The Production and Performance of Bi-Metal ZincSecure™ Coins

Jarden Zinc Products has introduced a new zinc alloy series, ZincSecure™, which provides a spectrum of alternative base metal electro-magnetic signatures (EMS), high performance and positive seigniorage for coinage applications. This paper discusses the key technical aspects involved in the development of bimetal coins based on ZincSecure™ technology. One focus area of study is to gain an understanding of the influence of factors such as material choice, die design, die pressure and locking design on the push-out strength and corrosion resistance properties of the coins.. The second focus area is to understand how the test parameters for push-out strength measurements affect the results and how these measurements may lead to development of guidelines and a possible industry standard. Finally, a benchmark comparison will be made between various circulation coins and Zincsecure™ based bimetal coins. The advantage of ZincSecure™ technology in a bimetal coin construction will be demonstrated based on its high security, high performance and positive seigniorage for coinage applications.

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The scope of this work was to understand how the factors such as material choice, die design, die pressure, plating combination and locking design affect the key properties of the bimetal coins including the separation force and corrosion resistance.

Commonly used through alloy Ni-silver and low carbon steel were paired with Zincsecure^{TM} alloy in various ring/core combinations to produce multiple sets of bimetal coins, see Table 1.

Table 1. Material sets and plating finishes used in the present study.

		Ring			Core				
Sample ID	Material Plating finish		Thickness	Cut Diameter	Material Plating finish	Thickness	Cut Diameter	Nominal Clearance Prior to Assy	Clearance High Low
1A-01	**Zinc**	Dimension	0.068"	1.074"	**Zinc**	0.068"	0.643	0.0060	0.0096
	Bronze/Cu	Tolerance	+/- 0.001	+/- 0.001	**Ni / Cu**	+/- 0.001	+/- 0.001		0.0044
1A-02	**Nickel Silver**	Dimension	0.068"	1.074"	**Zinc**	0.068"	0.643	0.0060	0.0093
		Tolerance	+/- 0.001	+/- 0.001	**Bronze/ Cu**	+/- 0.001	+/- 0.001		0.0047
1A-03	**Zinc**	Dimension	0.068"	1.074"	**Nickel Silver**	0.068"	0.643	0.0060	0.0092
	Bronze/Cu	Tolerance	+/- 0.001	+/- 0.001		+/- 0.001	+/- 0.001		0.0048
1A-04	**Nickel Silver**	Dimension	0.068"	1.074"	**Nickel Silver**	0.068"	0.643	0.0060	0.0090
		Tolerance	+/- 0.001	+/- 0.001		+/- 0.001	+/- 0.001		0.0050
1B-01	**Zinc**	Dimension	0.068"	1.074"	**Zinc**	0.068"	0.643	0.0060	0.0095
	Nickel/Cu	Tolerance	+/- 0.001	+/- 0.001	**Bronze/Cu**	+/- 0.001	+/- 0.001		0.0045
1B-02	**Steel**	Dimension	0.068"	1.074"	**Zinc**	0.068"	0.643	0.0060	0.0095
	Nickel	Tolerance	+/- 0.001	+/- 0.001	**Bronze/Cu**	+/- 0.001	+/- 0.001		0.0045
1B-03	**Zinc**	Dimension	0.068"	1.073"	**Steel**	0.068"	0.643	0.0060	0.0095
	Nickel/Cu	Tolerance	+/- 0.001	+/- 0.001	**Bronze**	+/- 0.001	+/- 0.001		0.0045
1B-04	**Steel**	Dimension	0.068"	1.073"	**Steel**	0.068"	0.643	0.0060	0.0095
	Nickel	Tolerance	+/- 0.001	+/- 0.001	**Bronze**	+/- 0.001	+/- 0.001		0.0045

The plating thickness was kept constant at 25 microns except in the case of Ni-silver that was not plated, In case of zinc-steel combinations; the plating was chosen such that the ring had a white finish while the core had yellow finish. The dimensions of cores and of ring inside and outside diameters were rimmed and blanked to allow for a nominal clearance of 0.0060” during assembly after taking the effects of overplating into account. The standard Schuler locking design of having a groove in the core was used for this study.

