The Effect of Particle Size, Morphology, and Loading Levels, of Aluminum Pigments in Polypropylene Molded Products

Patrick Ryan
Johnny Donado
Jason Kuhla

SILBERLINE

This paper will investigate how the different geometries, morphologies, and particles sizes of aluminum pigments will affect color and performance of polypropylene molded products. The effect of various loading levels of these pigments will also be explored. Both visual and instrumental color comparisons will be presented as well as processing and loading recommendations to achieve the best color and metallic appearance in an injection molded application with compounded polypropylene.

For the purposes of this study, we have selected 6 products – three of each from both Pellet type A and Pellet Type B technologies. The products selected also were from different particle sizes (fine, medium and coarse) and different flake morphologies (cornflake and silver dollar). In theory, the bigger the particle size, the brighter, or whiter, the effect of the aluminum pigment. Also, at the median particle size (d50), a silver dollar geometry will almost always produce a whiter, more metallic effect than a cornflake aluminum pigment. See figure 1 and 2 below:

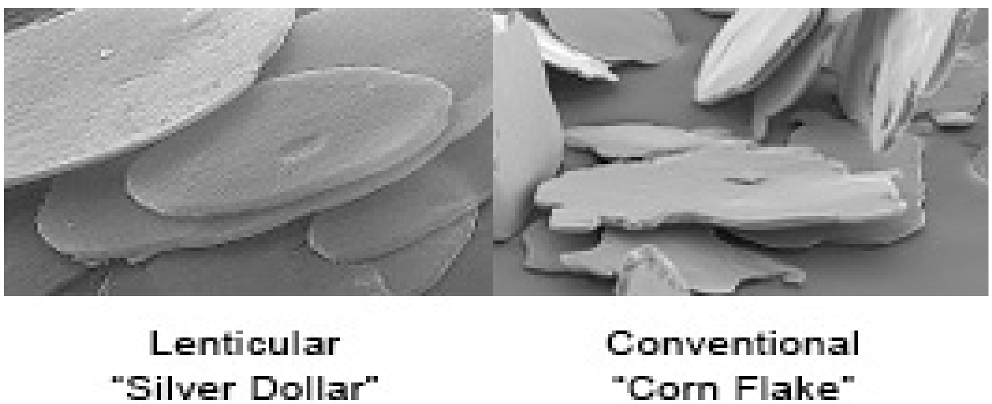


Figure 1: SEM Images of Silver Dollar and Cornflake Aluminum Pigments

Figure 2: Aesthetic Relationships in Aluminum Pigment Families

Both selected technologies provide aluminum pigments, both cornflake and silver dollar geometry, in a low-dusting, low- VOC pellet or Pellet for a variety of polymers and end uses. Suitable for an extensive range of functional and aesthetic applications, the high metal content and carrier types allow the formulator flexibility with selected designs. An explanation of the two technologies along with photos (see Fig. 3 & 4) are below:

Pellet Type A

These pellets are produced with aluminum flake and polyethylene wax. Several process steps ultimately result in a solid compact pellet form at 75-80% aluminum content by weight. The low VOC, low dusting, and ease of handling characteristics make these pellets suitable for use in polyolefin, rigid PVC and a wide range of engineering thermoplastics.

Figure 3: Pellet Type A Aluminum Pigment

Pellet Type B

These Pellets are produced with aluminum flake and polyethylene wax. Several process steps ultimately result in a less dense, softer Pellet form for ease of dispersion with a 70-90% aluminum content by weight. With low VOC, low dusting, ease of handling, and excellent dispersion, Pellet Type B products are suitable for use in polyolefin, polyamides, rigid PVC and a wide range of engineering thermoplastics.

Figure 4: Pellet Type B Aluminum Pigment

All six products chosen for this study was processed under the same conditions, using the same equipment. Polypropylene with a Melt Flow Index (MFI) of 12 was chosen as the main polymer for these evaluations. Each product was processed through a counter rotating, non-intermesh Twin Screw Extruder (TSE) with the following parameters (see Table 1):

Length:Diameter (L:D)	Temperature 1	Temperature 2	Temperature 3	Die Temperature
25:1	190°C	200°C	210°C	170°C

Table 1: TSE Processing Parameters

After extrusion and compounding, each product was then processed into panel chips using a BOY 55A Injection molder (see Figure 5). The processing conditions for the injection molding is shown below in Table 2.

Figure 5: BOY 55A Injection Molder

Temperature 1	Temperature 2	Temperature 3	Temperature 4	Mold Temperature
190°C	205°C	210°C	193°C	43°C

Table 2: Molding Processing Parameters

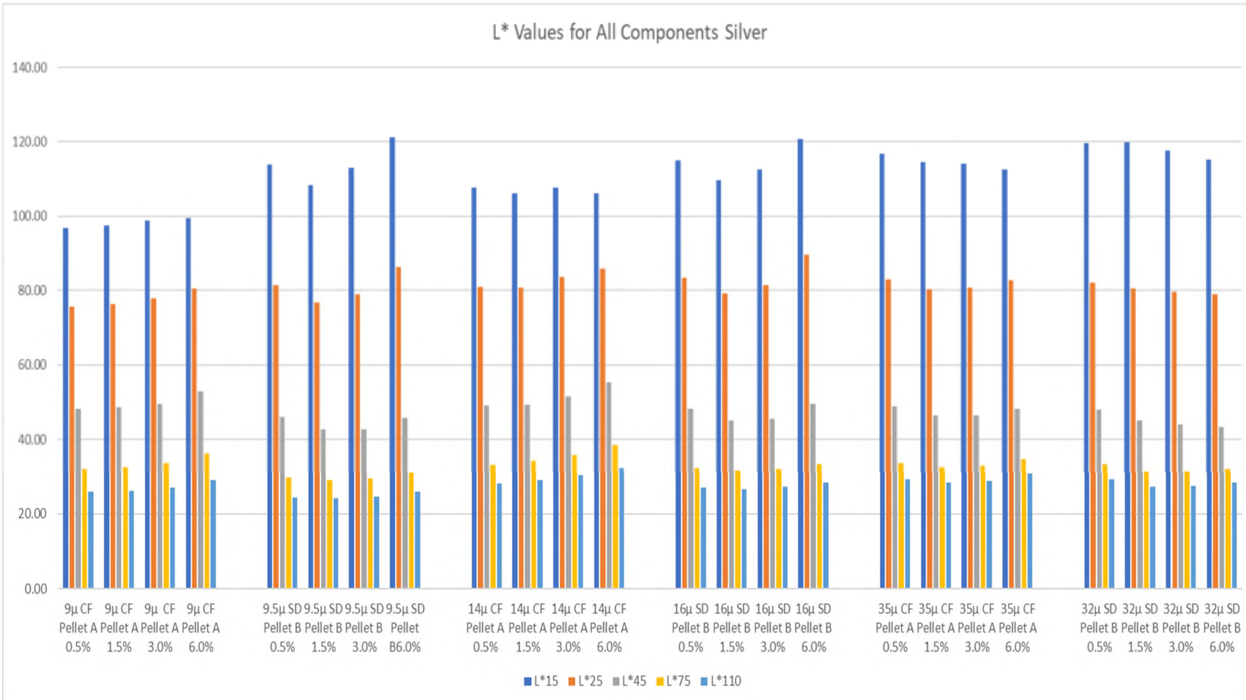
Each of the six products that were chosen utilized varying loading levels of the aluminum pigment pellet or Pellet, varying from 0.5% up to a maximum loading of 6% during compounding. Each of these loading levels was evaluated by injection molded chips in masstone (aluminum pigment only) and with a 1% blue tint addition (phthalo blue). An Xrite MA 68II goniospectrophotometer was used to collect color data (L*a*b* scale). Additionally, each chip was evaluated for gloss at varying angles, as well as opacity using an optical densometer. Visual assessment was also done, and all visual results match the data and trends seen instrumentally. Results of the masstone (Table 3) and the 1% Blue Tint (Table 4) evaluations are below:

Proudct	d(50) µm	Morphology	% Load	L*15	L*25	L*45	L*75	L*110	Gloss 20˚	Gloss 60˚	Gloss 85˚	Reflectance	Opacity
Pellet Type A	**9**	**CF**	**0.5**	96.94	75.62	48.25	32.04	25.89	80.70	92.70	94.40	30.60	0.100
Pellet Type A	**9**	**CF**	**1.5**	97.58	76.29	48.59	32.62	26.22	79.40	91.80	91.40	31.10	0.310
Pellet Type A	**9**	**CF**	**3.0**	98.81	77.81	49.66	33.73	27.06	74.50	88.50	91.60	32.00	0.521
Pellet Type A	**9**	**CF**	**6.0**	99.55	80.63	52.87	36.32	28.94	62.50	80.30	89.10	34.00	0.478
Pellet Type B	**9.5**	**SD**	**0.5**	113.94	81.46	45.96	29.63	24.36	84.00	101.40	93.10	44.50	0.087
Pellet Type B	**9.5**	**SD**	**1.5**	108.45	76.80	42.64	28.94	24.18	82.20	99.50	91.30	48.00	0.248
Pellet Type B	**9.5**	**SD**	**3.0**	112.94	79.08	42.79	29.45	24.69	78.10	97.10	93.70	49.20	0.410
Pellet Type B	**9.5**	**SD**	**6.0**	121.21	86.23	45.74	30.99	25.93	71.10	91.90	97.50	52.80	0.421
Pellet Type A	**14**	**CF**	**0.5**	107.75	80.89	49.17	33.24	28.07	82.50	98.00	94.60	38.40	0.083
Pellet Type A	**14**	**CF**	**1.5**	106.08	80.66	49.36	34.25	28.95	79.40	94.60	93.70	38.90	0.210
Pellet Type A	**14**	**CF**	**3.0**	107.65	83.68	51.63	35.96	30.26	70.20	87.80	94.20	39.30	0.458
Pellet Type A	**14**	**CF**	**6.0**	106.15	85.93	55.25	38.59	32.30	59.90	81.30	92.80	41.40	0.529
Pellet Type B	**16**	**SD**	**0.5**	115.11	83.30	48.14	32.28	26.94	82.80	102.30	93.80	45.90	0.073
Pellet Type B	**16**	**SD**	**1.5**	109.69	79.26	45.22	31.58	26.60	81.30	100.00	94.10	48.00	0.231
Pellet Type B	**16**	**SD**	**3.0**	112.48	81.33	45.68	32.11	27.27	76.20	96.40	92.60	49.80	0.425
Pellet Type B	**16**	**SD**	**6.0**	120.82	89.56	49.59	33.46	28.25	52.50	76.00	89.50	53.10	0.373
Pellet Type A	**35**	**CF**	**0.5**	116.73	82.96	48.82	33.62	29.17	84.30	101.10	92.80	39.90	0.029
Pellet Type A	**35**	**CF**	**1.5**	114.65	80.34	46.46	32.52	28.44	82.60	97.70	93.60	41.80	0.042
Pellet Type A	**35**	**CF**	**3.0**	114.08	80.77	46.40	32.97	28.88	78.30	96.40	91.00	43.10	0.073
Pellet Type A	**35**	**CF**	**6.0**	112.64	82.79	48.23	34.86	30.73	67.60	87.50	91.20	44.40	0.163
Pellet Type B	**32**	**SD**	**0.5**	119.74	82.05	48.06	33.46	29.17	85.30	102.50	93.40	40.90	0.014
Pellet Type B	**32**	**SD**	**1.5**	119.82	80.62	45.15	31.41	27.20	84.70	102.90	93.40	45.30	0.035
Pellet Type B	**32**	**SD**	**3.0**	117.77	79.70	44.02	31.48	27.43	80.50	99.40	92.30	46.80	0.071
Pellet Type B	**32**	**SD**	**6.0**	115.19	79.09	43.30	32.00	28.41	74.80	93.60	92.00	49.70	0.137

