens. A round-robin for 3 pt vs 4 pt was performed in the USA by the ASTM in the 1970s. The results may be available through ASTM B09.06 sub-committee.
Boart Research Centre, South Africa	Considerable experience of 3 and 4 pt tests with different surface finishes. No agreement on results. A worldwide standard which dealt more carefully with a range of available finishes (sintered, ground, shot-peened, polished) on rectangular and round specimens would be very helpful. However, experience indicates that failures are mostly sub-surface initiated, and surface finish may not be important.
Refractory and Hard Materials Research Institute, Russia	It is possibly unreasonable to have <i>one</i> standard test method which is equally applicable to all materials. A standard should be drawn which regulates the use of several tests of different geometry (to reflect component size) and different conditions of specimen preparation. The ability of the test to discriminate differences in structure should be assessed quantitatively.
Japan Cemented Carbide Manufacturers Association (seven companies — combined response)	Reasonable interest in development of new internationally agreed bending test, which has less scatter and is more accurate for evaluating 'toughness'. However, Japan is currently comfortable with data accumulated within current JCCMA standard (CIS 026). Also, the bend test is not thought to be an appropriate method for evaluating 'toughness'. In addition, a unified test method for carbides, cermets, ceramics and particularly coated materials would not have 'meaning'. Finally, a K_{Ic} test is thought to be more 'effective' than a bend test.
Neepsend, UK American National Carbide, USA Hydra Tools, USA	Interest in test method for round specimens. Would like to see 10% Co 88 HRA mining grade tested. Little confidence in existing standard because of uncertainties in relevance of results.
Hoybide, UK	Data in Brookes' <i>World Dictionary of Hardmetals</i> vary significantly from company to company, and it is believed results are affected by testing procedure; for example: quality of ground finish.
Hydra Tools International	Consider the usefulness of making jigs centrally for circulation to participants for testing.
Teledyne Advanced Materials, USA	USA use measurements by inch not mm. Use of non-metric jigs needs to be considered. Surface finishes as per ASTM standard
Boart Research Centre	Sample preparation carried out to ISO standard. No surface finish specified — grinding method constant.
Sandvik Coromant Kennametal	All faces ground, 45°-chamfer. Can readily make only a limited number of specimen geometries. Other geometries required would need to be considered in the light of the number required.
Boart Hardmetals Plansee Neepsend	Specimen surface prepared by sand blasting with A46 grit. R_A according to ISO < 1 μ m. Include 10% Co micrograin-hardmetal of hardness 1500–1600 HV30, since this is an accepted grade for rod. For round specimens a centreless ground finish of 12–16 CLA is required.

^aL; low for testing; H, for analysis.

Table 3. Standards (3 pt tests)

3 pt tests	Information source			
	ISO 3327	ASTM B406	CISO26-1983	EN 843
Specimen type (nominal dimensions (mm): length × width × height)	A 35 × 5 × 5 B 20 × 6.5 × 5.25	19 × 6.25 × 5	A 35 × 5 × 5 J 24 × 8 × 4	A 25 × 2.5 × 2 B ^a 45 × 4 × 3
Support distance (nominal)	A 30 mm B 14.5 mm	14.3 mm	A 30 mm J 20 mm	A 20 mm B 40 mm
Surface condition	Longitudinally ground (4 faces), remove 0.1 mm, no pass 0.01 mm, roughness < 0.4 μm Ra	Longitudinally ground (top and bottom), no pass ≥ 0.0127 mm, 0.381 μm roughness	Longitudinally ground (4 faces), remove 0.1 mm, 0.165 roughness (JIS B0601)	Longitudinal grinding, very specific — see standard for details
Parallelism	≥ 0.01 mm	≥ 0.0254 mm	≥ 0.02 mm	—
Out of squareness	—	< 2°	—	< 5°
Chamfer	45°, 0.15–0.2 mm	45°, ≥ 0.25 mm	45°, ≥ 0.2 mm	45°, 0.12 mm
Measurement tolerance	± 0.01 mm	± 0.02 mm	± 0.01 mm	± 0.01 mm
Visual inspection	Must be free from cracks and defects	Eliminate obviously damaged testpieces	Reject obviously defective testpieces or if failure > 3 mm from load pt	Include all results even if failure away from central zone
Number	< 5	5	< 5	10–30 (30 required for Weibull analysis)
Load	< ± 1%	± 1%	± 1%	± 1%
Load or stress rate	≥ 200 Nmm ⁻² s ⁻¹	≥ 1500 Ns ⁻¹	≥ 800 Ns ⁻¹	Maybe material dependent — record value
Load support	Cylinders	Cylinders	Round bars	Rollers
Load point	Cylinders or balls	Ball	Round bar	Rollers
Comments	—	—	—	Fractography recommended
Results	Round to 10 N/mm ²	—	Round to 10 N/mm ²	—

^aEN843 testpiece B is equivalent to ASTM C1161-1990 type B (ceramics).

