SD90-12-F

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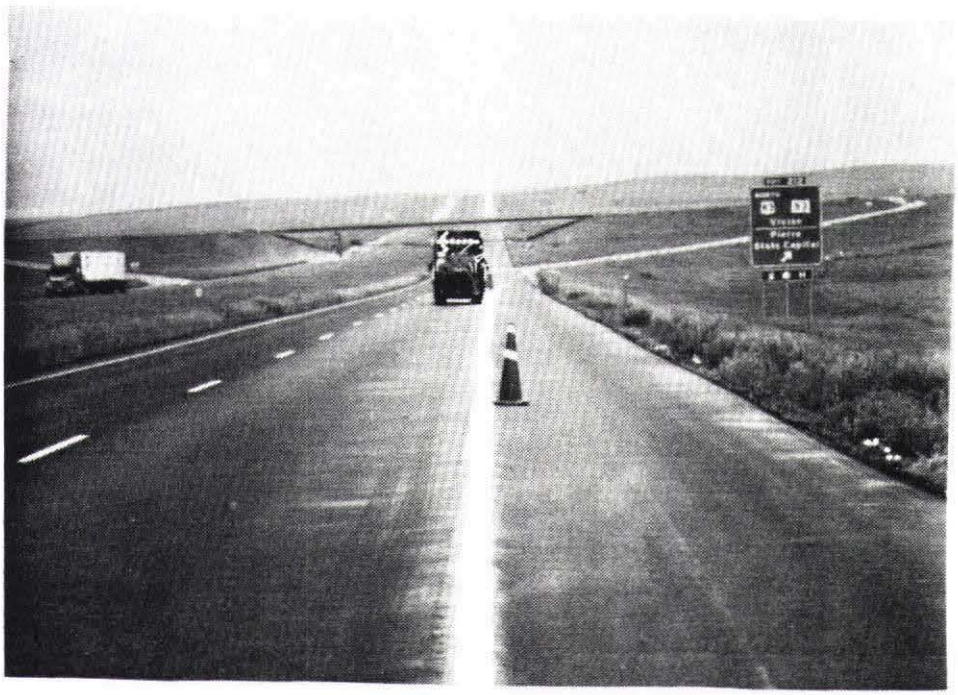

Pavement Marking Cost Effectiveness

Study SD90-12
Final Report

Prepared by
SD Department of Transportation
Office of Research
700 East Broadway Avenue
Pierre, SD 57501-2586

October, 1993

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16. Abstract

This report describes research performed by the South Dakota Department of Transportation on the cost-effectiveness of its present pavement marking material, alkyd, and several alternatives. Epoxy, water-based paint and tape were also monitored and evaluated in this study. Test sections were installed in both rural and urban areas. Reflectivity was monitored with the use of a retroreflectometer. Pavement markings used were compared to one another by monitoring their performance and comparing their cost per foot, with consideration being given to the amount of time the marking's retroreflectivity remained above some minimum level. It was found that although alkyd is cheaper than other pavement markings, it does not provide year-round traffic delineation, and is therefore not effective. Water based paint, while being only slightly more costly than alkyd, performed nearly as well as epoxy, making it the most cost effective marking for the rural environment. In the urban test sections, none of the markings lasted much longer than two or three months. The epoxy placed in Sioux Falls was installed in October, 1991. Because of the lateness of the installation and temperatures lower than manufacturer's recommendations, the epoxy did not perform as well as it normally would have. Water based paint was not used in the urban test sections, but it is recommended that water base be tried in an urban setting.

17. Keywords	18. Distribution Statement
paint, pavement markings, cost-effectiveness, striping, durability, reflectivity	No restrictions. This document is available to the public from the sponsoring agency.

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control section for asphalt pavement was from MRM 211.31 to 198.12. Both control sections were installed by state maintenance forces. These two rural test sections were twenty miles apart on I-90 and experienced very similar weather and traffic conditions.

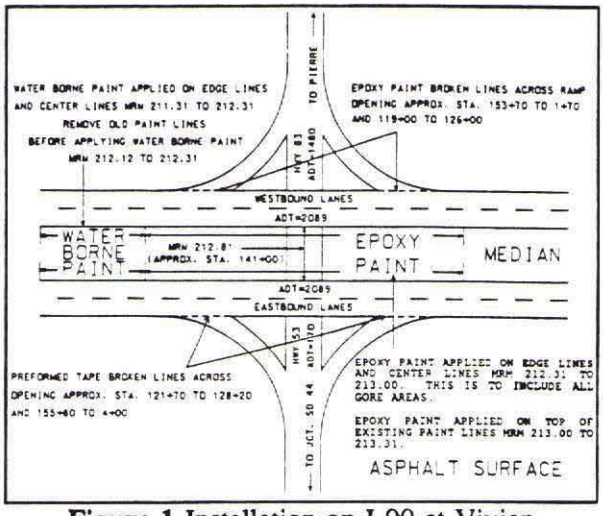

Figure 1 Installation on I-90 at Vivian

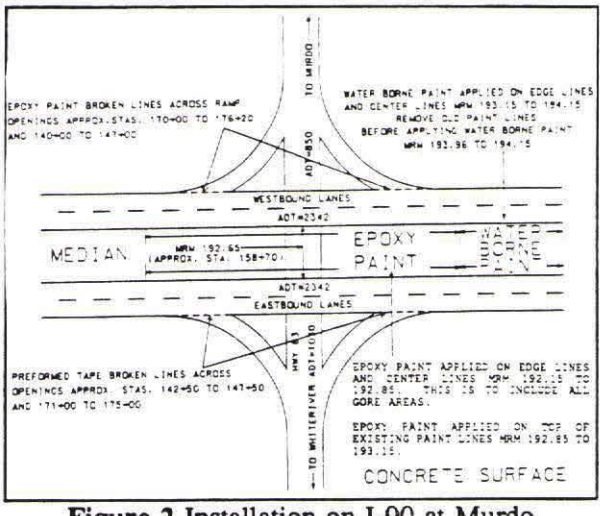

Figure 2 Installation on I-90 at Murdo

The urban test section was located at the north and east approaches at the intersection of West 12th Street and Western Ave. in Sioux Falls. Markings were also placed on West 12th from Kiwanis to Williams Avenue (Figures 3,4 and 5). Both epoxy paint and preformed plastic tape were used for all symbols, legends and lane lines within 200 feet of the intersection of Western Avenue and 175 feet on West 12th Street. The test section also included epoxy painted lane lines for several blocks on West 12th Street. Preformed plastic tape is the existing standard for urban areas, and was used as the pavement marking control.