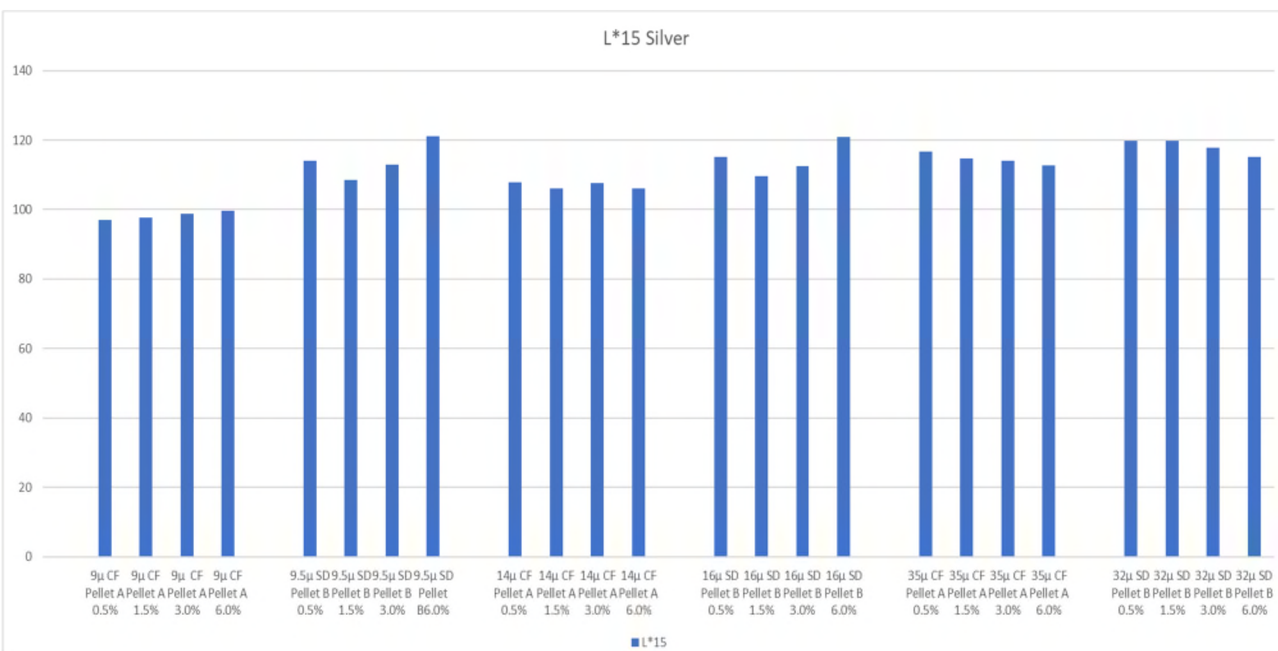
Table 3: Masstone Results

Product	d(50) µm	Morphology	% Load	L*15	L*25	L*45	L*75	L*110	Gloss 20˚	Gloss 60˚	Gloss 85˚	Reflectance	Opacity	b*15	b*25	b*45	b*75	b*110
Pellet Type A	**9**	**CF**	**0.5**	86.36	66.66	41.87	27.14	21.40	83.80	95.40	98.30	22.30	0.148	-12.26	-9.99	-8.00	-7.11	-7.24
Pellet Type A	**9**	**CF**	**1.5**	93.69	73.02	46.53	31.13	24.80	79.50	91.30	96.20	26.30	0.400	-8.28	-5.88	-3.76	-2.88	-2.82
Pellet Type A	**9**	**CF**	**3.0**	96.11	75.73	48.96	33.33	26.68	74.00	86.30	94.60	28.30	0.491	-7.22	-4.83	-2.64	-1.67	-1.44
Pellet Type A	**9**	**CF**	**6.0**	97.47	78.37	51.97	35.90	28.65	60.20	74.50	92.30	30.00	0.456	-5.91	-3.91	-1.89	-0.90	-0.51
Pellet Type B	**9.5**	**SD**	**0.5**	97.74	67.89	36.78	22.44	17.41	81.40	96.20	95.00	32.60	0.116	-16.07	-14.08	-12.37	-11.62	-12.33
Pellet Type B	**9.5**	**SD**	**1.5**	111.04	76.49	40.16	25.59	20.29	80.40	95.70	92.10	42.00	0.277	-8.06	-6.44	-5.49	-5.78	-6.61
Pellet Type B	**9.5**	**SD**	**3.0**	121.11	85.15	44.32	28.61	22.87	72.40	87.60	89.70	47.10	0.462	-6.19	-4.46	-3.23	-3.58	-4.16
Pellet Type B	**9.5**	**SD**	**6.0**	126.34	93.61	50.31	32.17	26.14	55.20	73.30	89.40	47.30	0.485	-4.76	-3.24	-2.03	-2.35	-2.75
Pellet Type A	**14**	**CF**	**0.5**	92.43	68.47	40.51	25.95	20.82	79.80	91.70	94.80	26.10	0.102	-15.87	-13.50	-11.59	-10.94	-11.55
Pellet Type A	**14**	**CF**	**1.5**	101.15	76.02	45.64	30.48	25.02	74.20	85.90	94.80	31.70	0.299	-8.89	-6.85	-5.38	-5.22	-5.76
Pellet Type A	**14**	**CF**	**3.0**	105.40	81.38	50.06	33.97	28.00	62.40	75.70	91.00	35.80	0.432	-6.52	-4.71	-3.17	-2.92	-3.20
Pellet Type A	**14**	**CF**	**6.0**	106.18	84.37	53.84	36.90	30.41	51.10	66.30	86.70	37.20	0.548	-5.25	-3.78	-2.48	-2.19	-2.29
Pellet Type B	**16**	**SD**	**0.5**	96.63	68.31	37.74	23.52	18.39	79.60	93.20	90.70	30.00	0.095	-18.41	-16.18	-14.34	-13.71	-14.53
Pellet Type B	**16**	**SD**	**1.5**	108.44	76.64	41.74	27.24	21.82	76.20	91.40	89.90	39.60	0.242	-8.78	-7.35	-6.65	-7.20	-8.22
Pellet Type B	**16**	**SD**	**3.0**	118.81	85.62	46.15	30.12	24.41	67.90	82.70	89.30	46.20	0.443	-6.30	-4.75	-3.80	-4.37	-5.11
Pellet Type B	**16**	**SD**	**6.0**	124.41	94.18	52.85	34.04	27.88	49.30	69.20	86.60	49.60	0.440	-4.91	-3.54	-2.51	-2.85	-3.38
Pellet Type A	**35**	**CF**	**0.5**	78.12	52.18	28.51	17.37	13.45	81.50	95.60	97.80	15.00	0.035	-33.16	-29.39	-25.46	-22.98	-22.85
Pellet Type A	**35**	**CF**	**1.5**	87.33	59.35	32.73	20.72	16.70	79.50	94.00	95.00	24.30	0.062	-25.08	-21.76	-18.50	-17.02	-17.53
Pellet Type A	**35**	**CF**	**3.0**	94.06	65.75	36.67	24.37	20.43	71.40	87.60	90.40	31.50	0.120	-15.93	-13.79	-12.20	-12.05	-13.05
Pellet Type A	**35**	**CF**	**6.0**	99.44	73.20	42.06	28.48	24.36	58.50	76.50	85.90	34.00	0.214	-10.30	-8.77	-8.03	-8.78	-9.88
Pellet Type B	**32**	**SD**	**0.5**	79.35	51.45	27.19	16.16	12.31	82.50	95.40	97.50	14.50	0.031	-34.54	-30.97	-27.01	-24.14	-23.77
Pellet Type B	**32**	**SD**	**1.5**	91.63	60.52	31.77	19.74	15.50	79.90	94.50	93.10	24.60	0.060	-25.80	-22.56	-19.47	-17.69	-18.10
Pellet Type B	**32**	**SD**	**3.0**	97.56	65.88	34.85	22.50	18.31	75.80	91.20	91.50	32.70	0.102	-17.32	-15.23	-13.53	-13.21	-14.10
Pellet Type B	**32**	**SD**	**6.0**	103.65	73.53	39.48	26.12	21.91	64.70	82.20	86.20	36.10	0.195	-10.95	-9.34	-8.75	-9.56	-10.70

