A SCIENTIFIC APPROACH TO WEAR TESTING OF DOCTOR BLADE MATERIALS

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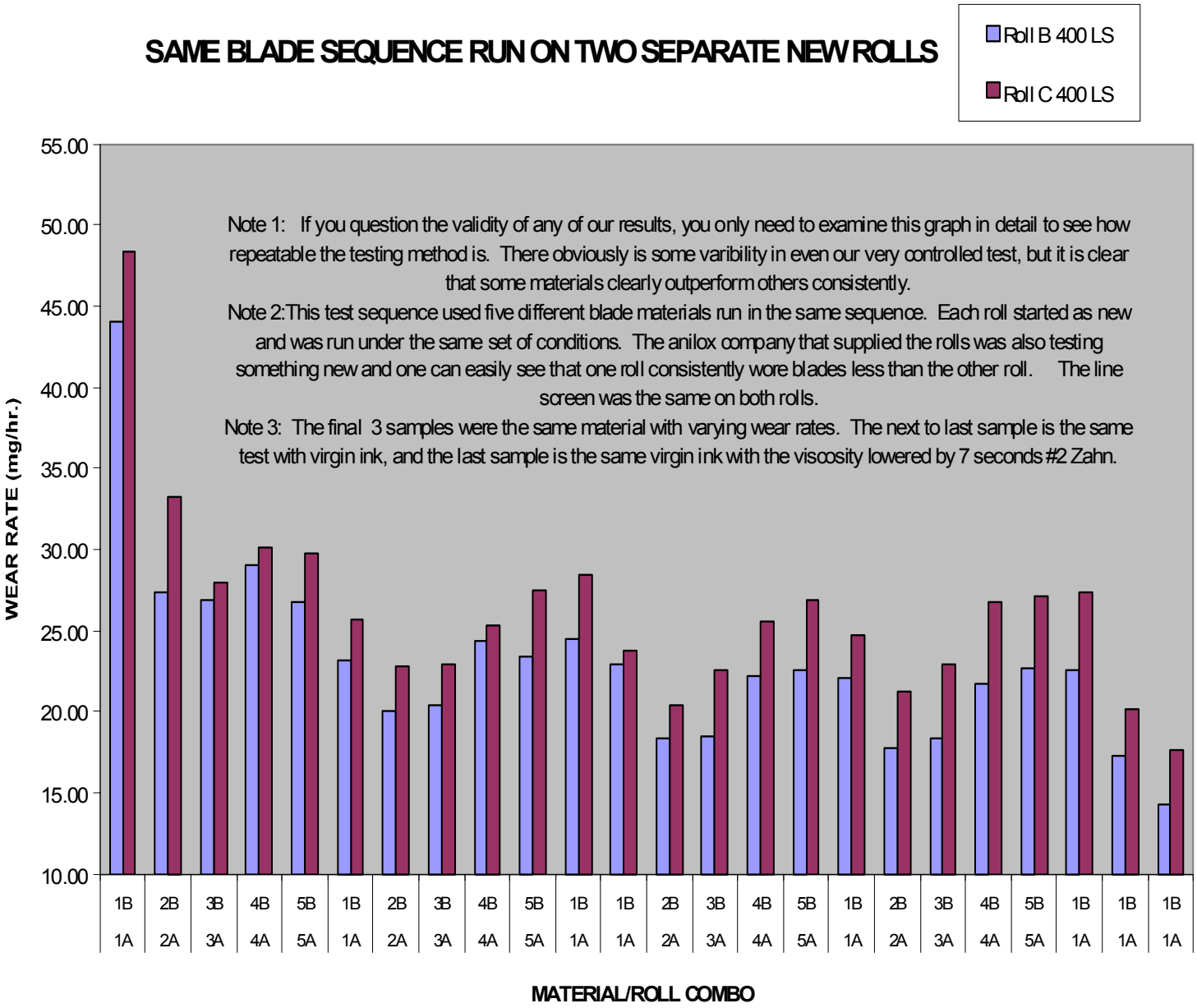
INTRODUCTION

Benton Graphics is involved in a continuous search for better performing and longer lasting materials for use in the manufacture of doctor blades. Approximately 5 years ago we set out to develop a better doctor blade material that would also be competitively priced. We felt that a testing procedure to evaluate materials for use in flexographic printing needed to be developed to help us in this search. Field testing, while indicative of a materials performance, always has so many uncontrolled variables that it was quickly ruled out as a valid testing method. In the past, claims of doctor blade merit based on unsubstantiated opinion or patently false claims have caused problems in the industry. A meaningful test method to compare different materials was needed to resolve these claims.

To this end, the R&D group at Benton Graphics devised a testing procedure and developed the testing machinery to provide answers to several basic questions relating to doctor blade applications in flexographic printing.

The testing took place from May 1999 through Oct 2000. To our knowledge it is the only testing to date that compares different manufacturers materials that were equally prepared and run under conditions that were repeatable. The interesting point was that after running a number of different materials we were able to repeat the results we started with on the standard blade within a couple percent, which validated this testing in our minds.

One of the most interesting observations was just how repeatable the testing was. See the graphical comparison of data on the next page where we ran the same sequence of blades and running conditions on two separate rolls. The graphical analysis of the data truly shows that our testing method was not only valid but also repeatable. Certain materials outperformed regardless of roll condition.



This paper sets forth the testing procedure, the testing equipment design and the results of the work to date. Several thousand hours of testing have included many different metals, several plastics and ceramic anilox rolls from three different roll manufacturers.

While we would like to point out that while our testing proved certain materials did not perform as well from a wear standpoint in this simulated flexo application, that in no way should be construed that those particular materials are unsuitable for doctor blades. In fact, one of the worst performing materials, from a wear standpoint, is a proven winner in waterbased gravure applications. It is one of the main reasons that we have kept the identity of each material confidential.

Many observations were made during the testing process a few of the observations are detailed below.