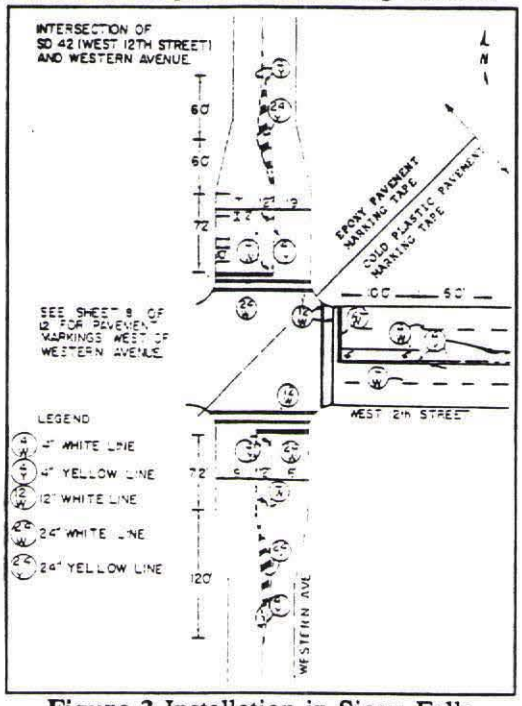

Figure 3 Installation in Sioux Falls

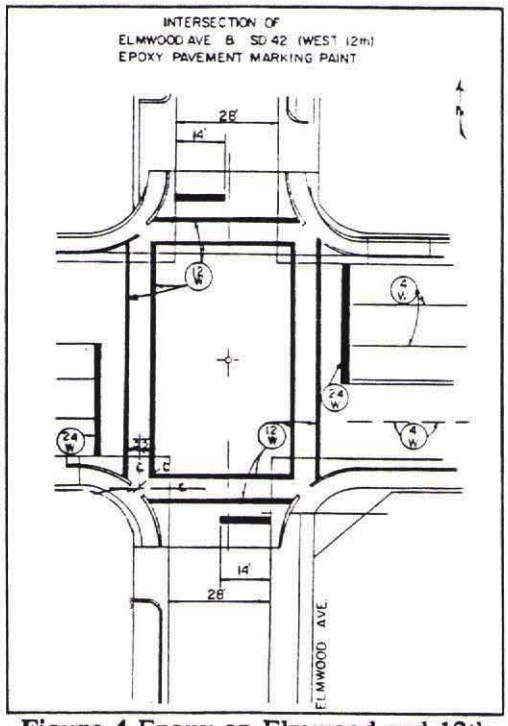

Figure 4 Epoxy on Elmwood and 12th

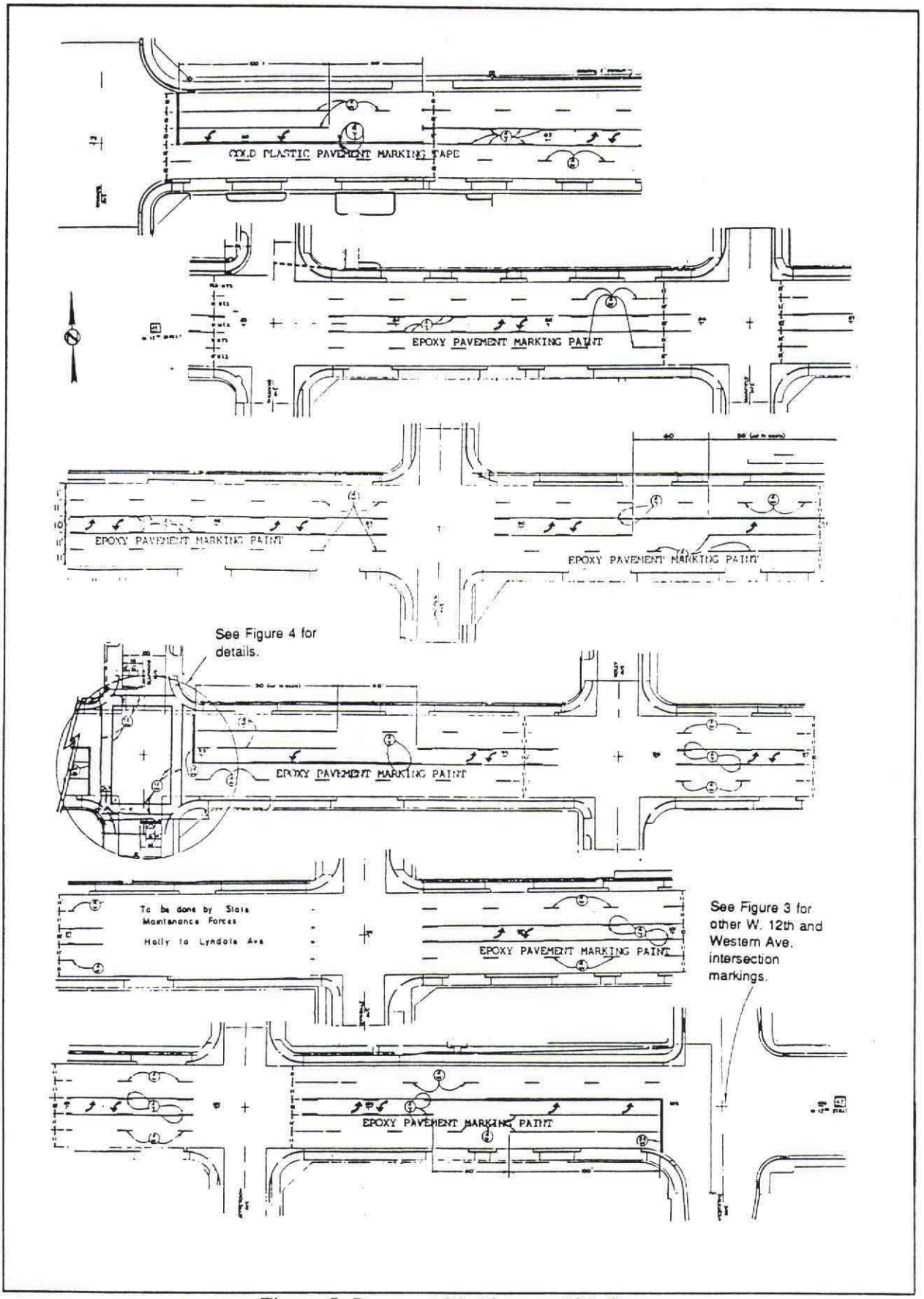

Figure 5 Pavement Markings on 12th Street

INSTALLATION

The rural installations at Murdo and Vivian were placed on June 4,5 and 6, 1991, by Swanston Equipment Company. In some areas, the A1A Sandblasting Company removed the old pavement markings. In Sioux Falls, pavement markings were placed by Work Zone Safety Inc. on October 2, 1991. Pavement marking application in each test section went normally. The only concerns in town were that the paint striper, after stopping, had to run epoxy paint through the nozzles into a bucket so it wouldn't set up. This resulted in small amounts of epoxy being wasted, which is normal for epoxy applications.

PERFORMANCE EVALUATION

The research team measured reflectivity of all markings at the test sites using a retroreflectometer owned by the SDDOT Pierre Region office. The model is a Microlux 12, built by Micro-Bran Assemblers, Inc. Reflectivity is measured in millicandelas (mcd) and is an absolute value, unaffected by day or night ambient light conditions.

A study performed by the New York State Department of Transportation established guidelines for reflectometer readings by having a panel of several people go out at night and rate pavement markings, and also take reflectometer readings on the same markings (Lorini, 1992). The relationship between measured reflectivity and subjective nighttime visibility developed for the Microlux 12 (the same model as the one used in South Dakota's study) was:

Subjective	Reflectivity (mcd)	
Rating	White	Yellow
Excellent	>275	>225
Good	≥200	≥150
Fair	≥120	≥100
Failed	<120	<100

The results of this study suggest 120 mcd as the lowest acceptable value for white paint, and 100 mcd for yellow paint. These values are marked in the charts used later in this report.

In the context of this study, desirable characteristics of pavement markings include low cost, long life, and a reflectivity value that is higher than 120 mcd for white paint and 100 mcd for yellow paint. A short drying time is also desirable, although past experience has shown that fast drying paints don't normally last as long as slower-drying paints.

To determine some value for measuring the cost effectiveness of a certain pavement marking, the research team measured the reflectivity of the markings, then noted the time it took for these readings to fall below the minimum accepted values. The cost per foot for each type of marking, which includes the cost of sandblasting, is then divided by the lifetime in days. For paints that didn't fall below the minimum value within the study period, one year is used as the lifetime because it is not known whether the marking would last another entire year before being restriped. The result is a cost per foot per day for each marking. These values can then be compared to evaluate cost effectiveness.

Applications rates vary among regions in South Dakota. Pierre region uses 16.9 gallons per mile of 4" wide solid line, Rapid City uses 17 gallons/mile, Mitchell uses 15 gallons/mile, and Aberdeen region paint stripers vary between 12 and 16 gallons per mile. In this study, 16.9 gallons per mile is used.

Several vendors were contacted to get current costs for pavement markings used in the study in large quantities. Cuba Industrial Coatings quoted water base paint at $5.50/gallon, and epoxy at $23-$30/gallon. Swanston's prices were a bit higher. Alkyd is sold for $9.37/gallon, water base is $7.50 to $8/gallon, and epoxy is $43.70 to $50/gallon. 3M A420 tape is $1.18/foot. Vogel's water base is $5.20 - $5.50/gallon, and alkyd is $3.55/gallon.

When making cost comparisons among types of pavement markings, the labor and equipment costs are based upon the percentages of total cost in 1992 using current pavement marking prices. According to Labor and Cost Data reports from the SDDOT Operations Support Program, in 1992 centerline striping operations, 69% of the total cost of putting a stripe on the road was material. 14% was labor and 16% was operation

of equipment. The material costs given below are divided by 69% to estimate the total cost of applying pavement markings. Note that the 69% material cost is for centerline operations. Edgelining operations material costs 81% of total cost, so the costs given here are slightly higher than if actual edgelining costs were taken into account. Only one set of costs is used in the performance evaluation for simplicity. The application of epoxy costs are given as if SDDOT were applying it. Because SDDOT has no equipment capable of applying epoxy, epoxy costs would have to be based on what a contractor would charge SDDOT.

The prices used for this evaluation were in the lower to average range of prices given above, since SDDOT would probably accept the lowest bid. They were:

alkyd

$$\frac{(\$3.55/gal)(16.9gal/mile)}{5280feet} = 1.14¢/foot$$

$$\frac{1.14¢/foot}{69\%} = 1.65¢/foot$$

epoxy

$$\frac{(\$25.00/gal)(16.9gal/mile)}{5280feet} = 8.00¢/foot$$

$$\frac{8.00¢/foot}{69\%} = 11.6¢/foot$$

water base

$$\frac{(\$5.50/gal)(16.9gal/mile)}{5280feet} = 1.76¢/foot$$

$$\frac{1.76¢/foot}{69\%} = 2.55¢/foot$$

3M A420 tape

$$\frac{\$1.18/foot}{69\%} = \$1.71/foot$$

The charts that follow show the retroreflectivity of the pavement markings, along with performance and cost evaluations.

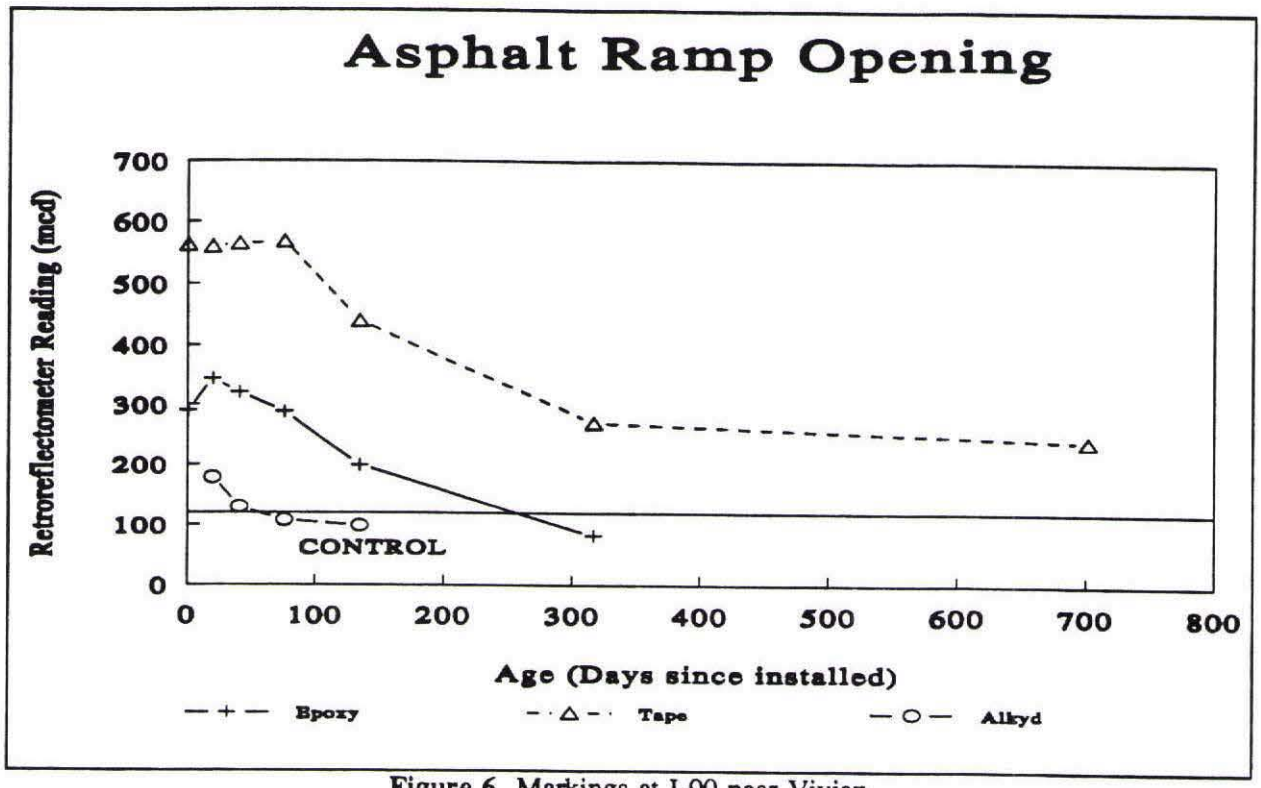

Figure 6 Markings at I-90 near Vivian

Figure 6 shows the reflectivity readings taken near Vivian on I-90 at the off ramp to highway SD 53 South or SD 83 North, exit 212.