550 coins of each combination were produced on xxx press. To examine the influence of die pressure and die design on the resultant properties of the coin, one hundred and fifty coins each were assembled at three different die pressures of 80 Ton, 95 Ton and 110 Ton respectively

for a single design. For a second design, one hundred coins were assembled at a die pressure of 95 Ton. A few examples of the coined samples for the two designs are shown in Figure 1. There was no evidence of any deformation in any of the coin sets; the features were distinctive/…………………… (steel versus zinc, nickel-silver versus zinc, function of pressure????).

Separation Force

Test Setup Considerations

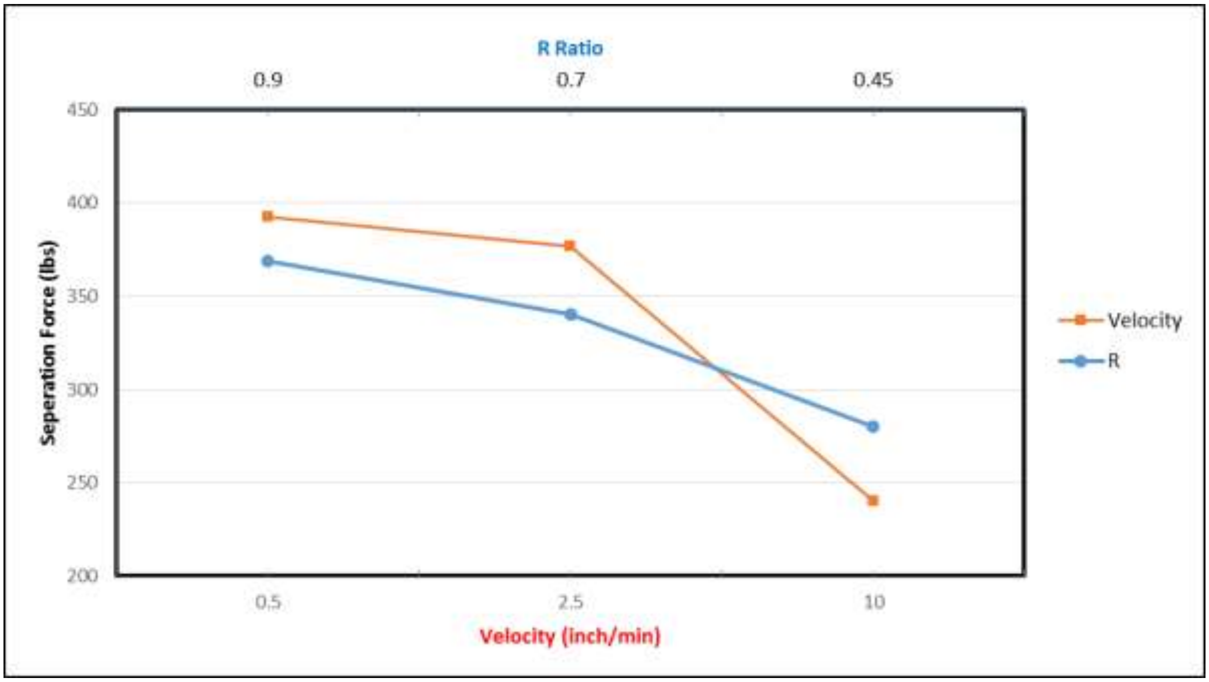
One of the key properties of interest in a bimetal coin is the force required to separate the core from the ring. It is very important that the two-piece coin remains intact and that the forces exerted during handling, sorting etc. do not lead to separation of the two parts. It is well known that …………Canadian Toonie issues….

Though the force required to separate the core from the ring can be measured using a simple desktop Spring tester such as ……..,, it is important to understand the nuances of these measurements and why is it important to design a test fixture that can provide repeatable and consistent measurements. An in-house Instron Machine (Modal XXX) was used in this study. A photograph of the test fixture design is shown in Figure 2.