- **Wear was roughly twice as high on new rolls versus a roll that had a number of blades run on it. This is the reason that you should never evaluate new materials by starting with a new roll. Your first impression will be the blades don't last long at all.**

- **When we replaced the ink with Virgin ink the wear rate decreased. The theory behind this is that there is no blade and ceramic particulate in virgin ink.**

- **When we dropped the viscosity the blade lasted even longer in our particular test.**

- **Increased pressure greatly affected the tendency of all materials to burr.**

- **No rolls were scored during the entire testing period.**

It should be emphasized that this project is ongoing. Input, suggestions and criticism from industry sources are both welcome and desired. We look at this project as a beginning. Further, we are making all the details of the testing, procedures, equipment design, measurement methods and test results available to the public.

TESTING PROCEDURE

In setting up a testing procedure it was necessary to set forth the parameters to be measured and to eliminate all other variables as much as possible. Further, since at the beginning of the project, several variables were not known, such as the rate of wear of anilox rolls and the effect of anilox wear on doctor blade wear, it was decided that a control material, Metal A, should be selected and used throughout the tests. In essence, other materials would be continuously compared to Metal A. In total 37 different materials were tested.

The variables that we wished to investigate were:

1. **The relative wear rates of different materials**
2. **The tendency to form burr that could damage anilox rolls**
3. **The appearance of the wear surface on the doctor blade**
4. **The size of wear particles released from the doctor blade as it wears.**
5. **The effect of pressure on burr formation and wear rate.**
6. **The wear rate of Anilox rolls.**

At first it was felt that a live test on an operating Flexo press should be used but was rapidly discarded because there were too many uncontrollable variables. A study of these uncontrollable variables pointed to the design of a testing machine. This equipment is described in detail in Appendix A, a short description is in order here:

TEST EQUIPMENT

A Mark Andy style anilox roll with a 7.375-inch face width was selected as a test cylinder due to its size and availability. The doctor blade holder, fabricated out of stainless steel, is center pivoted on tapered roller bearings to permit accurate alignment of the blade to the cylinder while maintaining accurate blade angle and positioning. A blade angle of 30 degrees (unloaded) was selected as typical of industry practice.

An enclosure surrounds the anilox roll and the doctor blade holder. The blade holder pivot is mounted on ultra-low friction linear ball bearings through the enclosure and is externally loaded by dead-weight loading. The load is measured by an electronic load cell and is displayed on a digital readout.

A variable speed DC motor controlled by an electronic controller drives the anilox roll. A digital pulse generator is connected to the anilox roll shaft. The pulse generator output is used to set the rate of rotation in feet per minute and total feet run in a given test. Each of these factors is digitally indicated on separate controllers. Since many of the tests have durations of up to 24 hours the number of revolutions for a given test may be set into the controller and shut the machine down when the test is completed. When the selected test count is reached the controller reduces the cylinder drive to idle speed and retracts the blade holder.

A recirculating closed ink system consisting of a sump, pump, debris strainer, rare-earth magnet, plumbing and applicator pan provide a continuous supply of ink to the roll. Provisions for temperature and viscosity measurements are included. Appendix (D) covers viscosity equipment details.

A series of tests was run on the control material, Metal A, to determine if the procedure was repeatable. The results were promising and further modifications were made and the repeatability improved to an acceptable point.

See Table (1) for the results of repeatability achieved.

Appendix (A) covers the design details of the testing equipment.

MEASUREMENT of WEAR

Initially it was planned to measure material wear by mechanical measurement of samples. A few attempts at such measurements showed the technique was invalid due to variations in material thickness, precision of sample manufacturing and accuracy of even precision metrology equipment.

Calculations showed that precision weighing of the samples before and after wear testing would work if scales of sufficiently high precision were used and tests were of a long enough duration.

A review of available laboratory balances showed that there were several that would meet our requirement of accuracy of .0002 grams (divide by 27 to get ounces). An A&D Company Model HM-200 was purchased with auto-calibration and under-scale weighing capability. Testing showed that a special draft shield and magnetic shielding were necessary in addition to the isolated platform mounting in a temperature-controlled room to obtain the required accuracy. Appendix (C) shows the details of the scale, scale mounting and shielding.

SAMPLE PREPARATION

The size of the test blades was set at 8.00 inches long x 1.00 inches wide. This length permitted the blade to overhang each end of the anilox roll by .3125 inch. This allowed measurement of wear at each end to determine that wear was even along the length of the blade.

The blades were cut to length and slit or sheared approximately .015 inch oversize. A group of samples were then clamped and surface ground on both edges (to a width of 1.000-inch +/- .002) to remove any slitting damage and to insure that all samples had the same square edge configuration.

Each group of sample materials is tested for hardness using a Buehler Micro-Hardness tester to insure uniformity of the group. See Appendix (B) pg.11 for details.

For a given test, the sample was cleaned with N-propyl alcohol, air dried, and weighed. Scale calibration is performed prior to sample measurements. Standard laboratory procedure for precision weighing was followed: taking a series of measurements, eliminating the highest and the lowest readings and readings that were not followed by a return to zero after sample weighing, and then averaging the remaining readings. Although time consuming, this method results in a reading within the +- .0002 gram accuracy. It was found that a 45 second settling time gave more repeatable results than the several seconds A&D claims is needed to reach stability. See Appendix (C) pg. 12 for details.
Following initial weighing, the sample is marked with removable ink with the test number and placed in the cleaned blade holder and clamped.

TESTING SEQUENCE

The blade holder is placed into the test chamber and held in place by the two tapered roller bearings that permit the blade to align with the anilox roll when the load is applied. The anilox roll has been idling at approx. 30 FPM during this process and is fully inked.

While speed is increased to testing speed, the pneumatic hold out cylinder releases the holder assembly and permits it to slowly move forward until the blade makes contact with the anilox roll. The test cycle counter is reset to the test duration and the load cell and load indicator monitors load. At the end of the test duration the test cycle counter activates the holdout air cylinder and the blade assembly retracts and the anilox roll speed is reduced back to idle speed of approx. 30 FPM.

The blade holder is then removed and rinsed in suitable cleaner without touching the doctor blade. The blade is then removed from the blade holder.