The control paint, alkyd, failed long before the others, falling below the minimum within 60 days after application. Epoxy lasted 260 days before falling below the minimum. Upon initial application, epoxy was 290 mcd and then increased to 344 mcd. This may be caused by traffic "polishing" the glass beads after the paint was first applied. Tape had a very high initial retroreflectivity reading, 564 mcd. It was still 271 mcd when the study ended 336 days after application.

Lasting a lifetime of 260 days on the asphalt gore area, epoxy paint cost

$$\frac{11.6¢/ft}{260days} = \frac{.045¢/ft}{day}$$

Alkyd paint, using a lifetime of 60 days and the same application rate, cost

$$\frac{1.65¢/ft}{60days} = \frac{.028¢/ft}{day}$$

At the time this study terminated, 336 days after initial readings were taken, tape reflectivity had not decreased below the minimum value of 100 mcd. Tape used in South Dakota has been known to last between as short as one year to as many as five years. Because the tape did not fail during the time frame of this study, one year was arbitrarily chosen as the lifetime of this marking. Based on this arbitrary assumption, tape cost

$$\frac{\$1.71/ft}{365days} = \frac{.47¢/ft}{day}$$

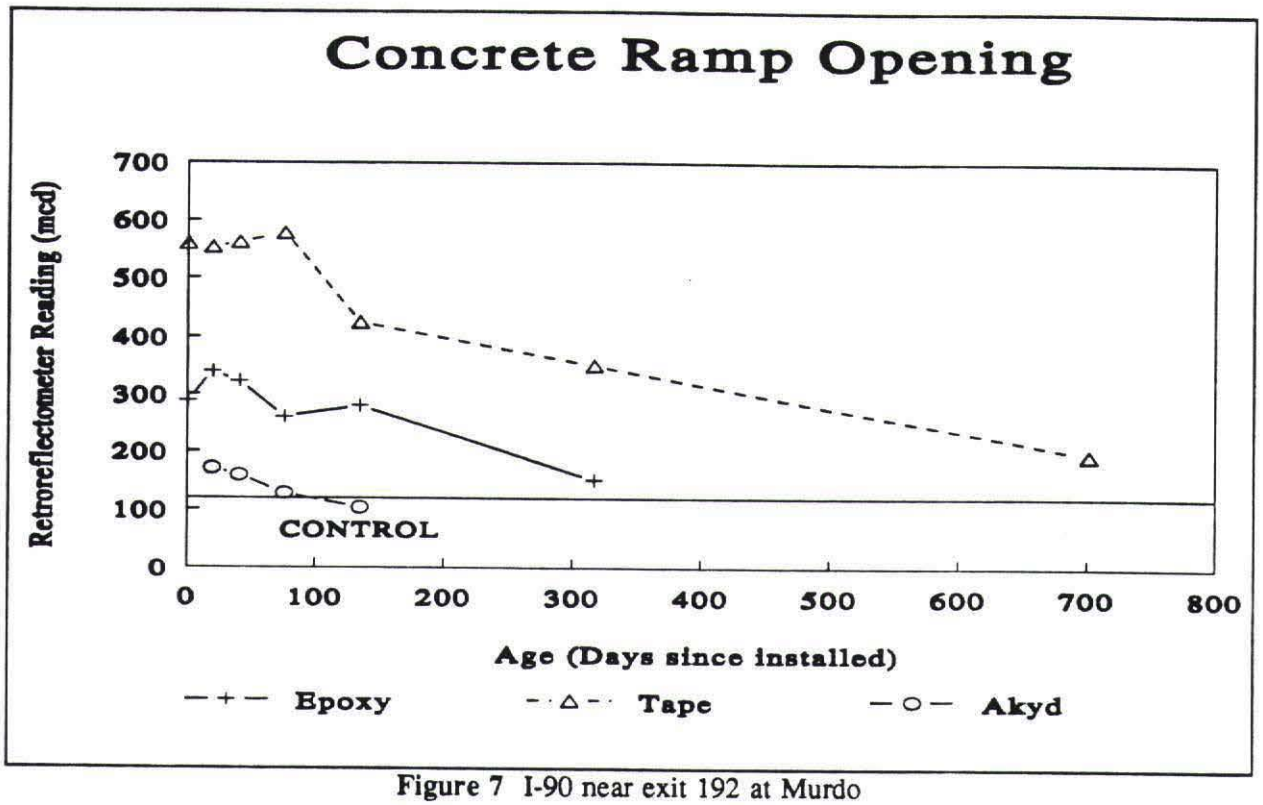

Figure 7 I-90 near exit 192 at Murdo

Figure 7 shows retroreflectivity of the markings installed on the concrete gore area near Murdo, on I-90, exit 192.

Again, alkyd failed long before the others. Epoxy again shows the polishing effect at the beginning of the study. It was slightly above the minimum value at the end of the study. The retroreflectivity of tape, as before, was much higher than the other two.

The costs for each marking are listed below.

paint	days	cost
alkyd	95	.017¢/ft/day
epoxy	365	.03¢/ft/day
tape	365	.47¢/ft/day

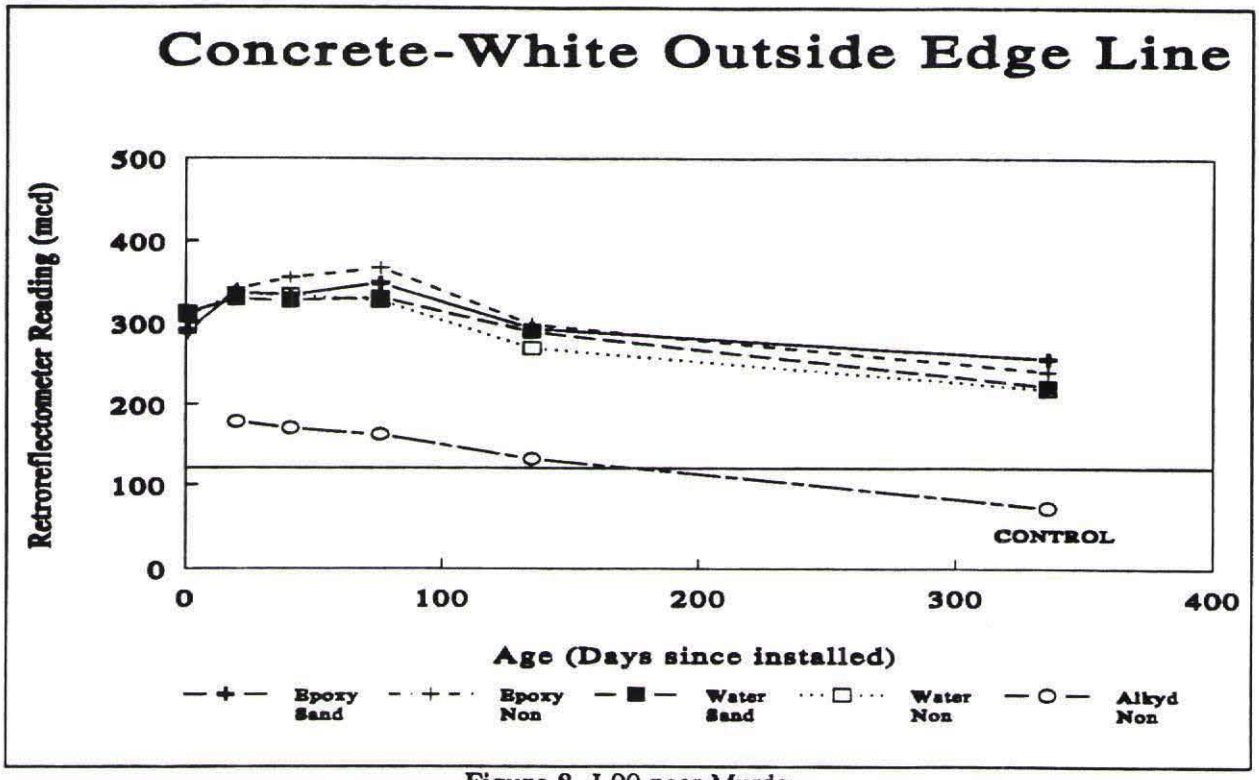

Figure 8 I-90 near Murdo

Figure 8 shows reflectivity of pavement markings installed on I-90 near Murdo. In some epoxy and water based test sections, the surface was first prepared by sandblasting. These were compared with test sections which were not sandblasted. Sandblasting adds 12¢ per foot to the cost of the marking. The first marking to fail was alkyd, with a life of 170 days. The other two markings, with and without sandblasting, were very closely grouped. Sandblasting the surface prior to applicatio had little effect if any.

paint	days	cost
alkyd non	170	.01¢/ft/day
water non	365	.007¢/ft/day
water sand	365	.04¢/ft/day
epoxy non	365	.03¢/ft/day
epoxy sand	365	.06¢/ft/day