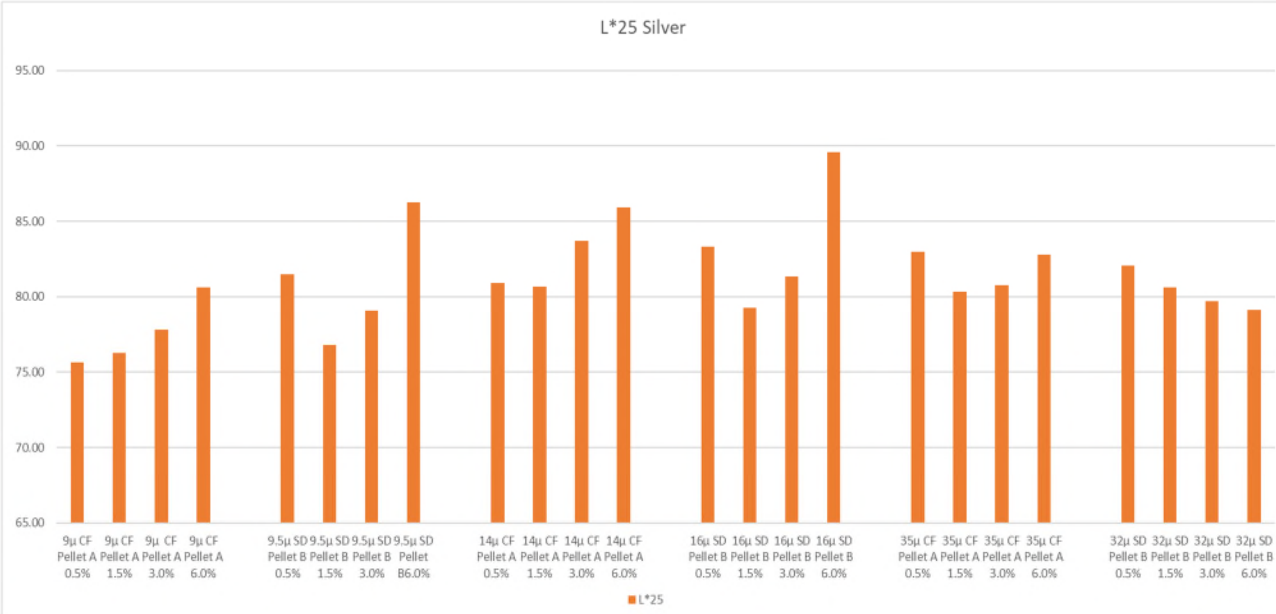
Table 4: 1% Blue Tint Results



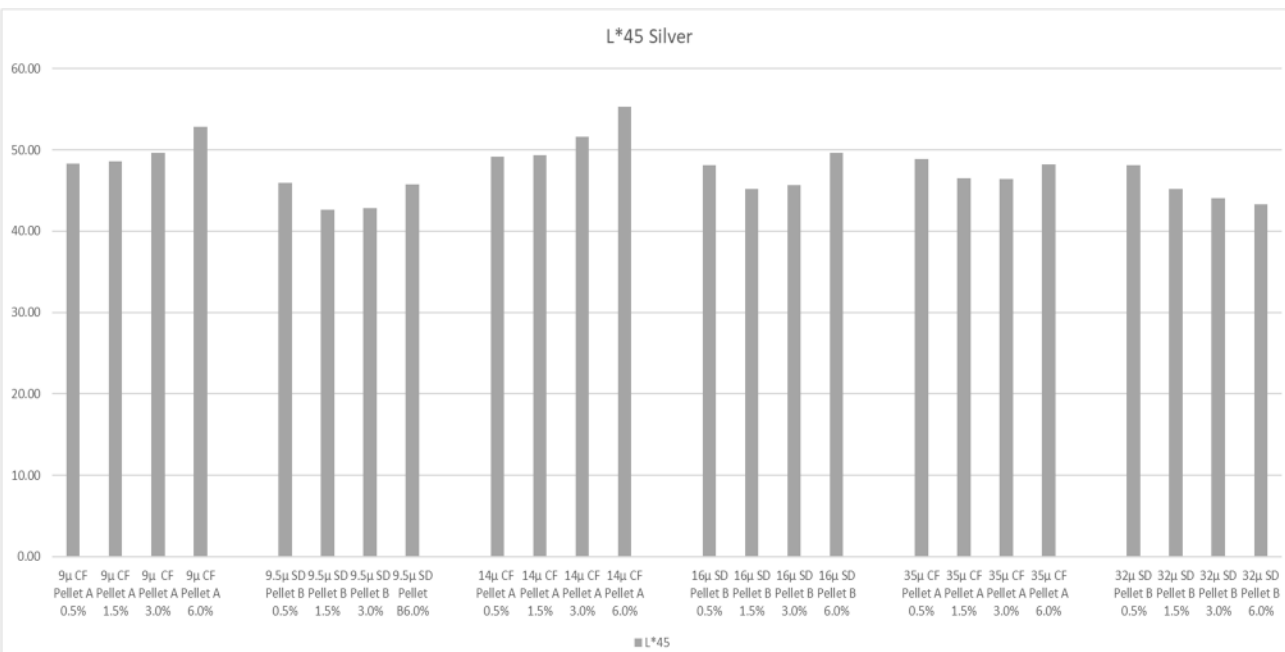
Graph 1: Masstone L Values – All Angles*



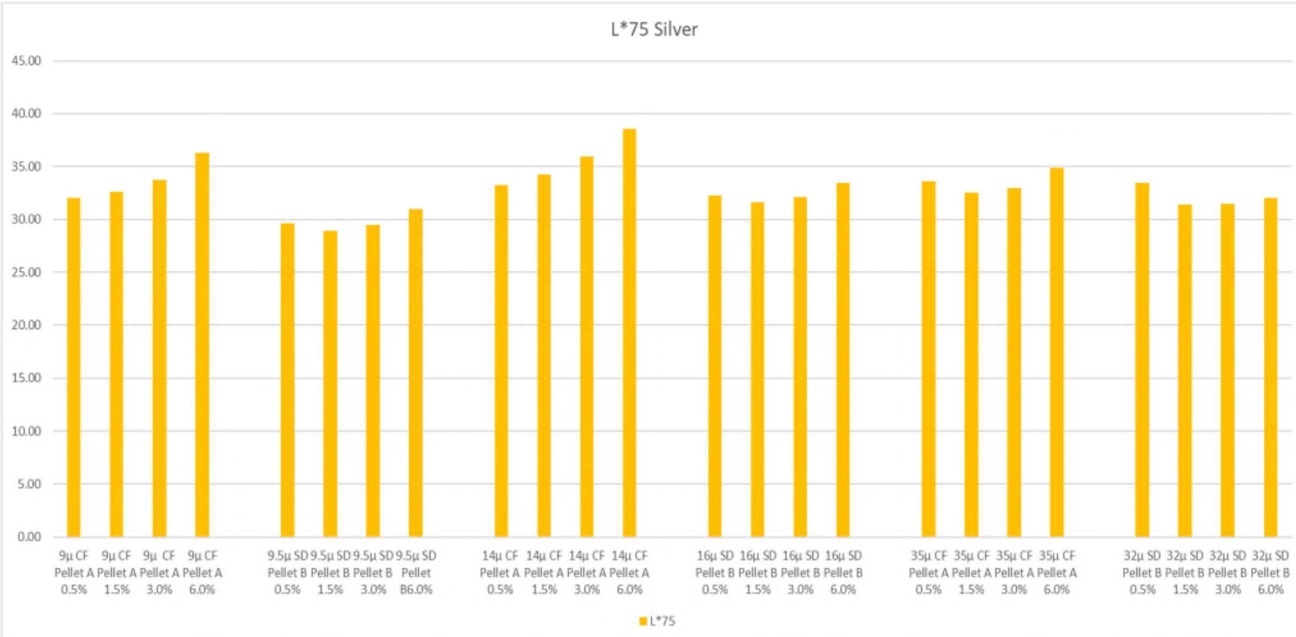
*Graph 2: Masstone L*15 Loading Comparison*



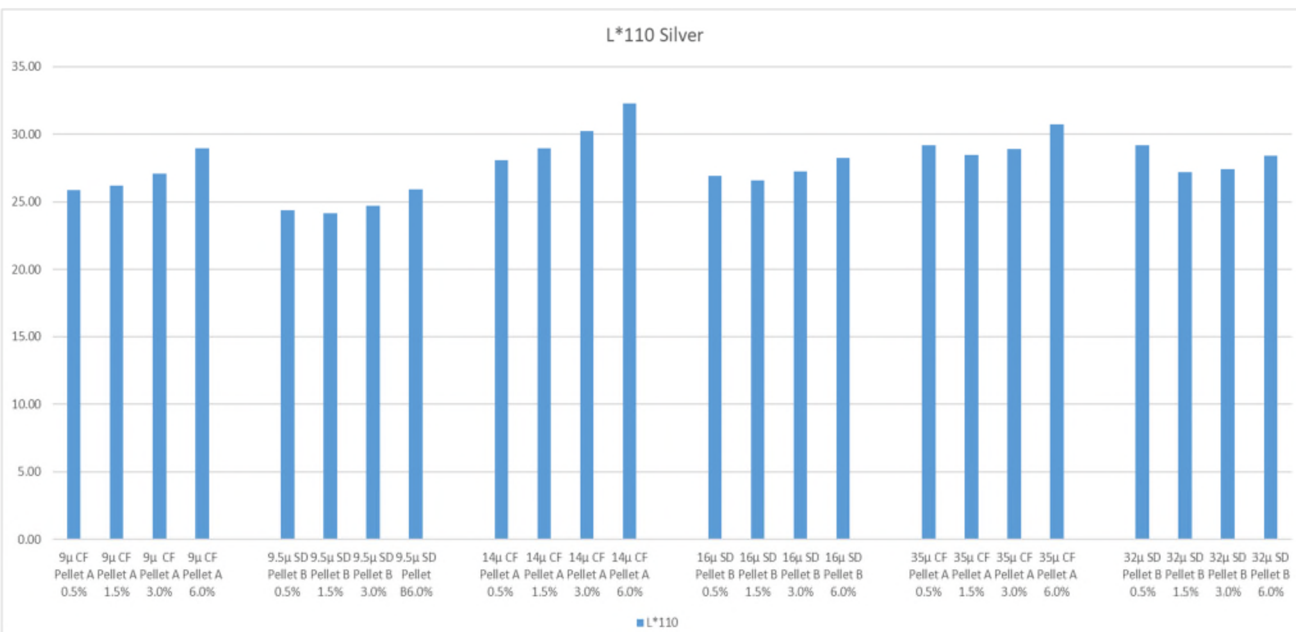
*Graph 3: Masstone L*25 Loading Comparison*