At this point it is necessary to determine if burr has formed during the test. If burr is present, it is detached from the blade by adhering it to adhesive tape. The blade is then fully cleaned of ink and markings with N-propyl alcohol and/or Acetone, then weighed as previously described. Following this weighing the blade is again marked with the test number and any burr that was removed with tape is re-fastened back onto the sample. The difference between the initial and final weights represents the wear.

TESTING EQUIPMENT DESIGN

The test chamber, which encloses the anilox roll and doctor blade, is constructed of hard-anodized aluminum with a tempered glass top. This allows for full viewing of the testing without disturbing the internal atmosphere and also controls evaporation. The anilox roll shafts are mounted and extend through the chamber sidewalls using squeeze lock sealed ball bearings. The left side roll shaft is pulley driven by an electronic 90v dc-drive package. The right side roll shaft is direct-mounted to a pulse encoder.

Roll inking control is accomplished using a stainless steel tray mounted under the roll. This tray is mounted on an anodized aluminum stage, which can be adjusted up or down to control the submersion level of the roll. Ink is fed into the center of this pan on the "input" side of the roll, which is on the opposite side of the anilox roll from the doctor blade holder.

The Stainless blade holder is designed with a double angle clamp bar which locks the doctor blade at a 30 degree angle (unloaded) to the tangent of the cylinder. The blade tip is aligned to the centerline of the anilox roll. The blade is bottomed out in the angle clamp bar slot in the holder to ensure the parallelism of its extension out of the holder assembly. The blade holder is mounted to a horizontal sliding stage using loaded double tapered roller bearings. This allows the holder to pivot freely on its centerline automatically aligning the blade to the anilox roll. The sliding stage is mounted on two sealed ball bushings, which extend through the chamber front wall to the outside of the unit. The ball bushing shafts are tied together on the outside by a aluminum clamp bar. A Entran® strain gauge is fastened on the centerline of the clamp bar, which reads the dead weight load, applied to the test blade. The ball bushings are mounted horizontally so that the weight of the holder assembly does not effect the blade loading against the anilox roll.

The test chamber is mounted at a height sufficient enough to allow the ink return line to gravity feed back into the main sump. The return line contains a three-way ball valve to allow clean out of the test chamber. This valve diverts the drain to a waste drum for disposal of cleaning fluids.

The main ink sump is plastic with a fifty-gallon capacity. It

incorporates a closed lid for evaporation control. The test inks are pumped using a tube pump, which is controlled by an electronic dc drive package. A PVC basket strainer is in-line on the suction side of the pump for particulate control. The tube pump feeds a manifold, which contains the ink thermometer and a low-pressure cut-off switch. The ink then travels through a bulkhead fitting in the back wall of the test chamber to feed the ink into the center of the anilox roll tray. The tray then overflows into the base of the test chamber and into the drain. The drain line into the main ink sump incorporates a six-inch rare earth magnet rod to catch any magnetic particles coming from the wear tester chamber. All ink must pass past this magnet before entering back into the main sump. It is of a dip tube design, which allows cleaning, or checking during a run without shutting down the ink flow. The main sump also contains a electric impeller slow speed mixer, which constantly runs during testing.

APPENDIX B

HARDNESS TESTING EQUIPMENT AND PROCEDURE

Equipment- All test samples are tested by batch on a Buehler Micromet model # 1600-6400 Micro-hardness tester. (S/N 534-MMT7-00308) All hardness readings are taken with a Vickers indenter and converted to Rockwell C scale automatically by the Micromet. Tests are for 15 seconds using a 500-gram weight load. These conditions match most steel mills around the world. The tester incorporates a thin specimen holding stage designed by Buehler for testing thin gauge materials. The micro-hardness tester is also equipped with an automatic motorized turret and a X/Y micrometer adjustable stage mount. The Tester is re-certified once a year by Buehler technician. The last calibration date was June 14th 1999 using calibration block #750-978. In addition we check calibration internally using an ASAHI S/N 72043-gauge block with a certified, calibrated 685.4 HV hardness. (Certificate # 1396)

The tester itself is mounted and leveled on a rigid vibration control bench and is temperature and humidity controlled.

Testing- Samples are checked for flatness and cleaned with N-Propyl alcohol and /or Acetone before being placed on the tester. The tester stage is checked and cleaned then the prepared sample is placed on the stage. The stage contains a hold down spring device, which is used to ensure that the sample is held tight and flat against the stage. Once the material is mounted and focused in the microscope, the test sequence is activated. After the 15-second time period ends the tester automatically swings into the read position. The Vickers indentation is measured both X and Y in microns to give the hardness result. The average of three readings is used as the hardness reading for that sample. Each test material was produced from the same master coils and were randomly checked for average hardness levels after being converted into the testing size of 1.00 inch x 8.00 inch.

APPENDIX C

WEIGHING EQUIPMENT AND PROCEDURE

Equipment- before each test sample is run on the wear tester, an accurate measurement of "starting weight" has to be taken. Directly after each run another accurate "Ending weight" has to be recorded. To do this an A&D Engineering, Inc. precision electronic balance model HM200 is used. This balance was chosen for its accuracy and repeatability. The balance has a total capacity of 210 grams with readout to .0001 grams. (The average test sample weighed between 5 and 7 grams). The balance is run through an auto-calibration sequence on a daily basis before any material is weighed. The calibration uses an internal calibrated weight to check both scale and zero readings. The balance is mounted and leveled on a vibration control stand, which is designed for underhook weighing of the blade samples. The stand is designed with a full lexan enclosure and magnetic shield to prevent errors from stray air currents and magnetic forces. The front of the enclosure is hinged for access to the chamber to place the sample onto the balance for measurements. A small square magnetic patch is suspended from the underhook wire, which allows the test samples to be suspended from the balance to be weighed.