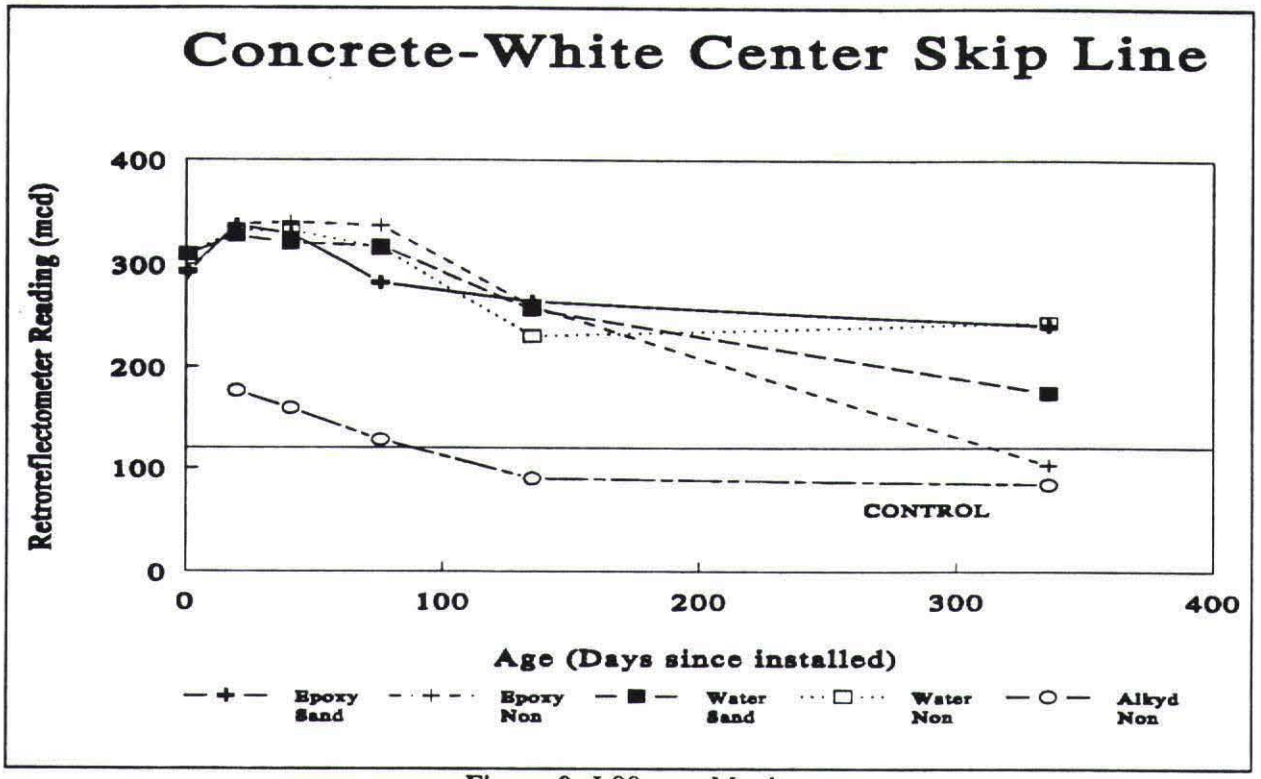

Figure 9 I-90 near Murdo

Figure 9 shows the markings on the center line. Alkyd failed after 87 days. The non-sandblasted epoxy failed about 310 days after application. This marking was applied over the top of existing alkyd. The alkyd under the new epoxy separated from the pavement surface in large flakes in areas. Sand-blasted epoxy and non-sandblasted water base performed equally well, having a retroreflectivity of 241 and 244 mcd 336 days after installation.

paint	days	cost
alkyd non	87	.019¢/ft/day
water non	365	.007¢/ft/day
water sand	365	.04¢/ft/day
epoxy non	310	.04¢/ft/day
epoxy sand	365	.06¢/ft/day

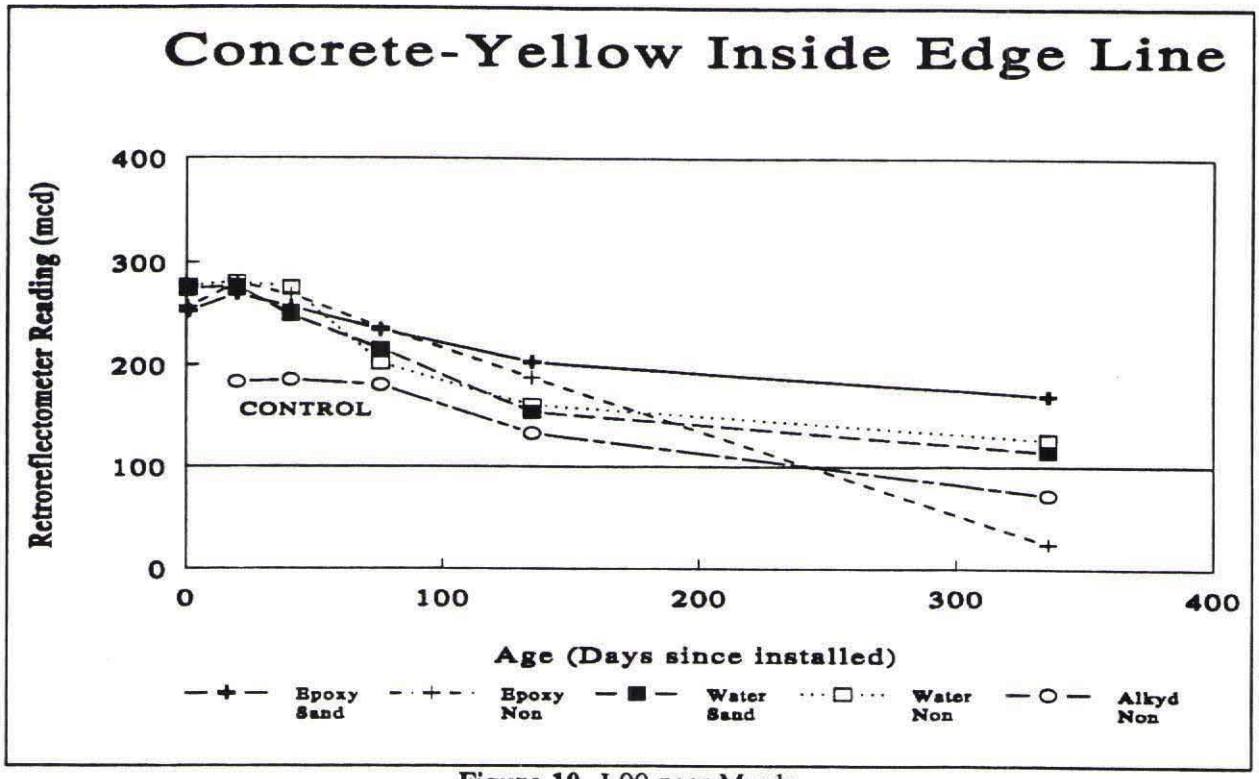

Figure 10 I-90 near Murdo

Figure 10 depicts reflectivity of the yellow edge lines on concrete. Non-sandblasted epoxy on concrete dropped again, as in figure 7, apparently because the concrete surface was not first prepared by sandblasting. The alkyd failed at about the same time, 240 days after installation. The sandblasted epoxy performed the best. The two water base stripes performed about the same, slightly above the 100 mcd limit after 336 days.

paint	days	cost
alkyd non	240	.007¢/ft/day
water non	240	.01¢/ft/day
water sand	365	.04¢/ft/day
epoxy non	365	.03¢/ft/day
epoxy sand	365	.06¢/ft/day

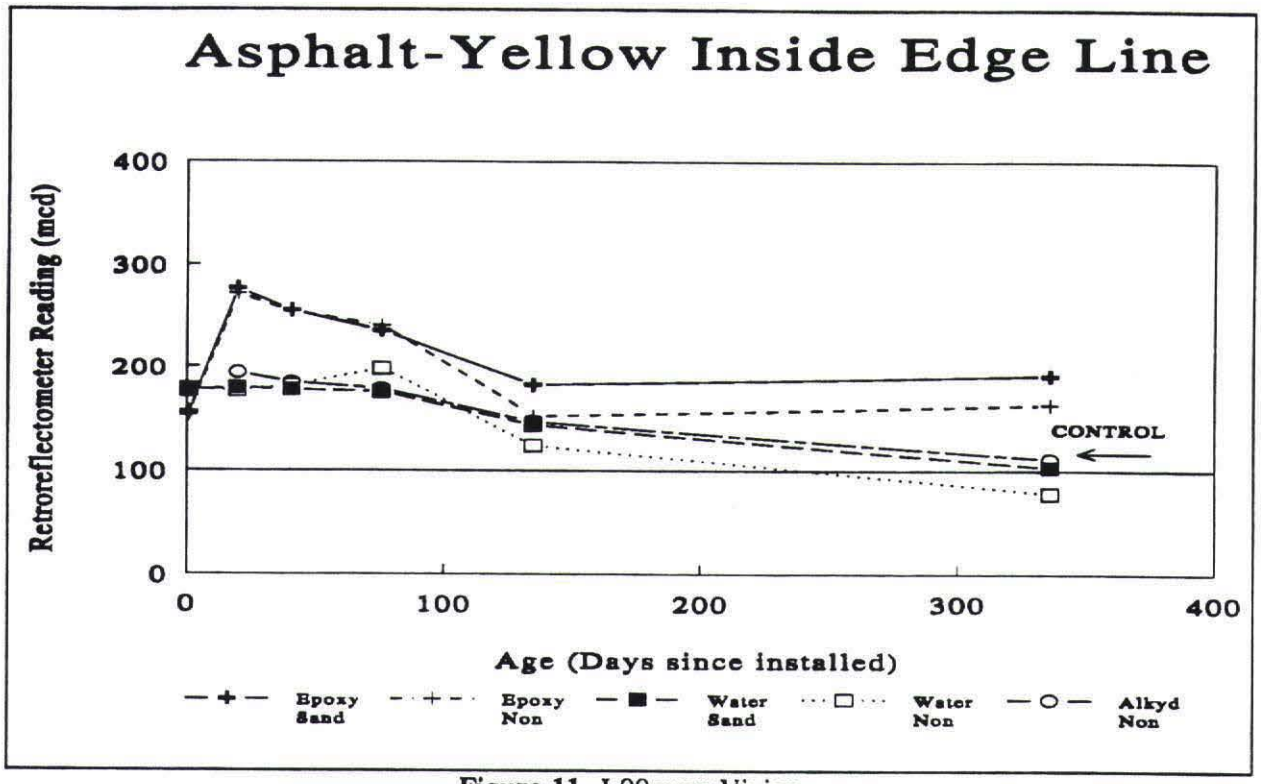

Figure 11 I-90 near Vivian

In Figure 11 shows the various markings on asphalt, on the inside edge line. The epoxy markings experience sharp increases in reflectivity after installation, and remained the highest of the markings for the duration of the study. This is one of the few cases where the alkyd did not fail, but the non-sandblasted water base did. The alkyd and sandblasted water base were very close to failure at the end of the study.