*Graph 4: Masstone L*45 Loading Comparison*



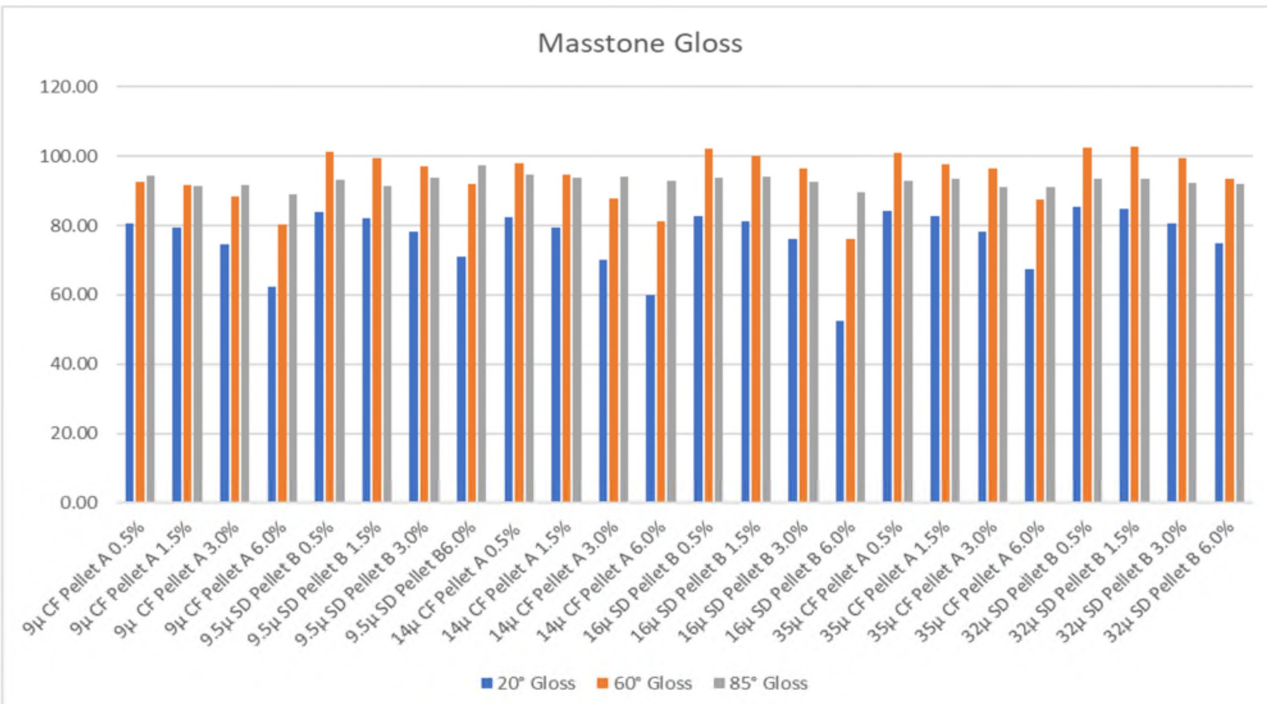
*Graph 5: Masstone L*75 Loading Comparison*



*Graph 6: Masstone L*110 Loading Comparison*

In nearly all instances, the effect of increased aluminum loading with masstone pigmentation is a whiter, brighter, more metallic appearance. All angles are affected by the increased loading, leading to more whiteness at multiple viewing angles. This is true for both Pellet Type A and Pellet Type B products. Also of important note is that the effect is more prevalent with finer flakes that have a silver dollar geometry. This is due to the polished flake surface and narrow particle size distribution that is typical of silver dollar aluminums. These attributes allow the incoming light to reflect more directly at the viewer, as opposed to being scattered by uneven flake surfaces, ultra-fine particles, and rough edges. This data suggests that to achieve a whiter, chrome-like, metallic appearance, silver dollar flakes and higher aluminum concentrations during formulation should be employed.

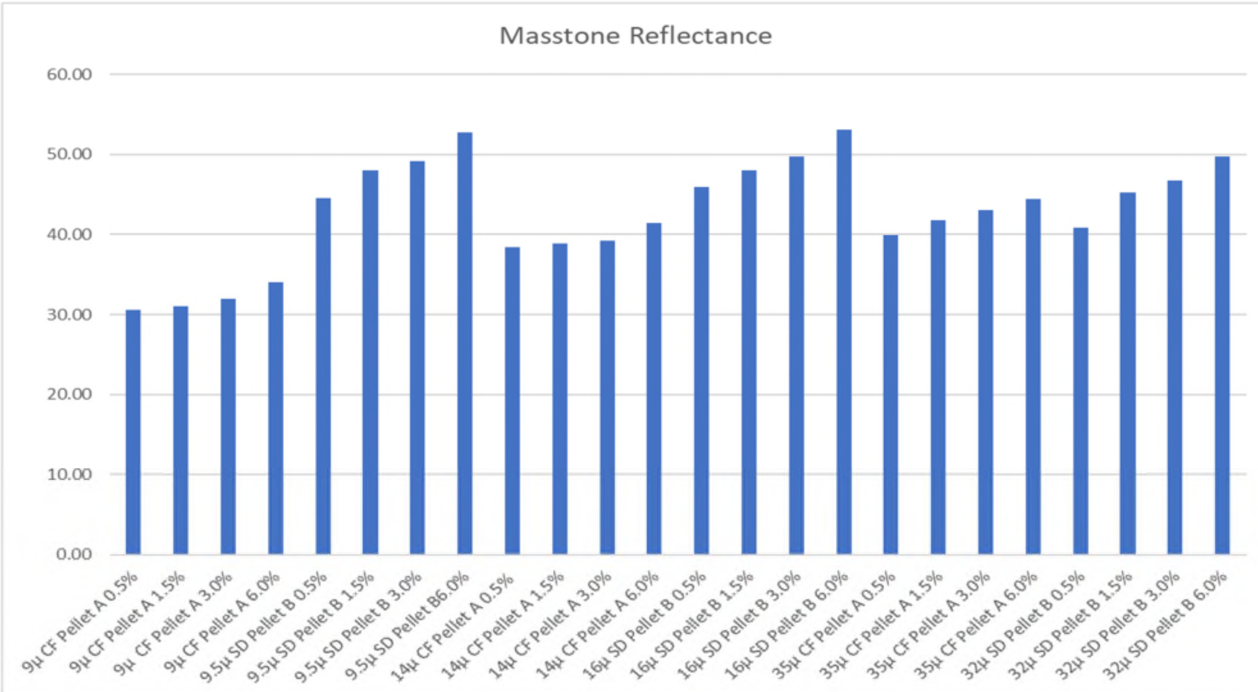
20°, 60°, and 85° gloss was measured and compared at multiple aluminum loading levels for all products. Results of these comparisons are below.