Several factors play a role in the accuracy of test results and the effect of these factors was examined, the factors included; piston travel speed, the ratio of piston diameter (Dp) to diameter of core (Dc) and the clearance between coin ID and fixture ID (CL = Df – Dcoin)

Another important design consideration was the placement of coin rim on a flat surface or inside a groove. It was noted that a slight bend resulting from the placement of coin on a flat surface (rim touching the flat surface) led to a slight bend in testing, which, in turn, lead to wide fluctuations in observed separation force numbers. Hence, as a standard design practice, it was decided to place the coin in the test fixture such that the rim rests in a groove. It should be noted that the upset height of the rim will play a significant role on the observed issues. A shallow rim may encounter less or no issue at all but it would still be better to have the coin sit on its flat face during testing.

The ratio of piston diameter to diameter of core (R= Dp/Dc) was tried at three values of 0.9, 0.7 and 0.45 and three levels of piston speed were used; 0.5 inch/min, 2.5 inch/min and 10 inch/min. While an exhaustive design of experiments was not performed, care was taken to independently evaluate the influence of various factors considered in this study. It was observed that a high value of R was desirable to get results that were close to the expected values. The influence of R ratio on the measured separation force values was quite pronounced (see Figure 3).



As the ratio became smaller, i.e., the piston diameter became smaller compared to the core diameter, the measured separation force values dropped. This may be due to effect of bending forces acting on the coin at smaller piston diameter, leading to effective lowering of the shear forces across the thickness of ring that the core goes through prior to separation. It is an assumption at this point and further test design modifications, such as pinning the ring to avoid any bending moment, would need to be done to validate the assumption. The data itself clearly shows the importance of keeping the piston diameter close to the core diameter to improve the accuracy of measurements.

From the above graph, it can also be seen that when the piston velocity was increased substantially, the measured separation force numbers experienced a significant drop. At slower velocities, the changes were much less, and hence, one should choose an optimum velocity that is not too fast but slow enough to allow for a reasonable measurement time that is not too long. In this study, a velocity of 2.5 inch/minute was chosen as the optimum number.

A clearance CL of > xxx mm was required to improve the accuracy of results. For a clearance that was too small, expansion of the coin during application of piston force and constraint from the test fixture led to an upward bend in the coin. The resultant separation force values were as low as half of the expected values. This may happen due to the ‘slippage’ of core from the ring instead of it being working through the frictional forces over the thickness of the coin. When enough clearance was given, the numbers returned to the normal expected values. A clearance that is too high led to difficulties in centering of the coin during testing and to coin bending downwards due to off-centering. Hence the clearance value should be just high enough to allow for slight expansion or movement of coin during testing without leading to off-centering. Material properties will play a role in determining this clearance and it is suggested that an estimate of potential material expansion be determined via trial and error and the clearance be adjusted based on the estimated expansion number.

From the above it is clear that any measurement of the separation force should take several factors into consideration.

Seperation force and locking mechanism

Using the learnings as stated above, push-out strength was measured on 20 samples from each of the set in Table 1. The results are displayed in Figure 4 below.

For a given combination of ring and core material, it was noticed that the maximum separation force was generally obtained at a higher pressure and one of the designs seemed to give higher separation force numbers, at comparable die pressure. The combination of a steel ring with a steel core provided exceptionally high separation force while most of the other combinations (with the exception of a nickel silver ring and zinc core) had separation force averaging above 350 lbf????? It was also interesting to note that, at higher die pressure, the average separation force seemed to be similar regardless of whether zinc was in the core or the ring (for a zinc ring-zinc core combination 1A01 and 1B01). This would imply that the plated finish did not make a significant difference in these values as the two combinations had plated finishes that were reverse of each other (yellow ring and white core in one and white core and yellow ring in the other).