Paint	days	cost
alkyd sand	365	.004¢/ft/day
water non	240	.01¢/ft/day
water sand	340	.04¢/ft/day
epoxy non	365	.03¢/ft/day
epoxy sand	365	.06¢/ft/day

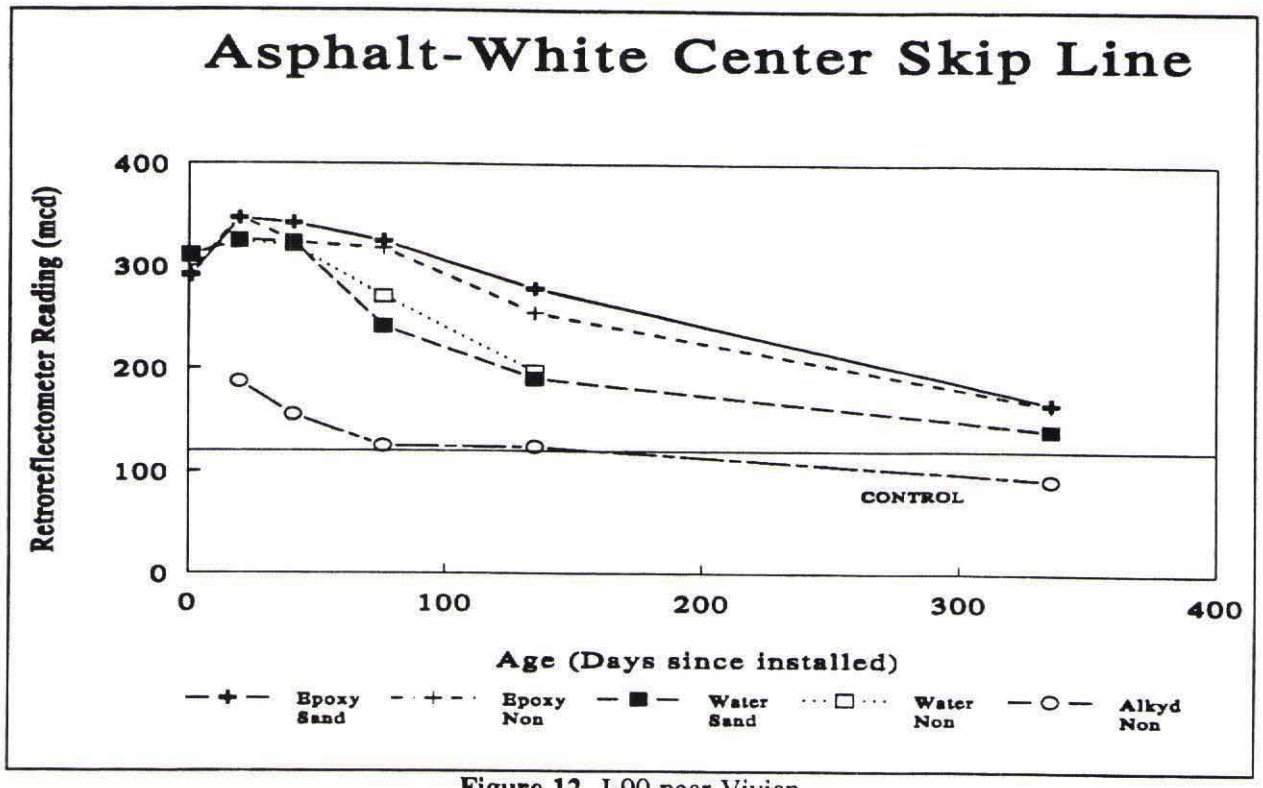

Figure 12 I-90 near Vivian

In figure 12, alkyd failed 160 days after installation. The epoxy was the best of the markings tested. Unfortunately, the non-sandblasted water base was painted over before the last readings were taken. The sandblasted water base had not failed 336 days after installation.

paint	days	cost
alkyd non	160	.01¢/ft/day
water non	365	.007¢/ft/day
water sand	365	.04¢/ft/day
epoxy non	365	.03¢/ft/day
epoxy sand	365	.06¢/ft/day

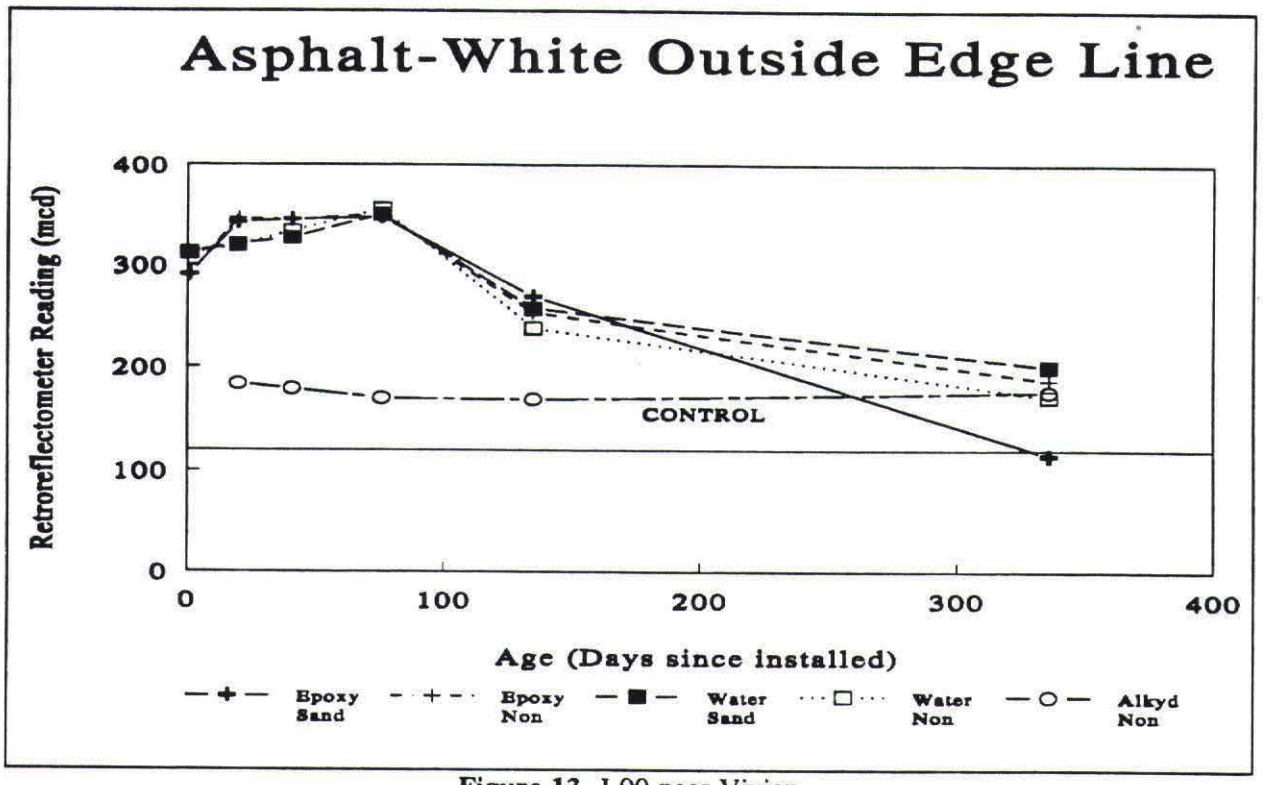

Figure 13 I-90 near Vivian

In Figure 13, alkyd performed surprisingly well. Sandblasted epoxy failed 335 days after installation. Notice that this time it was the sandblasted, not the non-sandblasted epoxy that failed. This may again have been caused by an adhesion failure in the epoxy. The water based stripes, non-sandblasted epoxy and alkyd all performed similarly.

paint	days	cost
alkyd non	365	.004¢/ft/day
water non	365	.007¢/ft/day
water sand	365	.04¢/ft/day
epoxy non	365	.03¢/ft/day
epoxy sand	335	.07¢/ft/day

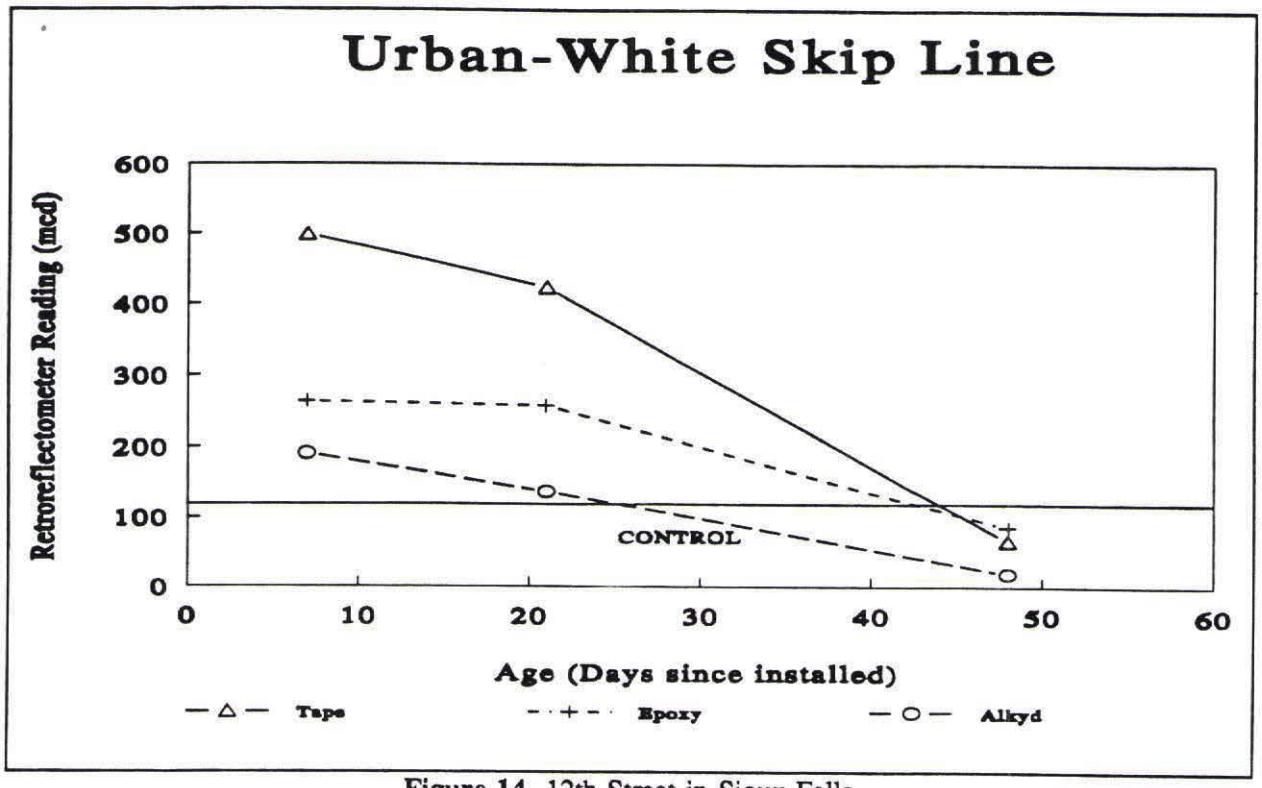

Figure 14 12th Street in Sioux Falls

Figure 14 shows striping in the urban test section. Again the alkyd failed at 25 days, before any of the others. Tape and epoxy both failed about the same time, 44 and 43 days, although tape had a much larger initial retroreflectivity. The time from installation to failure is less than two months for all these markings. The urban environment is very harsh on these markings because of sanding and snow plowing operations, high traffic concentration, and a combination of the two. The markings were installed in early October, which affected the durability of the markings. These markings are temperature dependant, and more research will have to be done to determine the true effectiveness of them when installed according to manufacturer's recommendations.

