Online exclusive

A Deep Dive into Hail-Caused Dents: A Study of Corrosion Resistance within Dents in Galvalume-Coated Steel Roof Panels

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FOR METAL ROOFS in hail-prone regions, such as the area stretching generally from Wyoming, through the Front Range, to Texas—commonly referred to as "Hail Alley"—the occurrence of hail-caused dents is more a question of "when" than "if." Consequently, in recent years the insurance industry has been writing exclusions or endorsements that limit coverage to the effects of hail deemed "functional," as opposed to "cosmetic" or "aesthetic." While various definitions abound, and it is not the intent of this paper to haggle over legalese, functional damage is generally considered to be damage (typically, dents or deformations) that results in diminished water-shedding ability of the roof assembly (in other words, that causes leaks) and/or damage that will reduce the roof assembly's expected service life. Conversely, cosmetic damage is generally understood to be dents that only affect the appearance of the panel, but not its performance or service life. An oft-cited industry definition is that used by United States Steel:[1]

> In general, hailstone damage can be categorized into two types: aesthetic damage and functional damage. Aesthetic damage is simply damage that has an adverse effect on appearance but does not affect the performance of the roof. Functional damage results in diminished water-shedding ability and a reduction in the expected service life of the roof.

The intent of the cosmetic damage endorsements and exclusions is fairly clear: to eliminate or reduce the insurance carrier's liability for hail-caused dents that do nothing but affect the appearance of otherwise functional roof panels.

Recently, however, various engineers, metallurgists, forensic experts, and other property-claim stakeholders have challenged the idea that hail-caused dents can ever be merely a cosmetic issue, even in cases that do not result in moisture intrusion. In the case of hail-caused dents that have not split, fractured, or punctured the metal, or otherwise compromised the panel's ability to resist moisture intrusion (such as by disengaging a seam), the argument that the dents still constitute functional damage generally comes in the form of a concern for the long-term performance, or service life, of the roof panels. The arguments against cosmetic-only dents typically take on one of two forms (or both). The first challenge usually goes something like this: "The hail-caused dents created microfractures (or microfissures, coating craze cracks, and the like), which will lead to premature failure of the corrosion-resistant coating and, in turn, premature corrosion of the underlying base metal." A related, but separate, challenge usually states something along the lines of "The hail-cased dents (or divots) will accumulate water, which will evaporate slower than the

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panel would otherwise (increasing the time of wetness) and accelerate coating deterioration, thereby causing premature corrosion of the underlying base metal." The intent of this paper is to evaluate these two assertions as they pertain to Galvalume-coated steel panels.

While there are a number of different metal panels currently available in the market, the most common types of panel are Galvalume-coated steel panels. As such, the focus of this paper specifically relates to effects of hail-caused dents in Galvalume-coated steel panels.

Previously, two recent research projects on the effects of hail to Galvalume-coated steel panels were commissioned by the Metal Building Manufacturers Association (MBMA).[2,3,4] A summary of these findings was also presented at the 2023 IIBEC International Convention and Trade Show in the proceeding "Oh Hail! Metal Roofs, Hail Impact, and Long-Term Performance."[5] In response to the arguments based on coating damage, the researchers concluded the following, as summarized by Dutton:

> The coating damage study is based upon a metallographic assessment of rollformed profile rib specimens from a 43-year-old roof in Denver. The profile of the Denver roof is representative of trapezoidal standing seam metal roofing that is common industry wide. The results show that a minor degree of metallic coating crazing may occur immediately upon manufacture and may even occasionally penetrate through the coating to expose the base steel, but that no detrimental corrosion has occurred on this roof for over 40 years. This observation is consistent with the unique and well-documented corrosion resistance mechanism characteristics of 55% Al-Zn alloy-coated steel globally. This study also demonstrated that the occasional minor degree of rollformed coating damage is much smaller in size than the size of 55% Al-Zn alloy-coated steel uncoated spots of up to 0.079 inches in diameter which, upon exposure to marine, industrial and rural atmospheres, showed no adverse effects on corrosion resistance after 9 years. In addition, the degree of coating damage associated with a recent hailstorm "functional" damage insurance claim was about 50 times smaller than the coating damage associated with roll-forming on the 43-year-old Denver roof. Thus, it is concluded that such minute coating cracks or base steel exposures from hail impacts do not rise to the level of "functional" damage when compared to the degree of coating crazing which may occur on newly produced 55% Al-Zn alloy-coated steel roof panels.