To better understand how the coin locking mechanism and the choice of material sets affect the separation force values, two coins from all the combinations in this study were mounted and polished for cross-sectional examination. In order to avoid the separation of core from the ring during the cutting and mounting process, the coins were cut at about one tenth of an inch offset from the center and were ground and polished to the approximate center.

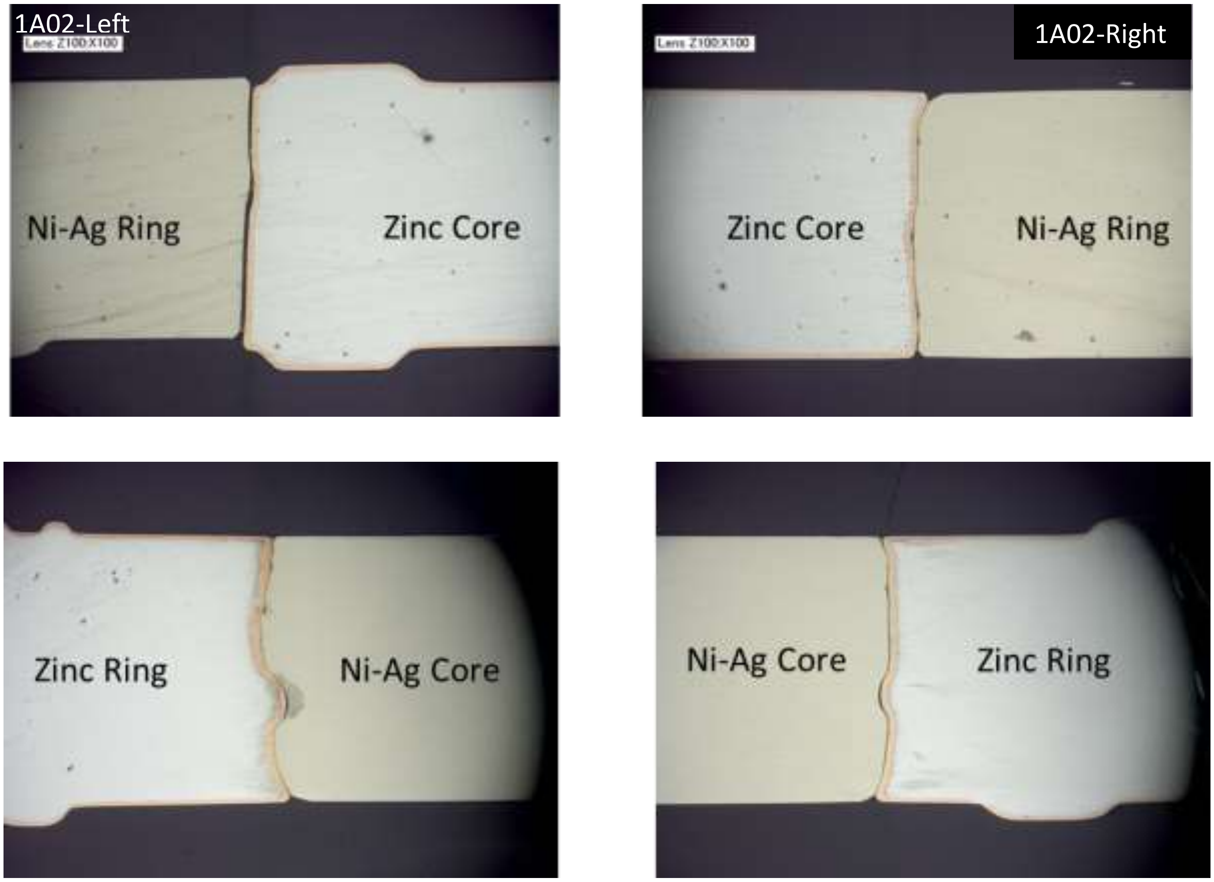
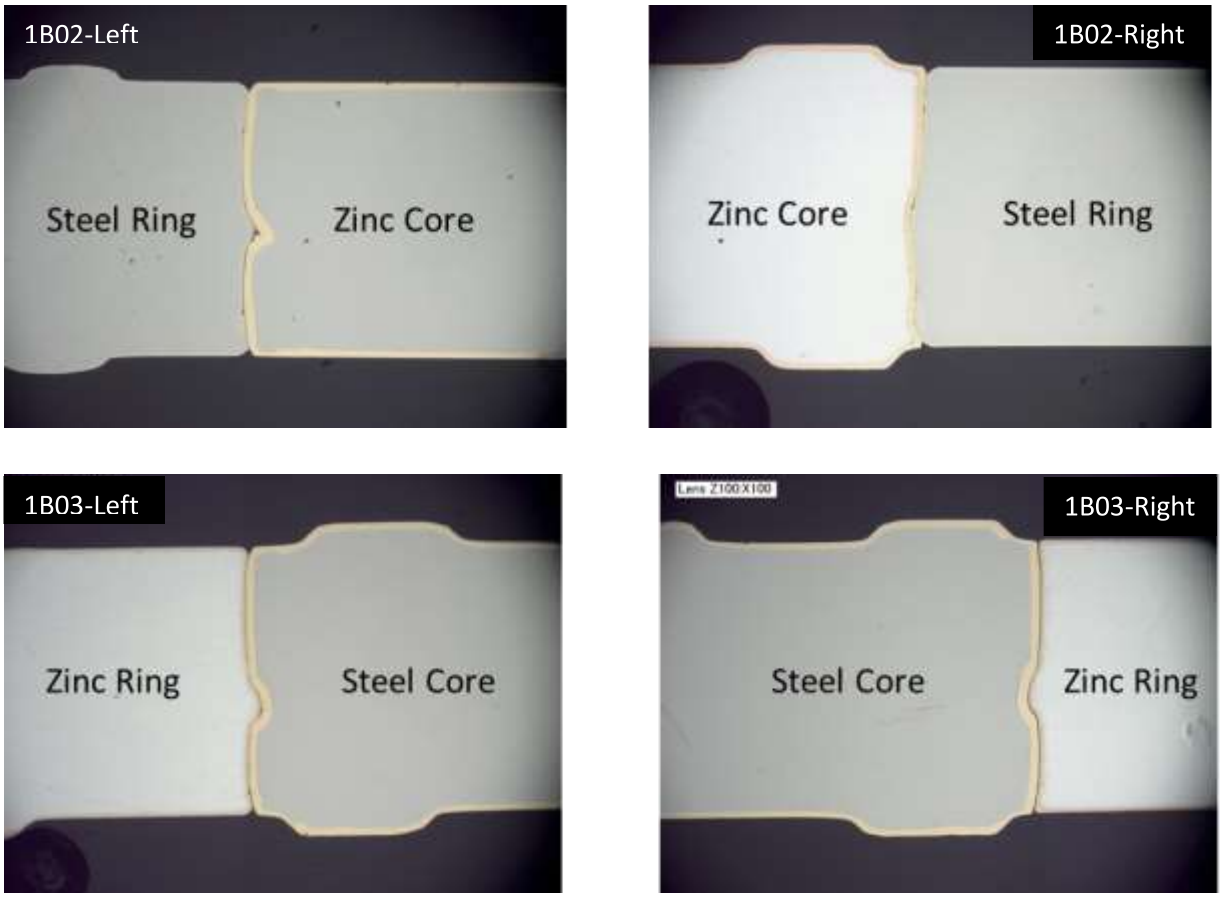