paint	days	cost
alkyd	25	.07¢/ft/day
epoxy	43	.27¢/ft/day
tape	44	3.9¢/ft/day

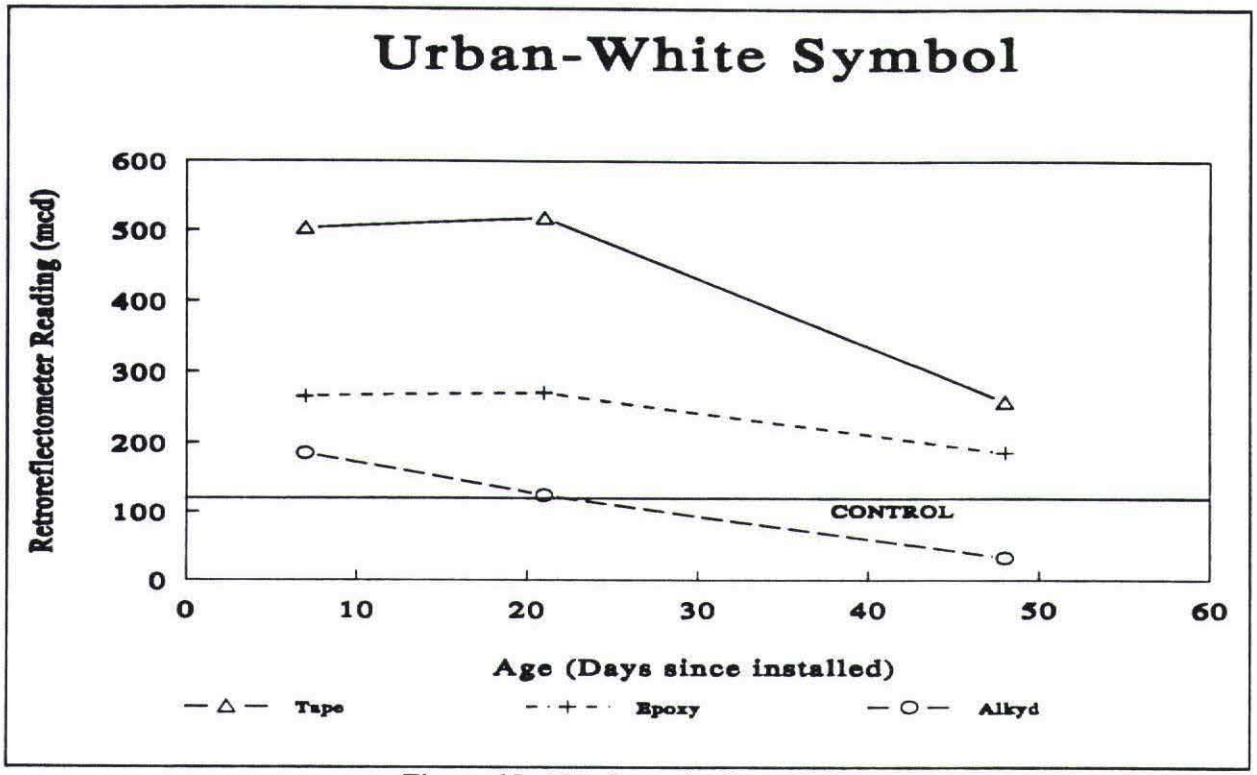

Figure 15 12th Street in Sioux Falls

The alkyd marking in Figure 15 failed after 21 days. Epoxy and tape had not yet failed by the end of the study.

paint	days	cost
alkyd	21	.08¢/ft/day
epoxy	70	.17¢/ft/day
tape	70	2.4¢/ft/day

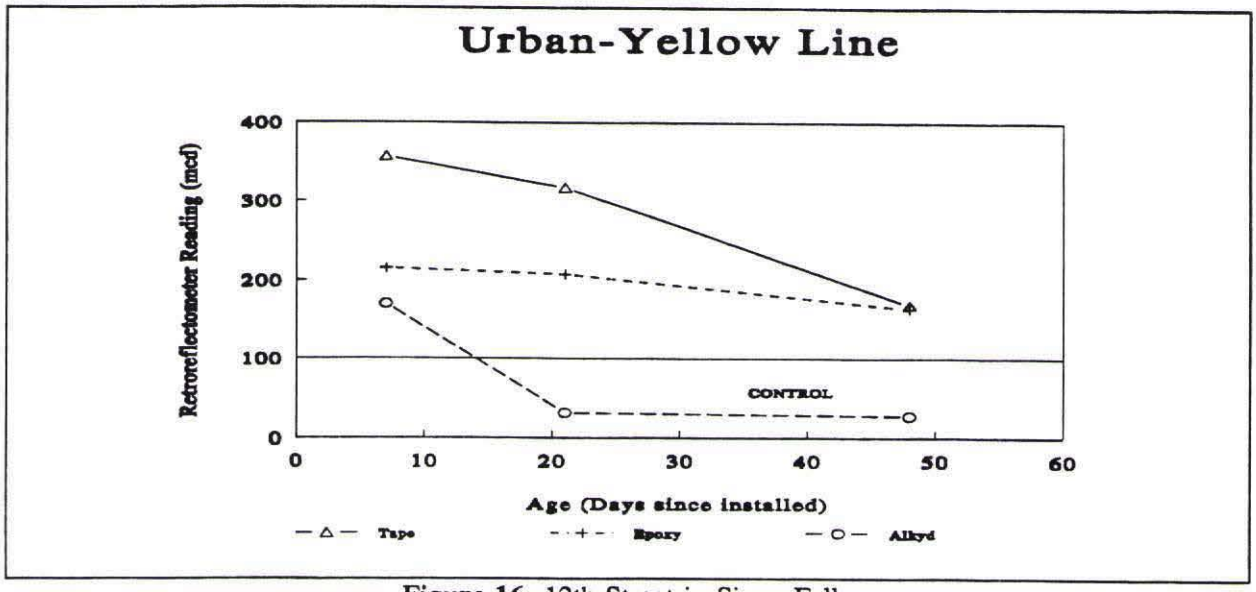

Figure 16 12th Street in Sioux Falls

In Figure 16 alkyd failed after only 13 days on the pavement. At the end of the study, the tape and epoxy were 169 and 164 mcd. Figure 17 shows how tape installed on 12th Street has been damaged by snow plows 60 days after installation.