In response to the arguments based on the accumulation of water ("ponding"), the researchers concluded the following, as summarized by Dutton:

> The water ponding study is based upon a controlled laboratory assessment of the time required for water to evaporate from simulated hail divots in a commercially produced GALVALUME standing seam panel. A standard laboratory impact testing apparatus was used to produce simulated hail divots by delivering energy impacts of 1, 4, 8 and 13.3 ft-lbs, energies which correlate with hail stone diameters of about 1 to 1-3/4 inches striking a surface at terminal velocity. The resulting divots ranged in depth from 0.035 to 0.159 inches. To put this in perspective, hail stones measuring up to about 1-3/4 inches in diameter have been documented as representing about 75 to 95% of the hail stone diameters associated with hailstorms in the US and Canada.
>
> The study shows that the time for water to evaporate from 0.150- inch divots is faster than the times for evaporation to occur at intentionally manufactured mechanical deformations associated with panel flutes employed to strengthen roof panels. For hail divots up to about 0.160-inch depth, water evaporates in a small fraction of the time required for the sheared-edge panel eave to dry.
>
> Based on these results, any argument that divots produced by hail stones up to about 1-3/4-inch diameter will result in accelerated corrosion of the 55% Al-Zn alloy-coated steel panel due to ponding water in the divots is not supported. Such 55% Al-Zn alloy-coated steel [standing seam roof] systems featuring flutes and sheared-edge conditions have performed excellently in service for over 40 years.

Our research builds on the findings of the previous research conducted by Dutton, Wilson, Giansante, Haddock, and others, in order to expand the knowledge base of this often-controversial topic. Our research was twofold:

- We commissioned a metallurgist for laboratory salt spray testing of panels with simulated hail dents.
- We evaluated the condition of in-service panels that were subjected to large hail impact (from hailstones up to approximately 2.5 inches in diameter) more than 27 years prior.

SALT SPRAY TESTING

Roof Technical Services Inc. (ROOFTECH) secured a 26-gauge Galvalume-coated steel R-panel meeting ASTM A653 Grade 80 and UL 2218 Class 4 hail rating. **Fig. 1** is a drawing by ROOFTECH showing the profile of the R-panel that was tested.

The R-panel was tested in general accordance with UL 2218-2012, *Impact Resistance of Prepared Roof Covering Materials*,[6] which is a test

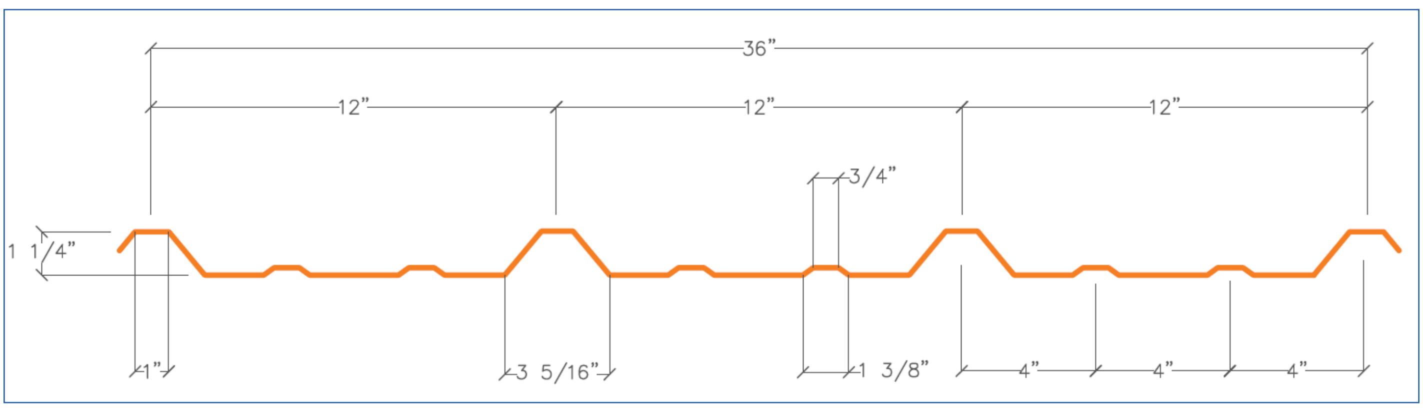

Figure 1. *Diagram of a typical R-panel.*

TABLE 1. Drop height and kinetic energy

Class	Steel ball diameter		Distance		Energy	
	in.	mm	ft	m	ft-lbf	J
1	1¼	31.8	12	3.7	3.53	4.78
2	1½	38.1	15	4.6	7.35	9.95
3	1¾	44.5	17	5.2	13.56	18.37
4	2	50.8	20	6.1	23.71	32.12