Test sample weighing- Samples are cleaned using N-Propyl Alcohol and are air dried to a stable temperature of 74 to 76 degrees F. The balance is run through the auto-calibrating sequence and verified to read at zero. The enclosure door is opened and the sample is placed on the magnet patch for weighing. The door is fully closed and a 45-second count down electronic timer is started. (This time was chosen based on our observations that the balance needed that amount of time to give a stable repeatable reading). When the time is up a reading is recorded from the Balance LCD display. The sample is then removed and the scale is allowed to stabilize back to zero. If the scale does not return to full zero after a weight reading, then the error is noted and disregarded, and the balance is re-zeroed. Typically it takes 4 to 5 weight readings per sample to get an average to be recorded in the run log. This same process is repeated for each worn test sample after it is thoroughly cleaned and dried. The difference between the start weight and the finish

weight is considered the total wear weight. If any blades had burr on them after testing, it was removed before any weighing is done. The burr is then replaced back onto the test piece using the adhesive tape that it was removed with. We considered any burrs that were formed on test samples to be worn away and as such not included in the finish weight.

APPENDIX D

VISCOSITY MEASUREMENT

Ink viscosity was regularly measured using a Gardco® EZ Zahn-style (ASTM) #2 cup. Serial Number 42854.

The Cup is calibrated using Cannon® certified G-60 viscosity standard oil. Lot number 99501 with a expiration date of 31 Dec 2000.

An in-line stem thermometer allowed the ink temperature to be recorded during the viscosity measurements. Ink was adjusted using a combination of water and N-propyl alcohol.

All viscosity measurements were taken from the main ink sump and recorded in seconds #2 cup. After extended period shut downs, care was taken to insure that the sump ink mixer was run for several minutes before measurements were taken. The ink was re-checked after the temperature had reached a stable condition where needed. The ink temperature was recorded at 74 to 77 degrees F during all tests.

Acknowledgments-

Benton Graphics would like to thank the following suppliers for their generous donations, which have made this testing possible.

- **SUN CHEMICAL CORP.- PRINTING INKS DIVISION**
- **FLINT INK CORP. INKS**
- **PRINTEX / CERAMCO INC. ANILOX ROLLS**
- **PAMARCO CORP. ANILOX ROLLS**
- **DANKO INDUSTRIES CLEANERS**
- **CORTEX INTERNATIONAL CLEANERS**

Also we wish to thank Dr. George Krauss, Sc.D., P.E. and the Advanced Steel Processing and Products Research Center at the Colorado School of Mines for their invaluable assistance in this project.

We also wish to thank all of the major doctor blade manufacturers world wide for producing excellent products, which we have incorporated into our testing samples.

Some important notes
We are not out to bash our competitor's material therefore we have assigned a number to each material rather than listing the name.
We did not run all 224 runs under the same conditions, we set up a set of parameters we wanted to test, verified and moved on.
Some of the different test variations included: line screen of rolls, ink, speed, total length or time of run, loading force or pressure.

Run Number	material #	Roll	Ink	Initial Weight grams	Final Weight grams	Wear Weight grams	Blade Wear Rate (mg/hr)	Feet/Min	Run Length (ft)	Loading (lbs/linear in)	Run Time (hr)
1	22	Roll A 360 LC	Clear	8.1755	8.1683	0.0072	7.200	500	30000	0.27	1.00
2	28	Roll A 360 LC	Clear	8.1373	8.1292	0.0081	8.100	500	30000	0.27	1.00
3	24	Roll A 360 LC	Clear	8.0494	8.0452	0.0042	4.200	500	30000	0.27	1.00
4	25	Roll A 360 LC	Clear	8.1494	8.1332	0.0162	16.200	500	30000	0.27	1.00
5	22	Roll A 360 LC	Clear	8.1996	8.1920	0.0076	7.600	500	30000	0.27	1.00
6	24	Roll A 360 LC	Clear	8.0080	8.0035	0.0045	4.500	500	30000	0.27	1.00
7	26	Roll A 360 LC	Clear	7.9965	7.9879	0.0086	8.600	500	30000	0.27	1.00
8	27	Roll A 360 LC	Clear	8.0593	8.0548	0.0045	4.500	500	30000	0.27	1.00
9	11	Roll A 360 LC	Clear	8.2169	8.2115	0.0054	5.400	500	30000	0.27	1.00
10	22	Roll A 360 LC	Clear	8.2171	8.1930	0.0241	4.820	500	150000	0.27	5.00
11	22	Roll A 360 LC	Clear	8.1998	8.1926	0.0072	7.200	500	30000	0.27	1.00
12	22	Roll A 360 LC	Clear	8.2150	8.2128	0.0022	2.200	500	30000	0.27	1.00
13	28	Roll A 360 LC	Clear	8.1699	8.1618	0.0081	8.100	500	30000	0.27	1.00
14	22	Roll A 360 LC	Clear	8.2073	8.2050	0.0023	2.250	500	30000	0.27	1.00
15	22	Roll A 360 LC	Clear	8.1852	8.1795	0.0057	2.850	500	60000	0.14	2.00
16	28	Roll A 360 LC	Clear	8.1504	8.1435	0.0069	3.450	500	60000	0.14	2.00
17	24	Roll A 360 LC	Clear	8.0660	8.0621	0.0039	1.950	500	60000	0.14	2.00
18	26	Roll A 360 LC	Clear	8.0742	8.0694	0.0048	2.400	500	60000	0.14	2.00
19	11	Roll A 360 LC	Clear	8.2070	8.2032	0.0038	1.900	500	60000	0.14	2.00
20	24	Roll A 360 LC	Clear	8.1463	8.1254	0.0209	1.254	500	500000	0.14	16.67
21	22	Roll A 360 LC	Clear	8.2452	8.2221	0.0231	1.386	500	500000	0.14	16.67
22	24	Roll A 360 LC	Clear	8.1076	8.0664	0.0412	2.472	500	500000	0.27	16.67
23	22	Roll A 360 LC	Clear	8.2074	8.1423	0.0651	3.906	500	500000	0.27	16.67