Table 4. Standards (4 pt tests)

4 pt tests	ASTM	EN843: ceramic flexure tests
	GTE sylvania technical memorandum ASTM subcommittee B09.06	
Specimen type, nominal dimensions, mm (length × width × height)	ISO 3327 — A 35 × 5 × 5	A 25 × 2.5 × 2 B 25 × 4 × 3
Outer span support distance	27.94 mm	A 20 mm B 40 mm
Inner span support distance	9.27 mm	A 10 mm B 20 mm
Load support	Cemented carbide cylinders	Rollers
Load points	Cemented carbide cylinders	Rollers
Number	< 6	10–30

Table 5. Options and numbers of testpieces

Test type-testpiece size (mm)	Test category	Material category				
		1 WC/Co U. fine	2 WC/Co fine	3 WC/Co/CC fine/medium	4 Cermet fine	5 WC/Co coarse/medium
Rectangular (3 pt) ^a						
15 × 6 × 5	[C1] ^a	30	30	30	30	30
30 × 5 × 5	[C2] ^a	20	20	20	20	20
40 × 4 × 3	[C3] ^a	20	20	20	20	20
Rectangular (4 pt)						
30(10) ^b × 5 × 5	[D1] ^c	20	20	20	20	20
40(20) ^b × 4 × 3	[D2] ^c	20	20	20	20	20
Notched (3 pt)						
15 × 2 × 5	[E1] ^d	12	12	12	12	12
30 × 2 × 5	[E2] ^d	12	12	12	12	12
Notched (4 pt)						
30(10) × 2 × 5	[E3] ^d	12	12	12	12	12
Round (3 pt)						
30 × 5 mm Ø	[F1] ^e	20	20	20	20	20
Round (4 pt)						
40(20) × 5 mm Ø	[F2] ^e	20	20	20	20	20
Round and notched (4 pt)						
30 × 5 mm Ø	[F3] ^e	12	12	12	12	12

^aC1, Existing ISO 3327 Type B for base line; C2, C3, ISO Type A and ceramic Type B for comparison with C1.

^b30(10), 30 mm full support span, 10 mm loading points span; 40(20), 40 mm full support span, 20 mm loading points span.

^cD1, D2, Two different spans; which are based on ISO 3327 and ceramic Type B.

^dE1, E2, Notched testpieces; E1 based on ISO 3327 Type B; E2 based on ISO 3327 Type A; E3, 4pt notched, based on ISO 3327 Type A.

^eF1, 3 pt, based on ISO 3327 Type A; F2, 4 pt, based on Ceramic Type B; F3, 3 pt, notched; for comparison with E2.

Table 6. Materials and source

Category	Nominal type	Source
1	WC/Co; 6% Co fine grained HV30; 1800–1900	Teledyne Advanced Materials
2	WC/Co; 11% Co fine/medium grained HV30; 1500–1600	Boart RC Sandvik Hard Materials
3	WC/Cubic Carbide/Co; 16% Co HV30; 1500–1600	Kennametal
4	Ti(C,N) cermet HV30; 1500–1600	Sandvik
5	WC/Co; 12% Co medium/coarse grained HV30; 1000–1200	Sandvik American National Carbide

on request): (a) the ISO type B is recommended to be excluded because the data scatter was larger and bigger loads were required (and hence more damage to jigs); (b) the use of balls as load points was excluded; (c) no difference was noted between tests on ground compared with as-sintered testpieces, therefore both are allowed.

Non-standard testpieces

The proposed interlaboratory exercise includes tests on both round and notched testpieces. The justification for this is as follows:

Round testpieces

A number of organisations are currently using tests on round testpieces because it is an important product form. Their preliminary data indicate that there is a reduction in scatter associated with this form of testpiece. Accordingly, it is important to include a number of tests in the current exercise.

Notched testpieces

Previous work at NPL¹ has shown that the bend strength of hardmetals is determined by two factors:

- the distribution of large defects (pores etc.), greater in size than approximately 20 μm ,
- the intrinsic strength of the average microstructure, termed limiting strength.