Note: *Data from Underwriters Laboratories (2012).*

method that "provides impact resistance data for the evaluation of roofing materials." In addition, a rib of the panel was stepped on to simulate a typical foot-step deformation (buckle) in a rib, which commonly occurs on these types of roofs as a result of foot traffic or mishandling during maintenance, construction, or other rooftop activity. UL 2218 provides Class 1 through 4 hail impact resistance classifications. The test was based upon dropping 1.25-, 1.50-, 1.75-, and 2.00-inch steel balls from a distance calculated to simulate the kinetic energy of hail impacts of 1.25-, 1.50-, 1.75-, and 2.00-inch hailstones. The kinetic energy of hailstones has been established by the National Bureau of Standards and others. **Table 1** shows UL 2218's four hail classifications and associated kinetic (impact) energy.

Samples from the test panel subjected to the simulated hail impacts and footstep damage were delivered to Hurst Metallurgical Research Laboratory Inc. (HMRL) for metallurgical testing, which included a visual examination, salt spray (fog) testing, and evaluation at low and high magnifications using a variety of metallurgical methods both before and after salt spray (fog) testing was performed.

UL 2218 Impact Testing of Prepared Roof Covering Materials

The panels were stored inside at approximately 73°F, and each panel was subjected to two steel ball impacts: one in the rib and one in the flat portion of the panel. The locations of the impacts were circled and noted on the panel. **Fig. 2** shows the tower used to drop the steel balls and a view of a typical panel after the UL 2218 impact testing (in this case, the impacts shown were from 1.25- and 1.50-inch steel balls dropped from a height calibrated to approximate the energy of 1.25- and 1.50-inch hailstones).

The width and depth of the resulting dents were measured. **Fig. 3** shows the measurement of the depth of the dents resulting from the 2.00-inch steel ball impacts to the rib and flat portion of the panel.

Research performed by others and ROOFTECH's experience had found the impact dents in metal panels typically exhibit an inside diameter and an outside or overall diameter. Mathey[7] first reported the phenomenon wherein impacts to metal panels form a shallower outside dent and a steeper inside diameter. Mathey[7] included a diagram showing these diameters, which are depicted in a diagram of the typical cross section shown in **Fig. 4**.

The depth and width of the indentations were measured. **Table 2** summarizes the recorded measurements of the width and depth of the indentations resulting from the various hail sizes. UL 2218 states, "visual observations are to be facilitated by examining the samples under 5x magnification and the observations recorded for each impact location." The samples were examined under 5x magnification, and there were no visible cracks in the coating or other evident failure of the metal panel. There was some scuffing of the Galvalume surfacing resulting from the steel ball impacts, which would not be expected from actual hailstones. The impact locations were also examined under 80x magnification. **Figs. 5** and **6** are photographs taken at the maximum magnification of an 80x microscope with no evidence of a fracture in the Galvalume coating or failure of the panel.

Most metal roof panels, including 26-gauge Galvalume metal R-panel roofs, meet UL 2218 Class 4, which is the highest rating available with the UL 2218 test. Our testing corroborates the Class 4 resistance and provides an example of the approximate sizes of dents that can be expected from the various hail sizes.

Hurst Metallurgical Research Laboratory

A total of 11 samples were extracted from the test panel and delivered to HMRL in Euless, Texas, for metallurgical testing. The salt spray testing was performed in accordance with ASTM G85-11, Annex 5 Dilute Electrolytic Cyclic Fog/Dry test method. The HMRL examination included a visual examination; salt spray (fog) testing; and evaluation under various levels of magnification, using a variety of metallurgical methods both before and after salt spray (fog). The 11 test