24	22	Roll A 360 LC	Clear	8.2246	8.1735	0.0511	3.066	500	500000	0.27	16.67
25	22	Roll A 360 LC	Clear	8.1772	8.1314	0.0458	5.496	1000	500000	0.27	8.33
26	24	Roll A 360 LC	Clear	8.0894	8.0604	0.0290	1.740	500	500000	0.27	16.67
27	24	Roll A 360 LC	Clear	8.0334	7.9448	0.0886	5.316	500	500000	0.63	16.67
28	22	Roll A 360 LC	Clear	8.1924	8.0910	0.1014	6.084	500	500000	0.63	16.67
29	24	Roll A 360 LC	Clear	8.1441	8.0589	0.0852	10.224	1000	500000	0.63	8.33
30	22	Roll A 360 LC	Clear	8.2025	8.1407	0.0618	7.416	1000	500000	0.63	8.33
31	27	Roll A 360 LC	Clear	8.4633	8.3893	0.0740	8.880	1000	500000	0.63	8.33
32	29	Roll A 360 LC	Clear	7.9412	7.8771	0.0641	3.846	500	500000	0.63	16.67
33	29	Roll A 360 LC	Clear	7.9051	7.8732	0.0319	3.828	1000	500000	0.63	8.33
34	29	Roll A 360 LC	Clear	7.9101	7.8665	0.0436	1.308	250	500000	0.63	33.33
35	27	Roll A 360 LC	Clear	8.0801	8.0497	0.0304	3.648	1000	500000	0.63	8.33
36	29	Roll A 360 LC	Clear	7.8782	7.8361	0.0421	2.526	500	500000	0.63	16.67
37	22	Roll A 360 LC	Clear	8.1583	8.1098	0.0485	2.910	500	500000	0.63	16.67
38	2	Roll A 360 LC	Clear	8.1012	8.0560	0.0452	2.712	500	500000	0.63	16.67
39	12	Roll A 360 LC	Clear	8.1194	8.0733	0.0461	2.766	500	500000	0.63	16.67
40	22	Roll A 360 LC	Clear	8.1744	8.1242	0.0502	3.012	500	500000	0.63	16.67
41	3	Roll A 360 LC	Clear	8.2305	8.1843	0.0462	2.772	500	500000	0.63	16.67
42	3	Roll A 360 LC	Clear	8.1558	8.1091	0.0467	2.802	500	500000	0.63	16.67
43	27	Roll A 360 LC	Clear	8.1790	8.1364	0.0426	2.556	500	500000	0.63	16.67
44	22	Roll A 360 LC	Clear	8.1842	8.1350	0.0492	2.952	500	500000	0.63	16.67
45	30	Roll A 360 LC	Clear	7.9652	7.9186	0.0466	2.796	500	500000	0.63	16.67
46	11	Roll A 360 LC	Clear	8.2491	8.2016	0.0475	2.850	500	500000	0.63	16.67
47	24	Roll A 360 LC	Clear	8.0987	8.0568	0.0419	2.514	500	500000	0.63	16.67
48	22	Roll A 360 LC	Clear	8.1977	8.1498	0.0479	2.874	500	500000	0.63	16.67
49	22	Roll A 360 LC	Clear	8.1957	8.1079	0.0878	2.634	500	1000000	0.63	33.33
50	12	Roll A 360 LC	Clear	8.0858	7.9961	0.0897	2.691	500	1000000	0.63	33.33
51	2	Roll A 360 LC	Clear	8.1606	8.0747	0.0859	2.577	500	1000000	0.63	33.33
52	24	Roll A 360 LC	Clear	8.1103	8.0272	0.0831	2.493	500	1000000	0.63	33.33
53	22	Roll A 360 LC	Clear	8.2009	8.1104	0.0905	2.715	500	1000000	0.63	33.33
54	22	Roll A 360 LC	White	8.1698	8.0234	0.1464	43.920	500	100000	0.63	3.33
55	4	Roll A 360 LC	White	8.1596	8.0518	0.1078	32.340	500	100000	0.63	3.33
56	24	Roll A 360 LC	White	8.1573	8.0401	0.1172	35.160	500	100000	0.63	3.33
57	13	Roll A 360 LC	White	8.1089	7.9537	0.1552	46.560	500	100000	0.63	3.33
58	22	Roll A 360 LC	White	8.1455	8.0013	0.1442	43.260	500	100000	0.63	3.33