paint	days	cost
alkyd	13	.13¢/ft/day
epoxy	70	.17¢/ft/day
tape	70	2.4¢/ft/day

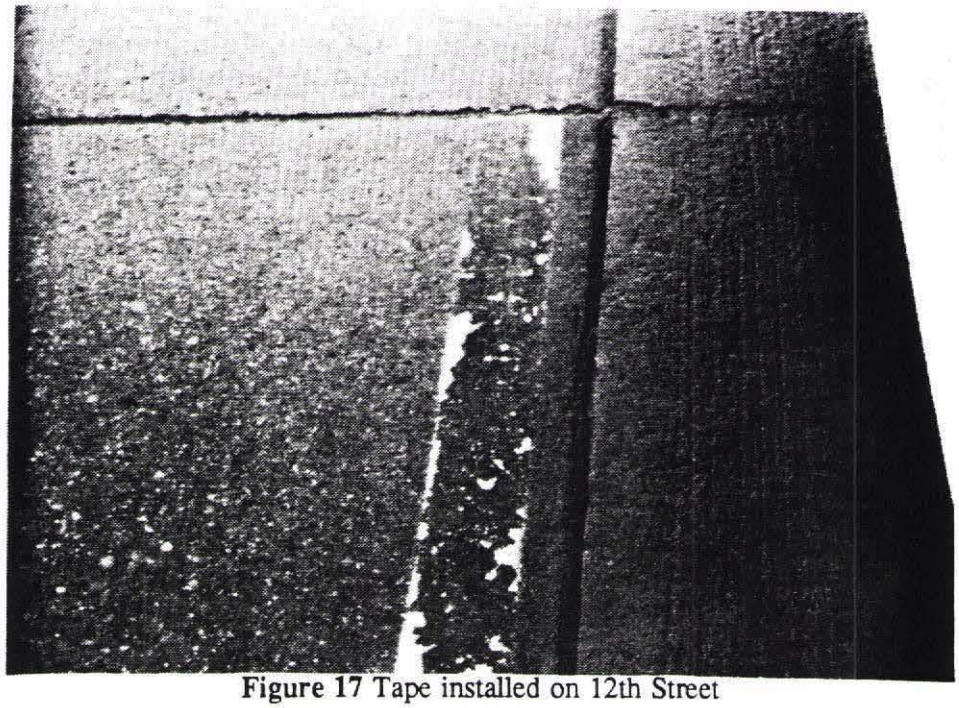

Figure 17 Tape installed on 12th Street

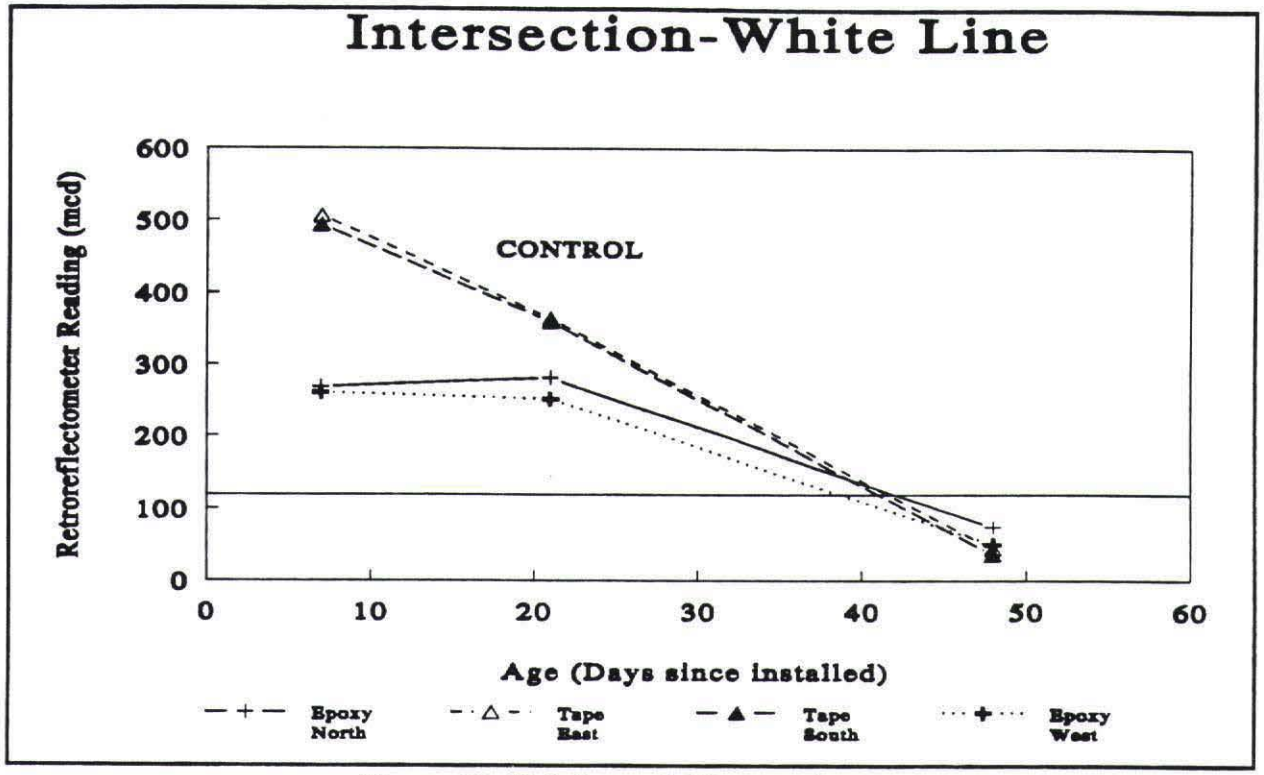

Figure 18 12th Street & Western Avenue

All four markings at the intersection of 12th Street and Western Avenue failed after 42 days on the pavement. Epoxy on the west and north legs of the intersection had initial readings of 261 and 269 mcd. Initial readings for tape on the east and south legs were 506 and 493 mcd, which dropped off very quickly.

paint	days	cost
epoxy west	42	.28¢/ft/day
epoxy north	42	.28¢/ft/day
tape east	41	4.2¢/ft/day
tape south	41	4.2¢/ft/day

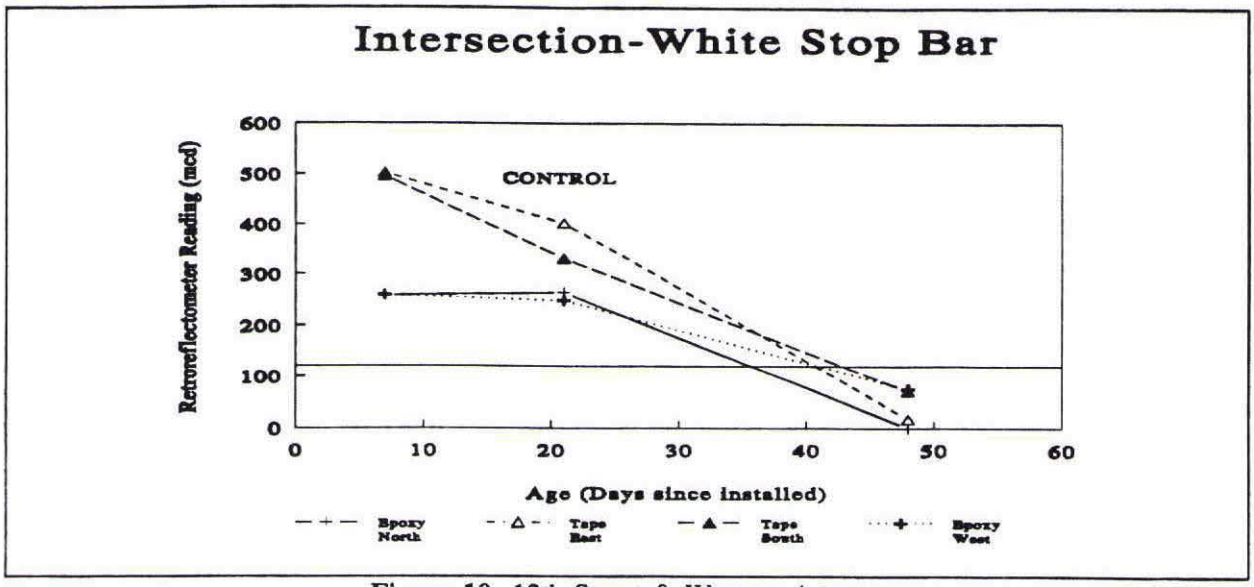

Figure 19 12th Street & Western Avenue

Figure 19 shows tape and epoxy stop bars at the intersection of Western Avenue and 12th Street. Here again tape is initially much higher than the epoxy, but they both quickly lose their retroreflectivity and fail between 35 to 45 days after installation. Figure 20 shows how the tape stop bar was deformed and torn on the intersection of Kiwanis and 12th Street.

paint	days	cost
epoxy west	41	.28¢/ft/day
epoxy north	36	.32¢/ft/day
tape east	41	4.2¢/ft/day
tape south	43	4¢/ft/day

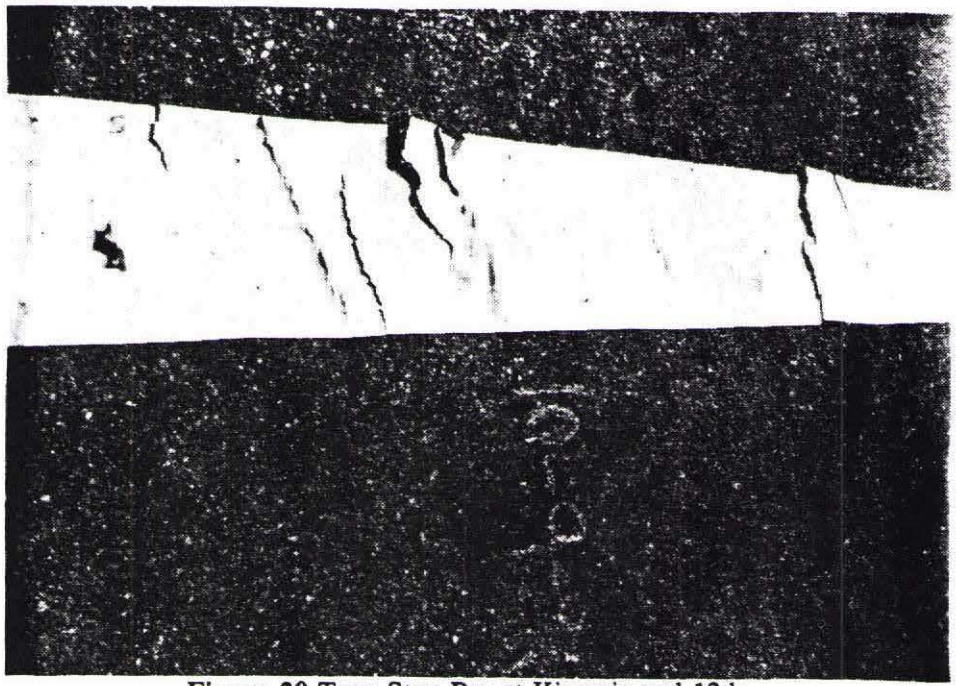

Figure 20 Tape Stop Bar at Kiwanis and 12th

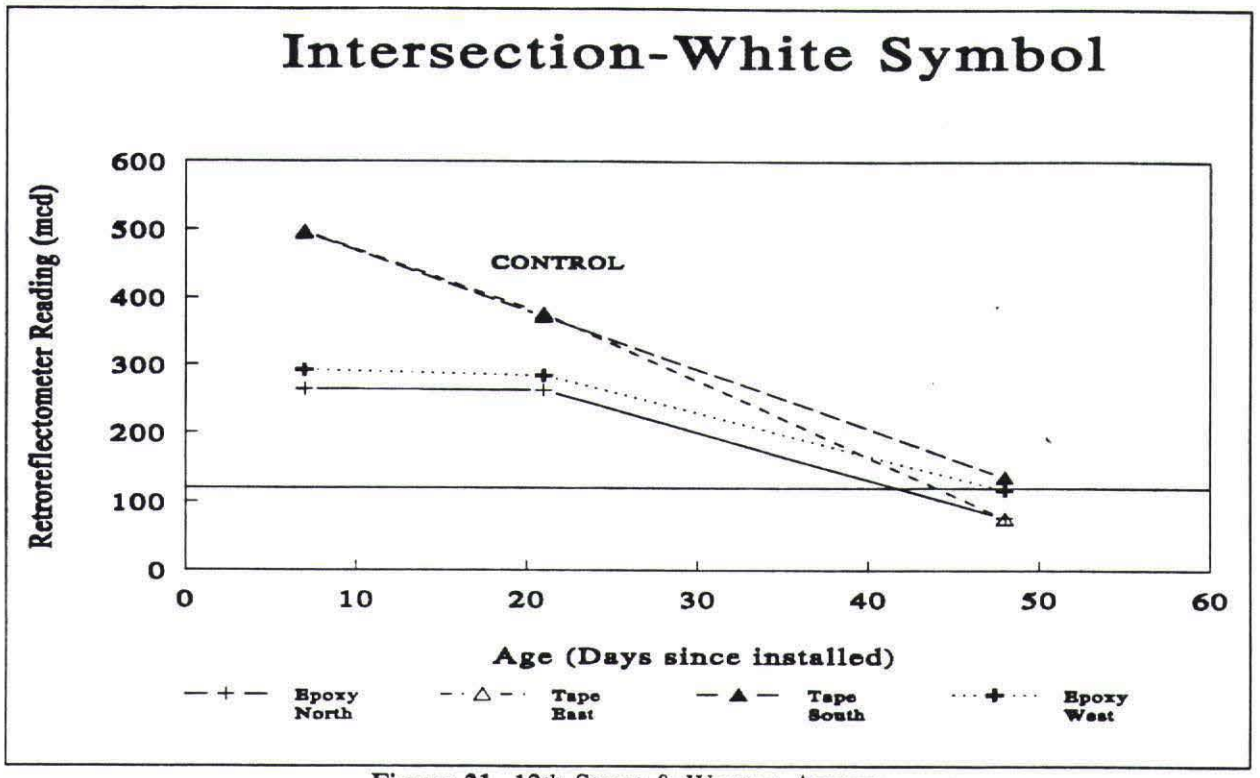

Figure 21 12th Street & Western Avenue

Figure 21 shows readings from the tape and epoxy left turn arrows on each leg of the intersection of Western Avenue and 12th Street. They, too, lasted less than two months.