Graph 7: Masstone Gloss Comparison

Regardless of pellet type, flake geometry or particle size, increased aluminum loading in masstone leads to lower gloss at 20°, 60°, and 85°. Silver dollar flake geometry yielded higher gloss than cornflake of similar particle size. Unlike masstone color or whiteness, increased aluminum loading has an adverse effect on gloss. This is typical of any pigmentation and not only true of aluminum flakes. This data suggests that silver dollar flakes at a lower aluminum loading, yield higher gloss at the three angles measured.

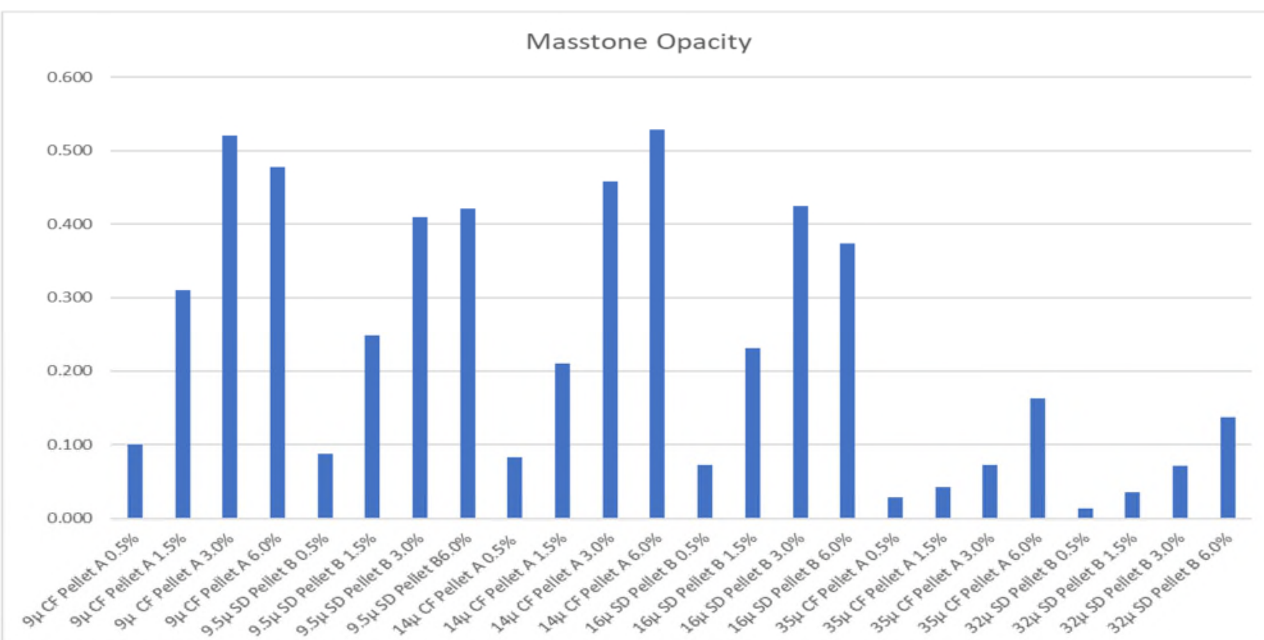
Total reflectance was also measured and compared at multiple loading levels for all products. Results of these comparisons are below.



Graph 8: Masstone Reflectance Comparison

In all tests, higher reflectance was achieved with higher aluminum loading levels. Silver dollar flakes have higher reflectance at all levels when compared to cornflake aluminums of similar particle size.

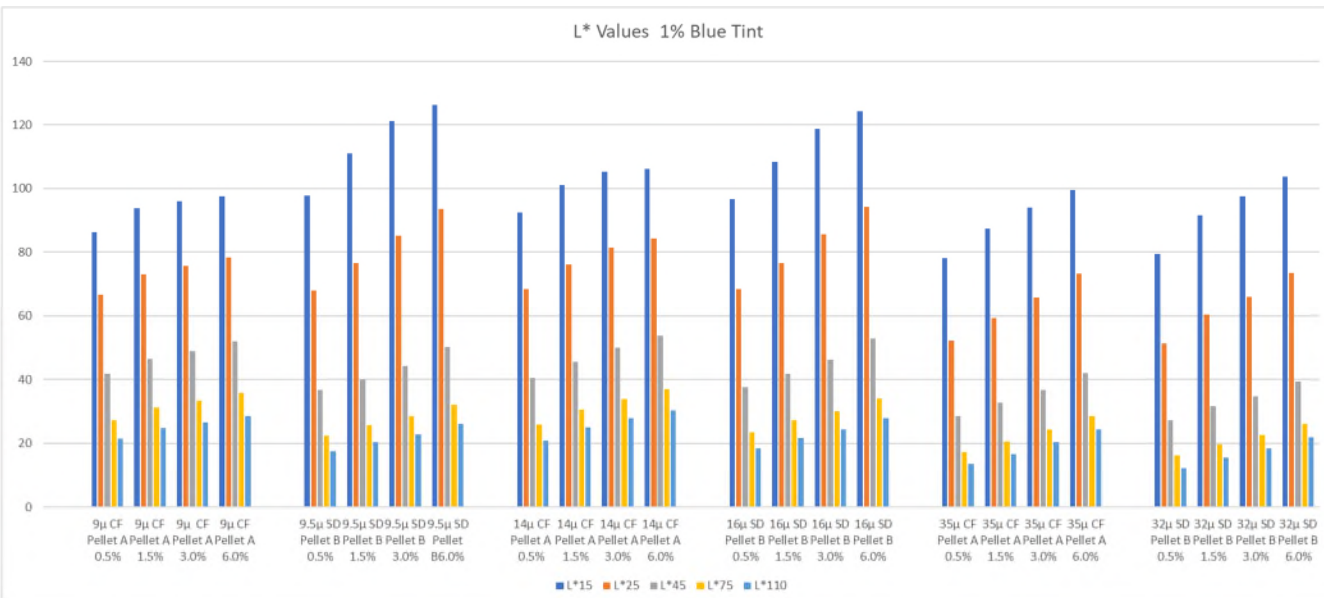
Opacity of all products was measured at multiple loading levels in a masstone formulation. An optical densometer was employed for these measurements. Results of these comparisons are below.



Graph 9: Masstone Opacity Comparison

In some instances, especially those with larger particle size flakes, increased aluminum loading showed a steady increase in opacity. However, with some flakes, especially fine cornflakes and silver dollars, opacity increases then either plateaus or shows a slight decrease. This is possibly due to the higher number of flakes present per weight for these aluminums. Too many flakes can lead to "crowding" and the aluminum becoming poorly oriented. If less flakes are positioned parallel to the substrate, less opacity can result, as seen in the data.