Further work^{2,3} has shown that the limiting strength can be measured using a notched bend testpiece. This test method has several advantages; as follows:

- the scatter is considerably reduced,
- much lower loads are required to break testpieces, i.e. less damage to jigs and perhaps less expensive test machines,
- the strength values obtained are higher (because failures from large defects are excluded).

The notched tests performed to date have been on modified ISO 3327 testpieces (type B), i.e. 14.5 mm span \times 2 mm wide \times 5 mm high (3pt) with a 1 mm deep notch with a 0.5 mm notch radius. It is proposed that the tests planned in this exercise examine 4 pt notched tests and 3 pt tests on different geometry specimens (Table 5). Table 6 is derived from the results of the questionnaires and presents the materials of interest and sources from which testpieces will be supplied.

REFERENCES

1. Almond, E. A. & Roebuck, B., Defect initiated fracture and the bend strength of WC/Co hardmetals. *Met. Sci.*, **11** (1977) 458-61.
2. Roebuck, B., Notched bend tests on WC/Co hardmetals. *J. Mater. Sci.*, **23** (1988) 281-7.
3. Roebuck, B. & Coles, W., Mechanical test discriminability for WC hardmetals. *Int. J. Refractory Met. and Hard Mat.*, **11** (1992) 127-36.

APPENDIX B

HARDMETAL BEND TEST SCHEDULE

(1) WC/Co - U Fine

Teledyne Advanced Materials

Test Type Testpiece Size, mm	Test Category	NPL	CERMeP	Kennametal
RECTANGULAR (3 pt) 15 x 6 x 5 30 x 5 x 5 40 x 4 x 3	R3 R3a R3b R3c	 - 10 10	 - 10 -	 - - 10
RECTANGULAR (4 pt) 30(10) x 5 x 5 40(20) x 4 x 3	R4 R4b R4c	 10 10	 10 -	 - 10
NOTCHED (3 pt) 15 x 2 x 5 30 x 2 x 5	RN3 RN3a RN3b	 6 6	 6 -	 - 6
NOTCHED (4 pt) 30(10) x 2 x 5	RN4 RN4b	 6	 6	 -
ROUND (3 pt) 30 x 5 mm ϕ	C3	10	-	10
ROUND (4 pt) 30(10) x 5 mm ϕ	C4	10	10	-
ROUND & NOTCHED (4 pt) 30(10) x 5 mm ϕ	CN4	4	4	4

Standard TRS

Boart Longyear

15

Sandvik Coromant

15

Plus annealed testpieces of R3b, C3 and C4 tested at NPL.

B(i)

(2) WC/Co - Fine

Boart RC Longyear

Test Type Testpiece Size, mm	Test Category	NPL	Sandvik Coromant	Teledyne
RECTANGULAR (3 pt) 15 x 6 x 5 30 x 5 x 5 40 x 4 x 3	R3 R3a R3b R3c	- 10 10	15 10 -	15 - 10
RECTANGULAR (4 pt) 30(10) x 5 x 5 40(20) x 4 x 3	R4 R4b R4c	10 10	10 -	- 10
NOTCHED (3 pt) 15 x 2 x 5 30 x 2 x 5	RN3 RN3a RN3b	6 6	6 -	- 6
NOTCHED (4 pt) 30(10) x 2 x 5	RN4 RN4b	6	6	-
ROUND (3 pt) 30 x 5 mm ϕ	C3	10	-	10
ROUND (4 pt) 30(10) x 5 mm ϕ	C4	10	10	-
ROUND & NOTCHED (4 pt) 30(10) x 5 mm ϕ	CN4	4	4	4

Standard TRS

Sandvik Coromant

15

Teledyne

15

B(ii)

(3) WC/Co - Fine

Sandvik HM

Test Type Testpiece Size, mm	Test Category	NPL	Dymet	Boart Longyear
RECTANGULAR (3 pt) 15 x 6 x 5 30 x 5 x 5 40 x 4 x 3	R3 R3a R3b R3c	 - 10 10	 10 -	 15 - 10
RECTANGULAR (4 pt) 30(10) x 5 x 5 40(20) x 4 x 3	R4 R4b R4c	 10 10	 10 -	 - 10
NOTCHED (3 pt) 15 x 2 x 5 30 x 2 x 5	RN3 RN3a RN3b	 6 6	 6 -	 - 6
NOTCHED (4 pt) 30(10) x 2 x 5	RN4 RN4b	 6	 6	 -
ROUND (3 pt) 30 x 5 mm ϕ	C3	10	-	10
ROUND (4 pt) 30(10) x 5 mm ϕ	C4	10	10	-
ROUND & NOTCHED (4 pt) 30(10) x 5 mm ϕ	CN4	4	4	4