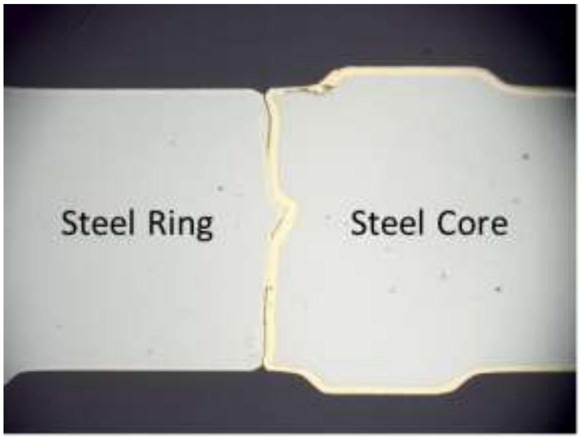
Figure 5 shows the x-sectional views of samples from sets 1A02 (Nickel silver ring with zinc core) and 1A03 (zinc ring with nickel silver core). The contrast between the two samples is quite striking. While there appears to be good amount of zinc in the ring flowing into the groove of nickel silver core in sample 1A03, there is no material flow in the groove in sample 1A02. On the contrary, the groove in the core seems to have straightened out during the bimetal assembly process. The reason for this observed behavior is the relative hardness values of the two materials; while the zinc used in this study has a hardness value of ~ 62 (Rc_{15} scale), Nickel silver is much harder at ~ 79. While the softer material zinc flowed into the core of a harder nickel silver in sample 1A03, the opposite did not happen in sample 1A02. Instead of flowing into the groove in the zinc core, harder nickel silver resisted it to the extent that it almost straightened the groove. This microstructure also explains the low separation force values for 1A02 combination. With hardly any locking strength or material flow into the groove, it was easy to separate the core from the ring in sample 1A02 while the filling of groove in the core in sample 1A03 provided good locking strength, and hence, a higher value of separation force.