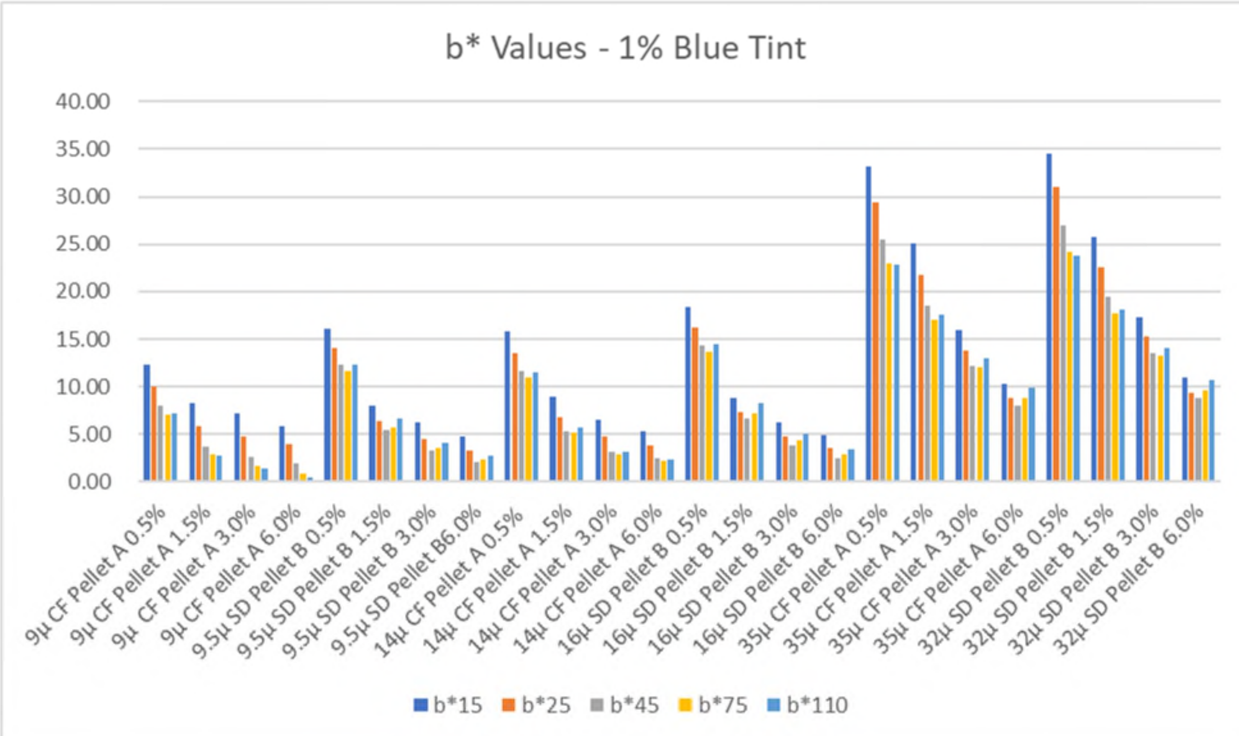
Like the masstone comparisons, each product was then used in a formulation that contained 1% phthalo blue pigment. Color, gloss, reflectance, and opacity were explored at increasing aluminum loading levels for both Pellet Type A and Pellet Type B. Aluminum levels vary for each product tested, with the blue tint value held constant at 1%. Results of the color evaluations are detailed in Graph 10.



Graph 10: 1% Blue L Values – All Angles*

In this comparison, the data shows a trend of higher L* value, or higher whiteness and brightness, with increasing aluminum loading levels. This was irrespective of flake geometry or particle size. Yet again, with this data, we see the benefits of silver dollar geometry for higher brightness when compared to similar particle size cornflake aluminums. Also, the narrow distribution and uniformity of flakes with silver dollar geometry yields a more metallic and "cleaner" color when combined with colored organic pigments.

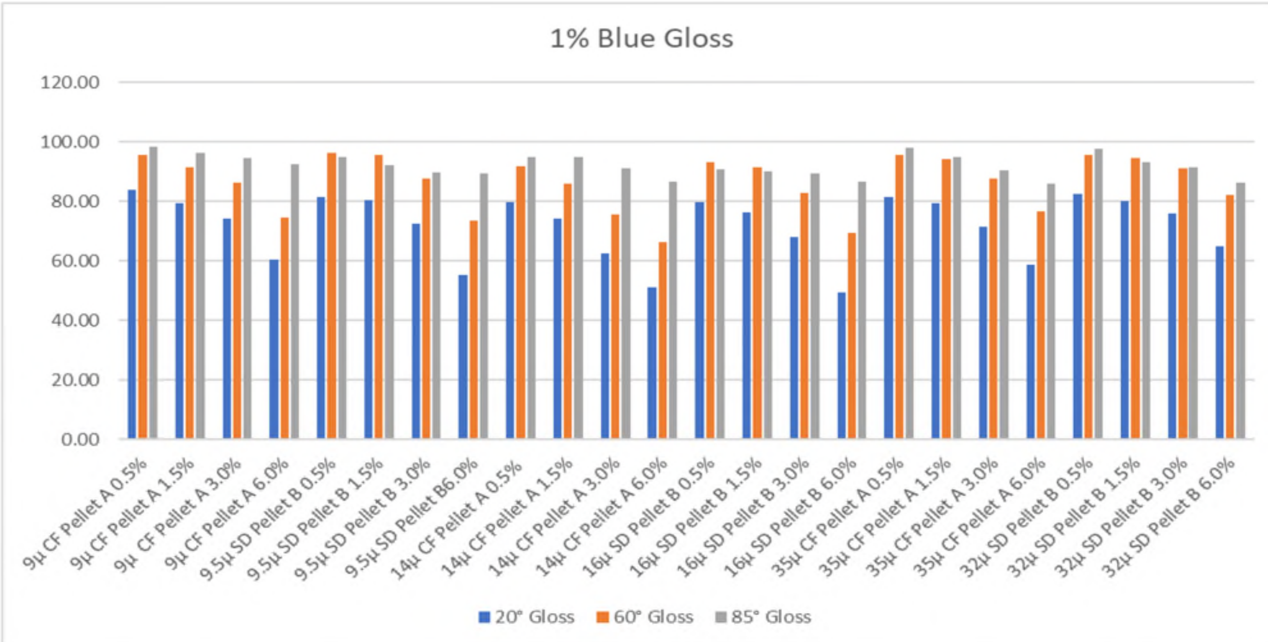
Along with L* measurements, b* can show the amount of "blue" that is lost or gained with varying aluminum loading levels. Again, the blue tint was held constant at 1%. Results of these trails are seen in Graph 11.



Graph 11: 1% Blue b Comparison*

The data of this comparison shows that increasing the aluminum content in the formulation while holding the tint concentration constant at 1% will yield b* values that trend towards whiter, with less chroma – essentially causing a lighter shade of blue. The higher the opacity of the aluminum used exacerbates this effect, as does smaller particle size. It should be noted that absolute values of the b* were used for graphical purposes.