paint	days	cost
epoxy west	48	.24¢/ft/day
epoxy north	41	.28¢/ft/day
tape east	43	4¢/ft/day
tape south	50	3.4¢/ft/day

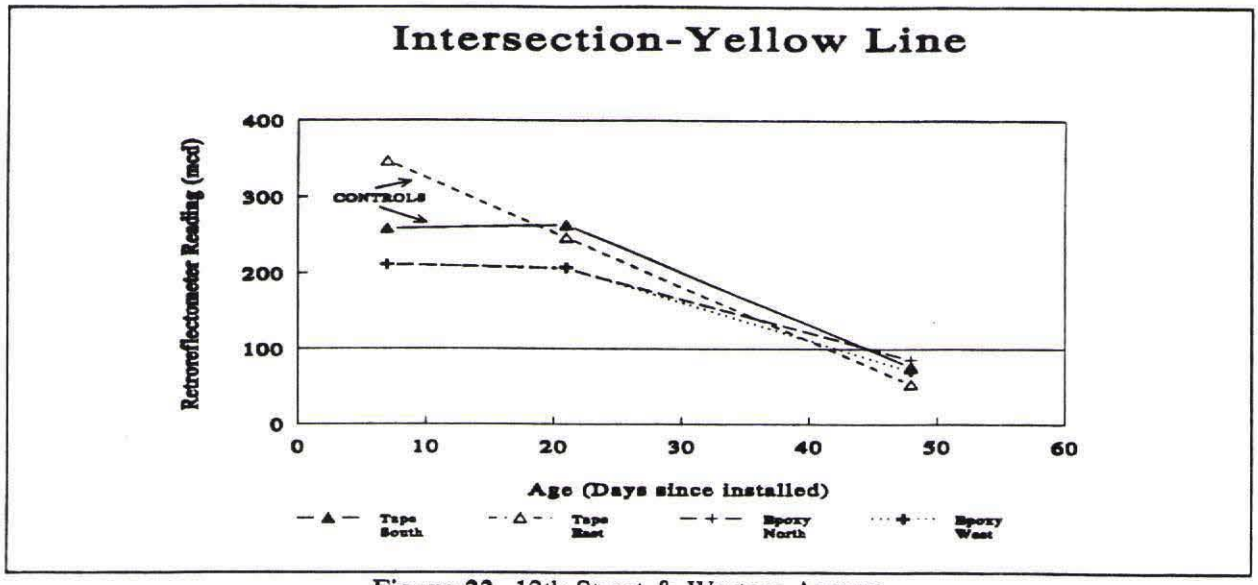

Figure 22 12th Street & Western Avenue

Yellow tape and epoxy lines in Figure 22 again quickly degraded below the failure level about 45 days after installation. In Figure 23, the A420 tape separated from the pavement. The tape did not stand up well to traffic and snow plows, and failed due to loss of material and glass beads.

paint	days	cost
epoxy west	42	.28¢/ft/day
epoxy north	45	.26¢/ft/day
tape east	42	4¢/ft/day
tape south	45	3.8¢/ft/day

Figure 23 3M A420 Tape lines at Western and 12th Street

OBSERVATIONS FROM RURAL PAVEMENT MARKING TEST SECTIONS

1. Epoxy and water based paint reflectivity with respect to time is far superior to alkyd paint. Alkyd paint reflectivity fell below 100 millicandelas (mcd) within 3 to 6 months (Figures 8 through 13).

2. Epoxy and water borne paints appear to perform similarly on both concrete and asphalt pavements, with the exception of yellow water borne paint on the inside edge line which had a lower reflectivity reading on asphalt (Figure 11).

3. Epoxy pavement markings separated from the pavement (concrete and asphalt) at 336 days (11 months) in some spots in rural areas. Figures 9, 10 and 13 show the non-sandblasted epoxy failing on concrete and sandblasted epoxy locations failing on asphalt.

4. In most cases, it appears that sand blasting before applying epoxy paint helps only moderately if at all, but in the long term (a year or longer) the paint seems to retain its reflectivity longer, possibly because of better adhesion. However, the costs of sandblasting seem to outweigh the benefits of better adhesion (Figures 8 through 13).

5. The ramp opening alkyd control areas had been painted over before reflectivity readings could be taken at 312 days after application, so there is no data available for this area. The same is true for the white center skip line on asphalt, which was painted with water borne paint applied to a non sand-blasted surface (Figures 6, 7 and 12).

6. In ramp opening areas, tape performs better than epoxy in terms of reflectivity and durability. Tape is also 2 to 3 times more expensive than epoxy. Tape has initial reflectivity of 500-600 mcd and remains above 300 mcd for most of the year. Epoxy has an initial reflectivity of between 300 and 400 mcd and remains above 200 for most of the year (Figures 6 and 7).

OBSERVATIONS FROM URBAN PAVEMENT MARKING TEST SECTIONS

1. In urban areas, tape has a higher reflectivity than epoxy or alkyd. However, although tape has a higher initial reflectivity (400 to 500 mcd) than epoxy, it is more susceptible to peeling, tearing and deformation due to snow plows and other vehicles turning in high traffic intersections. Tape reflectivity drops quickly (within two to three months in most cases) to levels equal to or below those of epoxy, making tape less cost effective than epoxy (Figures 14, 15 and 16).

2. Epoxy is 1/15 as expensive as tape. Epoxy has an initial reflectivity of between 200 and 300 mcd, which is relatively good, and decreases less quickly than tape (Figures 14 through 22).

3. Due to snow plow damage, bonding failures, and traffic wear, no pavement marking tested lasted more than two months on the pavement during the winter.

CONCLUSIONS

Epoxy paint requires two tanks because it is two components, and the truck requires heated paint lines to keep epoxy paint from setting. In urban applications, after the striper is stopped, epoxy had to be pumped through the nozzles to flush them out. The striping crews tried to avoid stopping at intersections, so additional personnel went ahead of the truck in the intersection to

stop traffic. Without proper signing and advance warning, this practice and can be unsafe.

When the epoxy was applied on October 2, 1991, the temperature of the pavement was lower than the recommended temperature range. SDDOT personnel have stated that this time of the year was too cool to apply epoxy. Also, at the time of application, there was moisture on the pavement which may not have entirely evaporated. The performance of epoxy may actually be better than the results of this test indicate if the paint is applied as recommended.

Tape, while being very reflective, is also very expensive, and requires more labor intensive installation procedures than the other markings. In this study, it was placed manually by personnel rather than applied automatically by machine.

Sandblasting pavement surfaces prior to applying pavement marking has little positive effect on the life of the markings, and sometimes has a negative effect. Sandblasting seemed to help the epoxy retain reflectivity better on concrete pavement. At 12¢ per foot, however, the small positive effects don't seem to be worthwhile.

Water based paint, although cost effective and nearly as durable as epoxy, has some drawbacks. It has a narrower temperature range which will restrict its use in cold weather (40° and below), it requires heated storage in the winter, it requires stainless steel tanks, a heat exchanger and other components.

It should be noted here that some time in the future federal requirements may require the use of water based paints.

Water based paint has many good qualities, such as easier clean up and no VOC's. Also available from vendors, is fast dry water base, which may also be a desirable, cost effective solution.

A telephone conversation with Rohm and Hass (Fesenmeyer, 1993) revealed that many states are already using water based paint. States who are using water based paint in the majority of their pavement marking programs are Arizona, Alabama, California, Connecticut, Iowa, Kansas, Michigan, Maryland, Missouri, New Jersey, Ohio, Texas and West Virginia. Minnesota is using water base in about half of the state, and Illinois is painting some test sections with water base.

In FY 1992, SDDOT used 262,102 gallons of alkyd at a cost of $907,269.32. If SDDOT used water based paint, at a current cost of $5.50/gallon, it would have spent a total of $1,441,561, or $534,291.68 more than alkyd.

Pierre Region has already purchased a new paint striper for $168,000. It has the capability of applying water based paint.

Mitchell Region reports that retrofitting for water base application would cost $40,000 to $50,000 for one striper, $15,000 to $20,000 for the other. The larger striper will have to be replaced in two years (1995).

Aberdeen Region states their two stripers would cost between $12,000 and $15,000 each to retrofit. They replace equipment when it has 150,000 miles on it, and they are presently at 80,000 miles. Aberdeen paints about 10,000 lane-miles a year.

Rapid City Region also has two stripers, which would cost $26,000 and $32,000 to retrofit.

Future Research

In urban areas, water based paint was not used in this study, but it would be interesting to see how it would perform. In the urban, high traffic situation, the study shows that almost nothing will provide delineation for over two months during the winter. During the summer of 1993, maintenance crews in Sioux Falls inlaid 3M 380 and 3M 5730 tape markings at various locations in the city. This may be the most promising

Testing of water base paint is already being done by SDDOT personnel on Highway US14 from Pennington county to Hughes county. Paint was applied to the test sections beginning June 14, 1993, and continued over the next three weeks. The section performance will be monitored over the 1993-1994 winter season.

Testing is also being done in South Dakota in various locations around Rapid City, using a North Dakota specification "fast dry chlorinated polyolefin". A type of alkyd, this traffic paint will be monitored until it requires replacement.

An alternate form of pavement marking, which was introduced in early 1992, after this study was well underway, is polyester paint. The manufacturer claims the material has a service life of two to three years, although no material has been in place for longer than a year. It is non-flammable, does not require heated lines, will not clog, does not require heated storage, works well in low temperatures, does not require specialized equipment, and has no VOC's. This material costs $16 - $19 per gallon.

RECOMMENDATIONS

- **Although epoxy performed very well, the research team recommends that SDDOT continue it present practices in urban areas until a more practical solution becomes available.**
- **Testing should be performed with water based paint in an urban area to determine how well it performs.**
- **The research team recommends that SDDOT use water based paint in rural areas.**
- **Testing should be done using polyester markings in rural and urban areas.**
- **Testing of inlaid tape in urban areas should continue.**

REFERENCES

Dan Johnston, South Dakota DOT, personal conversation, January 8, 1993.

Ron Lorini, *Evaluation of Polyester Pavement Markings*, New York State Department of Transportation, FHWA/NY/SR-92/102, 1992.

Chris Fesenmeyer, Rohm and Haas Company, personal conversation, February 12, 1993.