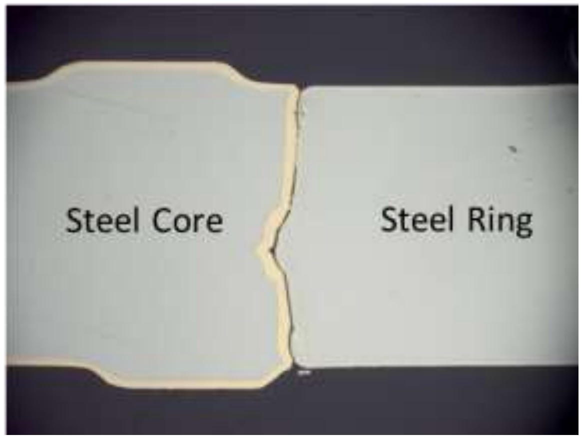
It was also seen that, at higher pressure and for Design 1, the separation force was similar (~ 470 lbf) for combinations 1B02 and 1B03 with zinc and steel in the core and ring. While the numbers were fairly constant regardless of die design and die pressure for 1B03 combination with a zinc ring and steel core, in the 1B02 combination (steel ring and zinc core) the highest number was seen at the highest pressure. Cross-sections of samples 1B02 and 1B03 are shown in Figure 6.



From the above figure it can be seen that the groove in the core has been filled well with the zinc material in both 1B02 and 1B03 sets. Given that the materials set for ring and core combination is same for these sets, it is not surprising to see the separation force numbers are also similar.

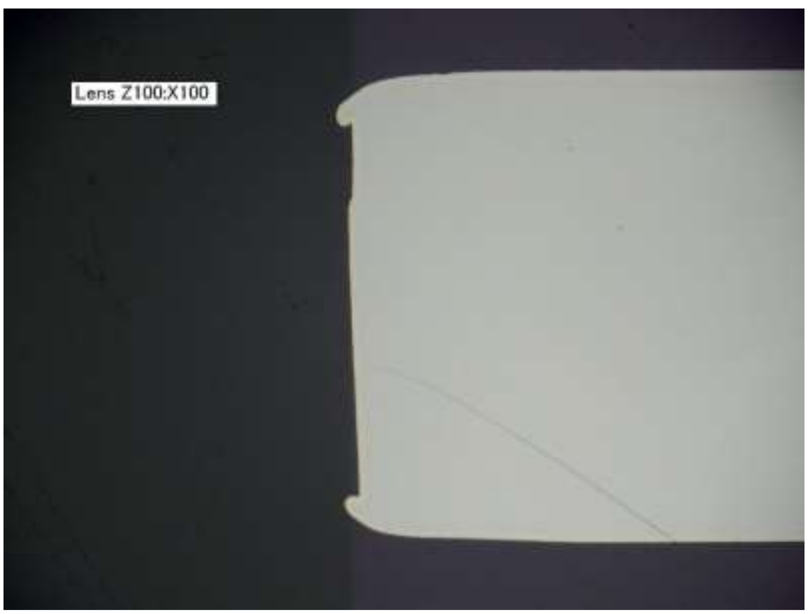
Another interesting observation in this study was the relatively high separation force numbers for set 1B04 with a steel ring and a steel core. Figure 7 shows the cross-section for set 1B04.