Standard TRS

Boart Longyear
Teledyne15
15

(4) WC/CC/Co - Med/Fine

Kennametal

Test Type Testpiece Size, mm	Test Category	NPL	United Hardmetals
RECTANGULAR (3 pt) 15 x 6 x 5 30 x 5 x 5 40 x 4 x 3	R3 R3a R3b R3c	 - 10 10	 - 10 10
RECTANGULAR (4 pt) 30(10) x 5 x 5 40(20) x 4 x 3	R4 R4b R4c	 10 10	 10 10
NOTCHED (3 pt) 15 x 2 x 5 30 x 2 x 5	RN3 RN3a RN3b	 6 6	 6 6
NOTCHED (4 pt) 30(10) x 2 x 5	RN4 RN4b	 6	 6
ROUND* (3 pt) 30 x 5 mm ϕ	C3	-	-
ROUND* (4 pt) 30(10) x 5 mm ϕ	C4	-	-
ROUND & NOTCHED* (4 pt) 30(10) x 5 mm ϕ	CN4	-	-

Standard TRS

CERMeP

15

Gen. Carbide

15

* Material not tested in round form.

(5) Ti(CN)Cermets - Fine

Sandvik Coromant

Test Type Testpiece Size, mm	Test Category	NPL	Sandvik Coromant	BAM
RECTANGULAR (3 pt) 15 x 6 x 5 30 x 5 x 5 40 x 4 x 3	R3 R3a R3b R3c	- 10 10	- 10 -	- - 10
RECTANGULAR (4 pt) 30(10) x 5 x 5 40(20) x 4 x 3	R4 R4b R4c	10 10	10 -	- 10
NOTCHED (3 pt) 15 x 2 x 5 30 x 2 x 5	RN3 RN3a RN3b	6 6	6 -	- 6
NOTCHED (4 pt) 30(10) x 2 x 5	RN4 RN4b	6	6	-
ROUND (3 pt) 30 x 5 mm ϕ	C3	10	-	10
ROUND (4 pt) 30(10) x 5 mm ϕ	C4	10	10	-
ROUND & NOTCHED (4 pt) 30(10) x 5 mm ϕ	CN4	4	4	4

Standard TRS

Kennametal
CERMeP

15

15

B(v)

(6) WC/Co - Med/Coarse

Sandvik Coromant

Test Type Testpiece Size, mm	Test Category	NPL	Edgar Allen Danite	Kennametal Hertel
RECTANGULAR (3 pt) 15 x 6 x 5 30 x 5 x 5 40 x 4 x 3	R3 R3a R3b R3c	 - 10 10	 - 10 -	 - - 10
RECTANGULAR (4 pt) 30(10) x 5 x 5 40(20) x 4 x 3	R4 R4b R4c	 10 10	 10 -	 - 10
NOTCHED (3 pt) 15 x 2 x 5 30 x 2 x 5	RN3 RN3a RN3b	 6 6	 - -	 - 6
NOTCHED (4 pt) 30(10) x 2 x 5	RN4 RN4b	 6	 6	 -
ROUND (3 pt) 30 x 5 mm ϕ	C3	10	-	10
ROUND (4 pt) 30(10) x 5 mm ϕ	C4	10	10	-
ROUND & NOTCHED (4 pt) 30(10) x 5 mm ϕ	CN4	4	4	4

Standard TRS

Gen. Carbide 15
United Hardmetals 15

WC/Co - Coarse

Boart Longyear

Test Type Testpiece Size, mm	Test Category	NPL
RECTANGULAR (3 pt) 15 x 6 x 5 30 x 5 x 5 40 x 4 x 3	R3 R3a R3b R3c	- 10 10
RECTANGULAR (4 pt) 30(10) x 5 x 5 40(20) x 4 x 3	R4 R4b R4c	 10 10
NOTCHED (3 pt) 15 x 2 x 5 30 x 2 x 5	RN3 RN3a RN3b	 6 6
NOTCHED (4 pt) 30(10) x 2 x 5	RN4 RN4b	 6
ROUND (3 pt) 30 x 5 mm ϕ	C3	10
ROUND (4 pt) 30(10) x 5 mm ϕ	C4	10
ROUND & NOTCHED (4 pt) 30(10) x 5 mm ϕ	CN4	4

Standard TRS NPL 15

Plus annealed testpieces of R3b, R4b, C3 and C4 tested at NPL.