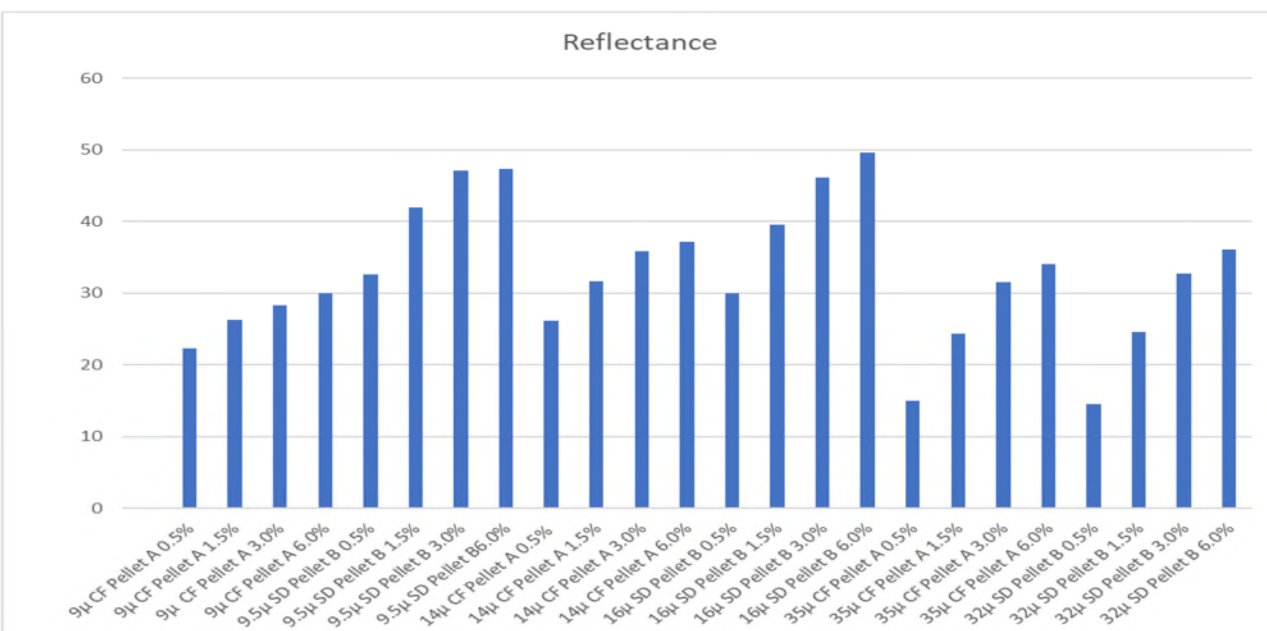
20°, 60° and 85° gloss were also measured and compared in a 1% blue tint formulation. Aluminum levels vary for each product tested, with the blue tint value held constant at 1%. Results of these comparison are seen in Graph 12.



Graph 12: 1% Blue Gloss Comparison

Similar to the trend in the masstone formulations, gloss at 20°, 60°, and 85° decreases with increasing aluminum loading – regardless of aluminum geometry, particle size, and pellet or Pellet type. In order to maintain a higher gloss, aluminum loading levels will need to be optimized by the formulator to give the opacity and color required, and then reduce aluminum as needed to increase gloss without detrimental effects to the aforementioned properties.

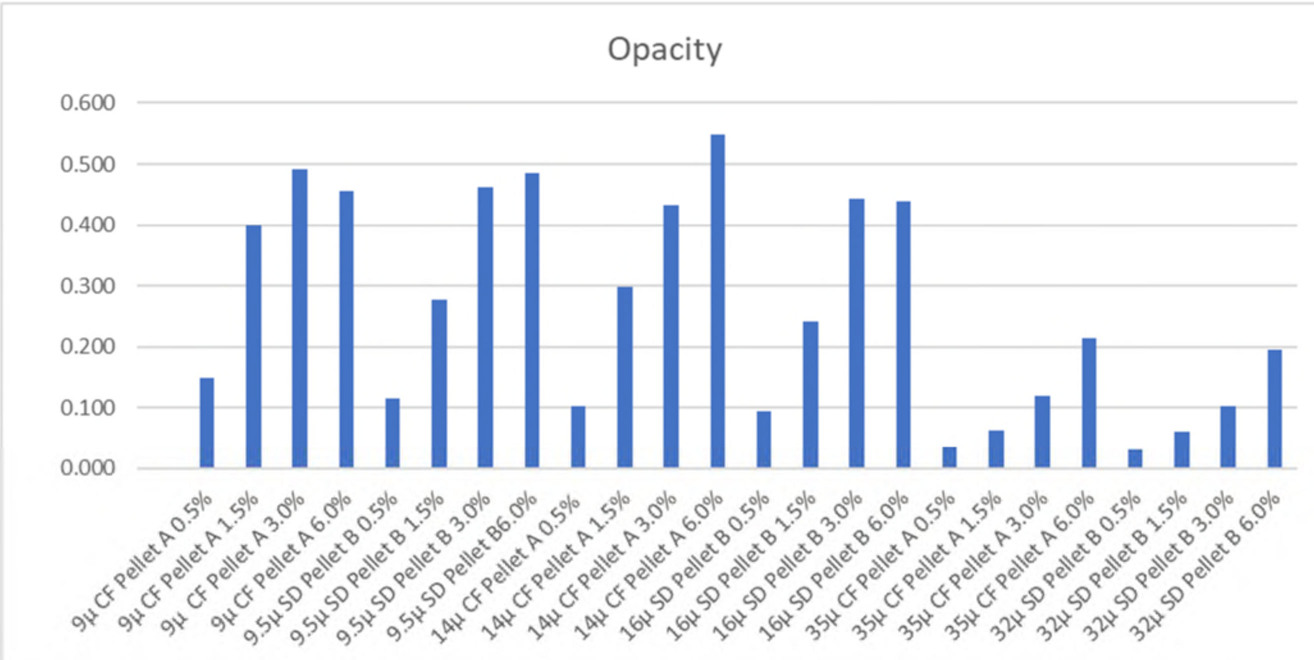
Total reflectance was also measured and compared at multiple loading levels for all products. Results of these comparisons are seen in Graph 13.



Graph 13: 1% Blue Total Reflectance Comparison

The data for the 1% blue formulations mimic that seen in masstone trials – the higher the aluminum loading, the greater the total reflectance of the finished part. Silver dollar geometries achieve higher reflectance at all loading levels when compared to cornflake aluminums of similar particle size.

Opacity of all products was measured at multiple loading levels in a 1% blue tint formulation. An optical densometer was employed for these measurements. Results of these comparisons are below in Graph 14.



Graph 14: 1% Blue Opacity Comparison

In some instances, especially those with larger particle size flakes, increased aluminum loading showed a steady increase in opacity. However, with some flakes, especially fine cornflakes and silver dollars, opacity increases, but at maximum loading shows a slight decrease. This is possibly due to the higher number of flakes present per weight for these aluminums. Too many flakes can lead to "crowding" and the aluminum becoming poorly oriented. If less flakes are positioned parallel to the substrate, less opacity can result, as seen in the data.

In summary, aluminum Pellets A and B are value-added pigments to formulators for multiple plastics applications. Higher loading levels trend toward a whiter, brighter more metallic effect – and with some finer aluminums can give the appearance of "near chrome" or even a brushed aluminum look. To get the best possible metallic appearance, with cleaner tints, high opacity, and optimal reflectance, a silver dollar aluminum at a minimum of 3% loading is suggested. If gloss reduction becomes a concern, then the aluminum loading level can be dialed back until required gloss is achieved.

When using aluminum pigments in plastics, along with other colored pigments, it is important to consider the "whiteness" that aluminum addition will bring to the finished part. Higher chroma and a cleaner, more metallic appearance can be achieved with optimum levels of silver dollar aluminum pigment. Cornflake pigments are also suitable for use in all applications; however, the wide particle size and rough surface features of these flakes lead to a slightly duller, more “washed out” appearance, especially when combined with other colored pigments.

Pellet type appears to not play a significant role in the final appearance of the plastic application, according to the results of this study. It becomes more of a question of the compatibility of the carrier resins and the practices used to handle and add the aluminums to the batches on a large scale that may dictate whether Pellet Type A or Pellet Type B is the suitable choice for the final application.