While the material from the ring seems to fill the groove in the core well, there does not appear to be a significant difference in the groove filling or the groove shape compared to other samples (1B02 and 1B03) that may explain the observed higher separation force in these coins.

As the separation force in a bimetal coins may depend on several factors including the locking strength (groove size and flow of ring material in the groove), material finish (rough or smooth), die design, die pressure (may determine groove filling), hardness of the materials and frictional forces between ring and core material. In the steel rings, the presence of burrs was observed quite often (see Figure 8 below) and this may have led to the inside wall of ring being relatively rough. A rougher surface would tend to have more frictional resistance and may have resulted in greater separation force numbers, as observed for the steel-steel combination.



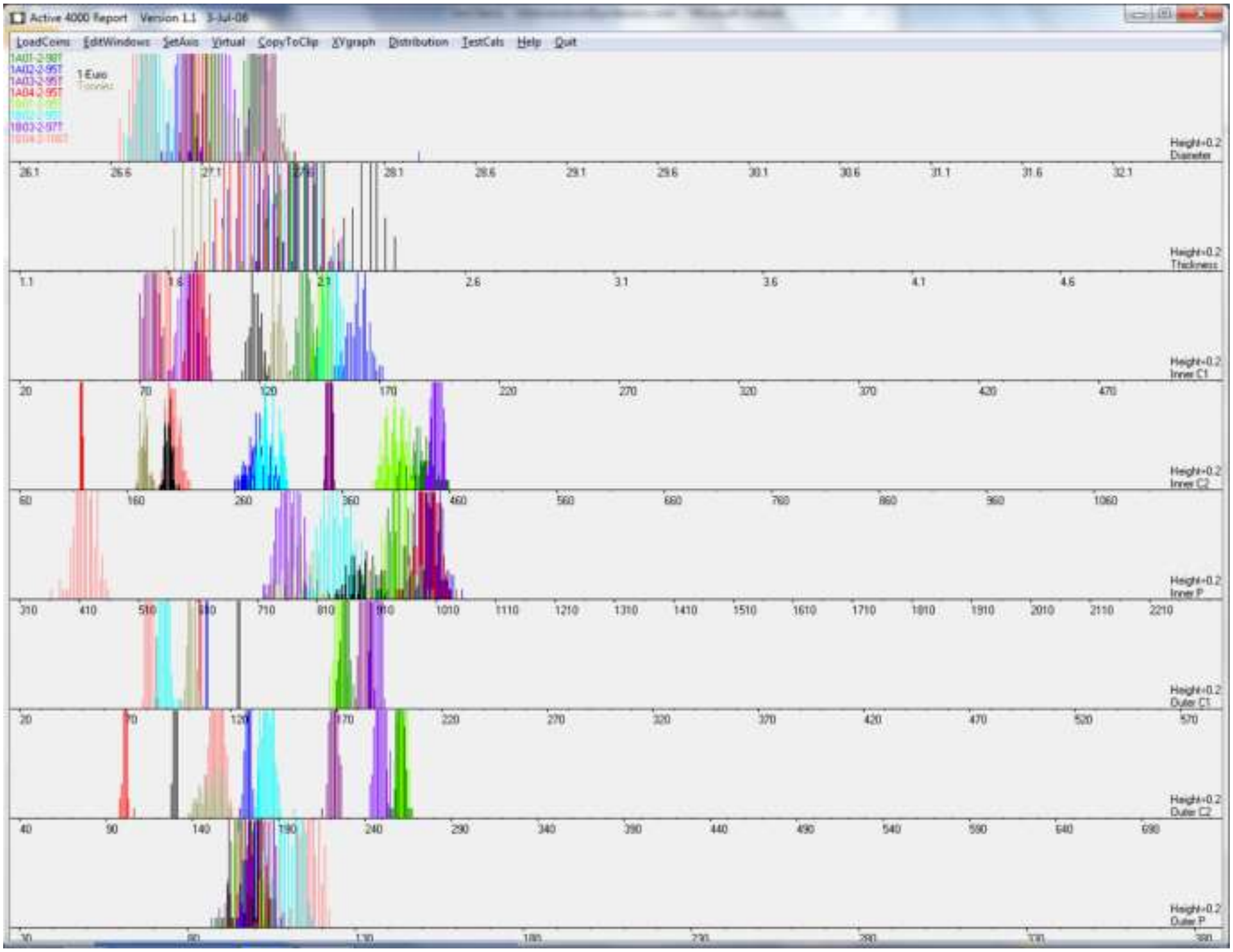
Though material hardness may also be a factor in separation force, it is not clear how much of an impact, if any, it had on the high numbers seen for 1B04 combination. Also, if material hardness played a significant role, we would have expected the sample set 1A04 with higher hardness material nickel silver in both ring and core to be high as well. However, this was not the case as the separation force values for nickel silver combination were similar or even lower than that for zinc core and zinc ring combinations (sets 1A01 and 1B01).