59	11	Roll A 360 LC	White	8.2426	7.9786	0.2640	79.200	500	100000	0.63	3.33
60	30	Roll A 360 LC	White	7.9498	7.8164	0.1334	40.020	500	100000	0.63	3.33
61	3	Roll A 360 LC	White	8.2186	8.0933	0.1253	37.590	500	100000	0.63	3.33
62	29	Roll A 360 LC	White	7.9019	7.8470	0.0549	16.470	500	100000	0.63	3.33
63	22	Roll A 360 LC	White	8.2367	8.0656	0.1711	51.330	500	100000	0.63	3.33
64	6	Roll A 360 LC	White	8.0568	7.9025	0.1543	46.290	500	100000	0.63	3.33
65	5	Roll A 360 LC	White	8.1766	7.5314	0.6452	193.560	500	100000	0.63	3.33
66	22	Roll A 360 LC	White	8.2377	8.0933	0.1444	43.320	500	100000	0.63	3.33
67	7	Roll A 360 LC	White	8.2553	8.0131	0.2422	72.660	500	100000	0.63	3.33
68	14	Roll A 360 LC	White	7.0872	6.9426	0.1446	43.380	500	100000	0.63	3.33
69	28	Roll A 360 LC	White	8.1529	7.9861	0.1668	50.040	500	100000	0.63	3.33
70	10	Roll A 360 LC	White	8.1151	7.9750	0.1401	42.030	500	100000	0.63	3.33
71	22	Roll A 360 LC	White	8.1700	8.0187	0.1513	45.390	500	100000	0.63	3.33
72	22	Roll B 400 LC	White	8.1903	8.0435	0.1468	44.040	500	100000	0.63	3.33
73	4	Roll B 400 LC	White	8.2508	8.1597	0.0911	27.330	500	100000	0.63	3.33
74	24	Roll B 400 LC	White	8.0455	7.9557	0.0898	26.940	500	100000	0.63	3.33
75	28	Roll B 400 LC	White	8.1333	8.0365	0.0968	29.040	500	100000	0.63	3.33
76	10	Roll B 400 LC	White	8.1930	8.1039	0.0891	26.730	500	100000	0.63	3.33
77	22	Roll B 400 LC	White	8.2173	8.1402	0.0771	23.130	500	100000	0.63	3.33
78	4	Roll B 400 LC	White	8.1967	8.1297	0.0670	20.100	500	100000	0.63	3.33
79	24	Roll B 400 LC	White	8.1060	8.0380	0.0680	20.400	500	100000	0.63	3.33
80	28	Roll B 400 LC	White	8.1684	8.0872	0.0812	24.360	500	100000	0.63	3.33
81	10	Roll B 400 LC	White	8.2453	8.1673	0.0780	23.400	500	100000	0.63	3.33
82	22	Roll B 400 LC	White	8.1993	8.1178	0.0815	24.450	500	100000	0.63	3.33
83	22	Roll B 400 LC	White	8.1923	7.6655	0.5268	22.904	500	690000	0.63	23.00
84	4	Roll B 400 LC	White	8.2335	7.8097	0.4238	18.426	500	690000	0.63	23.00
85	24	Roll B 400 LC	White	8.0304	7.6061	0.4243	18.448	500	690000	0.63	23.00
86	28	Roll B 400 LC	White	8.1468	7.6366	0.5102	22.183	500	690000	0.63	23.00
87	10	Roll B 400 LC	White	8.2543	7.7361	0.5182	22.530	500	690000	0.63	23.00
88	22	Roll B 400 LC	White	8.1645	7.6562	0.5083	22.100	500	690000	0.63	23.00
89	4	Roll B 400 LC	White	8.1856	7.7758	0.4098	17.817	500	690000	0.63	23.00
90	24	Roll B 400 LC	White	8.0275	7.6062	0.4213	18.317	500	690000	0.63	23.00
91	28	Roll B 400 LC	White	8.1555	7.6564	0.4991	21.700	500	690000	0.63	23.00
92	10	Roll B 400 LC	White	8.2270	7.7063	0.5207	22.639	500	690000	0.63	23.00
93	22	Roll B 400 LC	White	8.1597	7.6397	0.5200	22.609	500	690000	0.63	23.00

94	22	Roll B 400 LC	White	8.1283	7.7292	0.3991	17.352	500	690000	0.63	23.00
95	22	Roll B 400 LC	White	8.1472	7.8189	0.3283	14.274	500	690000	0.63	23.00
96	22	Roll C 400 LC	White	8.1594	7.9981	0.1613	48.390	500	100000	0.63	3.33
97	4	Roll C 400 LC	White	8.1258	8.0148	0.1110	33.300	500	100000	0.63	3.33
98	24	Roll C 400 LC	White	8.1758	8.0827	0.0931	27.930	500	100000	0.63	3.33
99	28	Roll C 400 LC	White	8.1763	8.0757	0.1006	30.180	500	100000	0.63	3.33
100	10	Roll C 400 LC	White	8.2095	8.1103	0.0992	29.760	500	100000	0.63	3.33
101	22	Roll C 400 LC	White	8.2345	8.1490	0.0855	25.650	500	100000	0.63	3.33
102	4	Roll C 400 LC	White	8.2753	8.1992	0.0761	22.830	500	100000	0.63	3.33
103	24	Roll C 400 LC	White	7.8119	7.7356	0.0763	22.890	500	100000	0.63	3.33
104	28	Roll C 400 LC	White	8.1524	8.0678	0.0846	25.380	500	100000	0.63	3.33
105	10	Roll C 400 LC	White	8.4232	8.3314	0.0918	27.540	500	100000	0.63	3.33
106	22	Roll C 400 LC	White	8.1286	8.0337	0.0949	28.470	500	100000	0.63	3.33
107	22	Roll C 400 LC	White	8.1419	7.5954	0.5465	23.761	500	690000	0.63	23.00
108	4	Roll C 400 LC	White	8.1215	7.6531	0.4684	20.365	500	690000	0.63	23.00
109	24	Roll C 400 LC	White	8.2427	7.7231	0.5196	22.591	500	690000	0.63	23.00
110	28	Roll C 400 LC	White	8.1799	7.5913	0.5886	25.591	500	690000	0.63	23.00
111	10	Roll C 400 LC	White	8.1159	7.4975	0.6184	26.887	500	690000	0.63	23.00
112	22	Roll C 400 LC	White	8.1564	7.5873	0.5691	24.743	500	690000	0.63	23.00
113	4	Roll C 400 LC	White	8.2017	7.7117	0.4900	21.304	500	690000	0.63	23.00
114	24	Roll C 400 LC	White	8.0286	7.5015	0.5271	22.917	500	690000	0.63	23.00
115	28	Roll C 400 LC	White	8.1813	7.5665	0.6148	26.730	500	690000	0.63	23.00
116	10	Roll C 400 LC	White	8.0290	7.4055	0.6235	27.109	500	690000	0.63	23.00
117	22	Roll C 400 LC	White	8.1831	7.5538	0.6293	27.361	500	690000	0.63	23.00
118	22	Roll C 400 LC	White	8.1511	7.6879	0.4632	20.139	500	690000	0.63	23.00
119	22	Roll C 400 LC	White	8.1904	7.7840	0.4064	17.670	500	690000	0.63	23.00
120	22	Roll D 400 LC	White	8.1670	7.8876	0.2794	8.786	1980	3777822	0.143	31.80
121	23	Roll D 400 LC	White	6.0567	5.8141	0.2426	13.837	500	526000	0.16	17.53
122	29	Roll D 400 LC	White	5.8650	5.6154	0.2496	14.236	500	526000	0.16	17.53
123	23	Roll D 400 LC	White	6.0573	5.8263	0.2310	13.175	500	526000	0.16	17.53
124	19	Roll D 400 LC	White	6.1340	5.8714	0.2626	14.977	500	526000	0.16	17.53
125	22	Roll D 400 LC	White	8.1544	7.8335	0.3209	13.952	500	690000	0.16	23.00
126	4	Roll D 400 LC	White	8.2021	7.9117	0.2904	12.626	500	690000	0.16	23.00
127	23	Roll D 400 LC	White	6.0630	5.0747	0.9883	42.970	500	690000	0.63	23.00
128	32	Roll D 400 LC	White	6.0181	5.3879	0.6302	27.400	500	690000	0.63	23.00

129	33	Roll D 400 LC	White	6.0279	5.4925	0.5354	23.278	500	690000	0.63	23.00
130	23	Roll D 400 LC	White	6.0559	5.2484	0.8075	35.109	500	690000	0.63	23.00
131	33	Roll D 400 LC	White	6.0280	5.4276	0.6004	26.104	500	690000	0.63	23.00
132	32	Roll D 400 LC	White	5.9786	5.3990	0.5796	25.200	500	690000	0.63	23.00
133	23	Roll D 400 LC	White	6.0388	5.1962	0.8426	36.635	500	690000	0.63	23.00
134	23	Roll D 400 LC	White	6.0518	5.6859	0.3659	15.909	500	690000	0.25	23.00
135	33	Roll D 400 LC	White	5.9735	5.5175	0.4560	19.826	500	690000	0.25	23.00
136	23	Roll D 400 LC	White	6.0122	5.5160	0.4962	21.574	500	690000	0.25	23.00
137	32	Roll D 400 LC	White	5.9721	5.5640	0.4081	17.743	500	690000	0.25	23.00
138	23	Roll D 400 LC	Black	6.0350	5.3506	0.6844	29.757	500	690000	0.63	23.00
139	32	Roll D 400 LC	Black	5.9730	5.2964	0.6766	29.417	500	690000	0.63	23.00
140	23	Roll D 400 LC	Black	6.0240	5.1521	0.8719	37.909	500	690000	0.63	23.00
141	22	Roll D 400 LC	Black	8.2303	7.2415	0.9888	42.991	500	690000	0.63	23.00
142	4	Roll D 400 LC	Black	8.2099	7.4472	0.7627	33.161	500	690000	0.63	23.00
143	24	Roll D 400 LC	Black	8.0333	7.0640	0.9693	42.143	500	690000	0.63	23.00
144	28	Roll D 400 LC	Black	8.1884	7.2043	0.9841	42.787	500	690000	0.63	23.00
145	18	Roll D 400 LC	Black	7.8869	7.5365	0.3504	15.235	500	690000	0.63	23.00
146	22	Roll D 400 LC	Black	8.2252	7.2028	1.0224	44.452	500	690000	0.63	23.00
147	23	Roll D 400 LC	Black	6.0252	5.4405	0.5847	25.422	500	690000	0.23	23.00
148	30	Roll D 400 LC	Black	6.0534	5.4898	0.5636	24.504	500	690000	0.23	23.00
149	23	Roll D 400 LC	Black	6.0518	5.5164	0.5354	23.278	500	690000	0.23	23.00
150	31	Roll D 400 LC	Black	5.9665	5.4070	0.5595	24.326	500	690000	0.23	23.00
151	23	Roll D 400 LC	Black	5.9831	5.4799	0.5032	21.878	500	690000	0.23	23.00
152	23	Roll D 400 LC	Black	6.0288	5.4339	0.5949	25.865	500	690000	0.23	23.00
153	32	Roll D 400 LC	Black	5.9527	5.4433	0.5094	22.148	500	690000	0.23	23.00
154	31	Roll D 400 LC	Black	5.9973	5.4415	0.5558	24.165	500	690000	0.23	23.00
155	23	Roll D 400 LC	Black	6.0024	5.5083	0.4941	21.483	500	690000	0.23	23.00
156	21	Roll D 400 LC	Black	8.0780	7.8948	0.1832	7.965	500	690000	0.23	23.00
157	21	Roll D 400 LC	Black	8.0612	7.8538	0.2074	9.017	500	690000	0.23	23.00
158	21	Roll D 400 LC	Black	8.0323	7.8217	0.2106	9.157	500	690000	0.23	23.00
159	20	Roll D 400 LC	Black	6.0004	5.8062	0.1942	8.443	500	690000	0.23	23.00
160	21	Roll D 400 LC	Black	8.0485	7.8650	0.1835	9.574	600	690000	0.23	19.17
161	23	Roll D 400 LC	White	6.0192	5.7073	0.3119	13.561	500	690000	0.23	23.00
162	30	Roll D 400 LC	White	6.0543	5.7736	0.2807	12.204	500	690000	0.23	23.00
163	23	Roll D 400 LC	White	6.0248	5.7079	0.3169	13.778	500	690000	0.23	23.00