Based on the above results and examination of several circulation coins, it appears that, for coins of same dimensions, the separation force numbers in general are largely determined by factors such as: (i) the locking mechanism between ring and core (size, shape and amount of ring material filing the core in case of a groove in the core); (ii) the roughness of the ring wall; (iii) the die pressure applied during coining; (iv) design of the die (details not studied within current scope of study); and (v) curvature of the core/ring interface (less curved seemed to have low separation strength). While there are no standard requirements (to the best of our knowledge) for the separation force in bimetallic coins, an understanding of these factors and the underlying mechanisms at play will help design robust coins with desired separation force.

EMS Signature Measurements

The EMS of a coin is one of the characteristics by which coins are validated, differentiated and discriminated in coin vending and coin sorting technology. The uniqueness of a coin with respect to EMS is driven by how well a coin is separated from the others on one or more of the factors measured in the coin validator machines. (Distribution Overlap Factor?)

Twenty coins from each of the sets used in the design of experiments were measured in a ScanCoin 4000 model coin sorter (SC4000). Some common steel based and through alloy based bimetal circulation coins were also measured for comparison. The results of the measurements are shown in Figure 9.



It is interesting to note that all the 7 different combinations of bimetal coins resulted in their own distinct signature in the OC2 plot. Combinations 1A01 and 1B01 in which zinc was utilized in both core and ring overlapped in the EMS signature. As the plated finish on 1A01 and 1B01 were essentially reversed, the result implies that plated finish had little role, if any, in driving the EMS signature on these coins.

Another interesting observation is the overlap in signature of 1B04 set and the Canadian Tonnie. Toonie outer ring is of steel.

Wear Testing

The wear test utilized in this study was the one that encompasses all three categories of wear; abrasion, impact and corrosive. It is a tumble test conducted using containers filled with parts and various media (leather, cork and cotton). This test structure creates sliding abrasive wear between the parts and media as well as incorporates a “bump” design into the container to create part-on-part impact wear. Finally, it includes a specific amount of sweat solution to introduce a corrosive wear component. The tumbler is rotated for XXXX hours stopping at 200 hour increments to weigh, measure and inspect the coins for condition.

Weight loss measurements????

During the dimensional measurements, it was noticed that all the coins with zinc in the ring had a higher rim height then the coins with nickel silver or steel as the ring material. The effect was more pronounced as the pressure was increased ?