164	31	Roll D 400 LC	White	5.9794	5.6569	0.3225	14.022	500	690000	0.23	23.00
165	23	Roll D 400 LC	White	6.0343	5.6761	0.3582	15.574	500	690000	0.23	23.00
166	23	Roll D 400 LC	White	6.0183	5.4121	0.6062	26.357	500	690000	0.63	23.00
167	30	Roll D 400 LC	White	6.0592	5.5421	0.5171	22.483	500	690000	0.63	23.00
168	31	Roll D 400 LC	White	5.9680	5.4279	0.5401	23.483	500	690000	0.63	23.00
169	8	Roll D 400 LC	White	6.1941	5.3930	0.8011	34.830	500	690000	0.63	23.00
170	32	Roll D 400 LC	White	5.9995	5.3943	0.6052	26.313	500	690000	0.63	23.00
171	20	Roll D 400 LC	White	6.0122	5.4501	0.5621	24.439	500	690000	0.63	23.00
172	23	Roll D 400 LC	White	6.0216	5.3524	0.6692	29.096	500	690000	0.63	23.00
173	30	Roll D 400 LC	White	6.0380	5.4501	0.5879	25.561	500	690000	0.63	23.00
174	31	Roll D 400 LC	White	5.9952	5.3943	0.6009	26.126	500	690000	0.63	23.00
175	23	Roll D 400 LC	White	6.0329	5.3930	0.6399	27.822	500	690000	0.63	23.00
176	8	Roll D 400 LC	White	6.6755	6.0197	0.6558	28.513	500	690000	0.63	23.00
177	22	Roll D 400 LC	White	8.2119	7.5303	0.6816	29.635	500	690000	0.63	23.00
178	23	Roll D 400 LC	White	6.0115	5.4593	0.5522	24.009	500	690000	0.63	23.00
179	15	Roll D 400 LC	White	5.9975	5.5464	0.4511	19.613	500	690000	0.63	23.00
180	23	Roll D 400 LC	White	6.0420	5.6388	0.4032	17.530	500	690000	0.63	23.00
181	15	Roll D 400 LC	White	5.9333	5.5053	0.4280	18.609	500	690000	0.63	23.00
182	23	Roll D 400 LC	White	6.0125	5.5877	0.4248	18.470	500	690000	0.63	23.00
183	23	Roll E 800 LC	White	6.0298	5.6173	0.4125	17.935	500	690000	0.375	23.00
184	15	Roll E 800 LC	White	5.8304	5.5282	0.3022	13.139	500	690000	0.375	23.00
185	23	Roll E 800 LC	White	6.0299	5.7334	0.2965	12.891	500	690000	0.375	23.00
186	15	Roll E 800 LC	White	5.9156	5.6270	0.2886	12.548	500	690000	0.375	23.00
187	23	Roll E 800 LC	White	6.0397	5.7391	0.3006	13.070	500	690000	0.375	23.00
188	23	Roll E 800 LC	White	6.0615		test failure - lost pump flow		500	690000	0.3	23.00
189	23	Roll E 800 LC	White	6.0181	5.7685	0.2496	10.852	500	690000	0.39	23.00
190	15	Roll E 800 LC	White	5.9710	5.7282	0.2428	10.557	500	690000	0.39	23.00
191	31	Roll E 800 LC	White	5.9398	5.7063	0.2335	10.152	500	690000	0.39	23.00
192	23	Roll E 800 LC	White	6.0707	5.7686	0.3021	13.135	500	690000	0.39	23.00
193	4	Roll E 800 LC	White	6.2320	6.0010	0.2310	10.043	500	690000	0.39	23.00
194	23	Roll E 800 LC	White	6.0088	5.7419	0.2669	11.604	500	690000	0.39	23.00
195	4	Roll E 800 LC	White	6.2060	5.9309	0.2751	11.961	500	690000	0.39	23.00
196	23	Roll E 800 LC	White	6.0400	5.7649	0.2751	11.961	500	690000	0.39	23.00
197	23	Roll C 400 LC	White	6.0687	5.8161	0.2526	10.983	500	690000	0.39	23.00

198	15	Roll C 400 LC	White	5.9271	5.7118	0.2153	9.361	500	690000	0.39	23.00
199	16	Roll C 400 LC	White	6.1029	5.9052	0.1977	8.596	500	690000	0.39	23.00
200	17	Roll C 400 LC	White	5.9064	5.6954	0.2110	9.174	500	690000	0.39	23.00
201	23	Roll C 400 LC	White	6.0531	5.8015	0.2516	10.939	500	690000	0.39	23.00
202	23	Roll C 400 LC	White	5.0905	4.8434	0.2471	10.743	500	690000	0.426	23.00
203	15	Roll C 400 LC	White	4.9360	4.7103	0.2257	9.813	500	690000	0.426	23.00
204	16	Roll C 400 LC	White	5.1044	4.8927	0.2117	9.204	500	690000	0.426	23.00
205	17	Roll C 400 LC	White	4.9630	4.7389	0.2241	9.743	500	690000	0.426	23.00
206	23	Roll C 400 LC	White	5.0876	4.8307	0.2569	11.170	500	690000	0.426	23.00
207	plastic 1	Roll C 400 LC	White					500	690000	0.39	23.00
208	plastic 2	Roll C 400 LC	White					500	690000	0.39	23.00
209	9	Roll C 400 LC	White	6.2309	6.0605	0.1704	7.409	500	690000	0.39	23.00
210	9	Roll C 400 LC	White	6.2258	6.1067	0.1191	5.178	500	690000	0.39	23.00
211	plastic 3	Roll C 400 LC	White					500	690000	0.39	23.00
212	1	Roll C 400 LC	White	8.1050	7.5931	0.5119	22.257	500	690000	0.39	23.00
213	22	Roll C 400 LC	White	8.2044	7.7664	0.4380	19.043	500	690000	0.39	23.00
214	1	Roll C 400 LC	White	8.1335	7.5998	0.5337	23.204	500	690000	0.39	23.00
215	22	Roll C 400 LC	White	8.1361	7.6910	0.4451	19.352	500	690000	0.39	23.00
216	18	Roll C 400 LC	White	7.8085	7.6657	0.1428	6.209	500	690000	0.39	23.00
217	22	Roll C 400 LC	White	8.1963	7.8357	0.3606	15.678	500	690000	0.39	23.00
218	18	Roll C 400 LC	White	7.8442	7.6949	0.1493	6.491	500	690000	0.39	23.00
219	22	Roll C 400 LC	White	8.2400	7.8580	0.3820	16.609	500	690000	0.39	23.00
220	23	Roll C 400 LC	White	6.0417	5.6562	0.3855	16.761	500	690000	0.39	23.00
221	29	Roll C 400 LC	White	6.2409	5.9450	0.2959	12.865	500	690000	0.39	23.00
222	23	Roll C 400 LC	White	6.0326	5.6650	0.3676	15.983	500	690000	0.39	23.00
223	29	Roll C 400 LC	White	6.3096	6.0264	0.2832	12.313	500	690000	0.39	23.00
224	23	Roll C 400 LC	White	6.0065	5.6663	0.3402	14.791	500	690000	0.39	23.00
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