Figure 2. *Test apparatus.*

Figure 3. *A field dent depth measurement.*

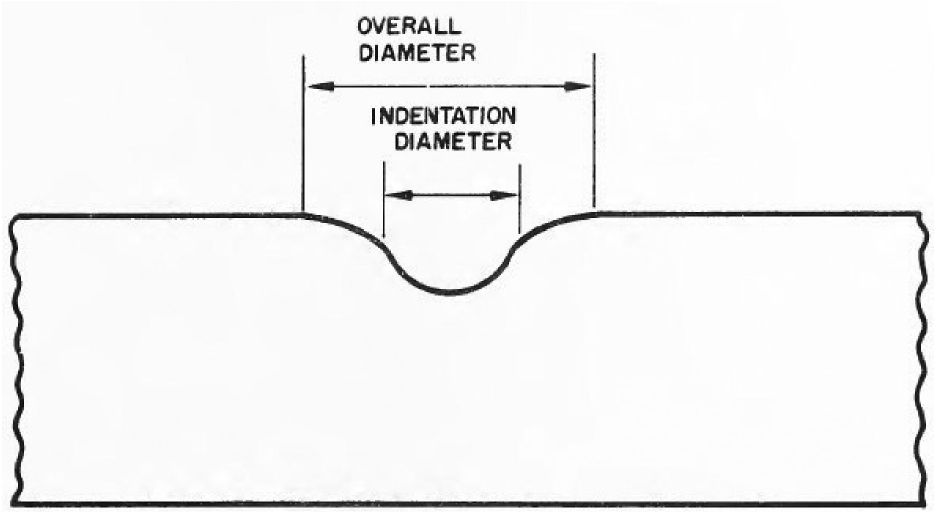

Figure 4. *Diagram showing inside and outside or overall diameter of impact dents in metal panels.*

TABLE 2. Depth and width measurements of the panel dents by various-sized steel balls

Hail size, in.		Field dent, mm	Rib dent, mm	Field dent, in.	Rib dent, in.
1.25	Depth	0.14	1.01	0.01	0.04
	Width	5.08	24.13	0.20	0.95
1.5	Depth	0.32	2.14	0.01	0.08
	Width	10.16	27.94	0.40	1.10
1.75	Depth	0.96	3.13	0.04	0.12
	Width	12.7	30.48	0.50	1.20
2.0	Depth	1.17	3.56	0.05	0.14
	Width	13.97	27.94	0.55	10.10

samples included the eight samples that had been impacted by the 1.25-, 1.50-, 1.75-, and 2.00-inch steel balls and two samples that HMRL scribed (scratched) to simulate a large crack in the Galvalume coating. Finally, the sample with the rib buckle caused by foot pressure was also tested. The HMRL findings are contained in Madhani.[8] **Table 3** shows Madhani's summary of the findings of the salt spray testing; note that the rust observed within the 1.-inch dent on the rib surface and 2-inch dent on the rib surface was found to be corrosion of the superficial residue from the steel ball and was not corrosion of the steel panel itself.

No visual evidence of corrosion (specifically, iron oxide or rust) was observed on the scribed roof surface after 336 hours. Isolated rust was observed within the footstep buckle after 72 hours. Slight rust-colored spots were observed on the dented ribs from the 1.75- and 2.00-inch simulated hail impacts after 252 hours on the 1.75-inch test sample and after 336 hours on the 2-inch test sample.

However, the examination of these rust-colored spots "revealed that the rust-colored spots were extremely superficial" and, upon further investigation, were found to be caused by residuals from the steel ball—an effect that would not occur with real hailstone impact. Madhani[8] noted that there was "no evidence of cracking or pitting of the coating" at the impact locations. The spots were cleaned and examined and "no cracking or corrosion of the coating or the substrate" was observed.

The scribed sample, which was tested to simulate a crack in the coating, revealed no evidence of rust after 336 hours of salt spray (fog). The cracks extended through the coating and into the carbon steel and were visible without magnification. Madhani[8] concluded,

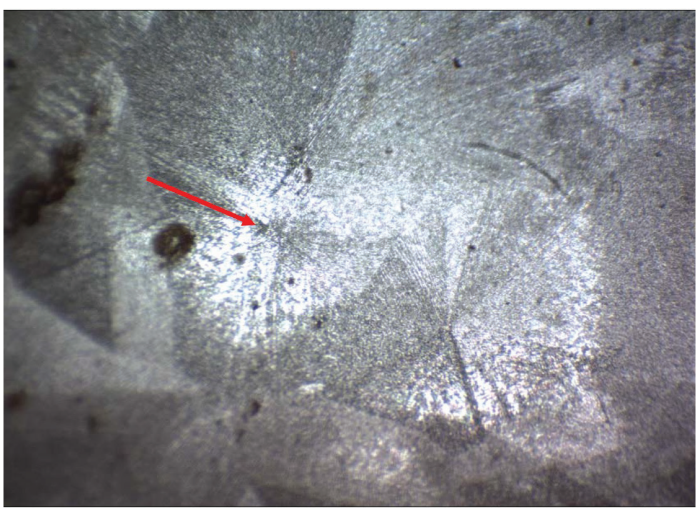

Figure 5. *A view of a 1.75-inch steel ball impact point center under 80x magnification. The red point indicates a coating scuff.*

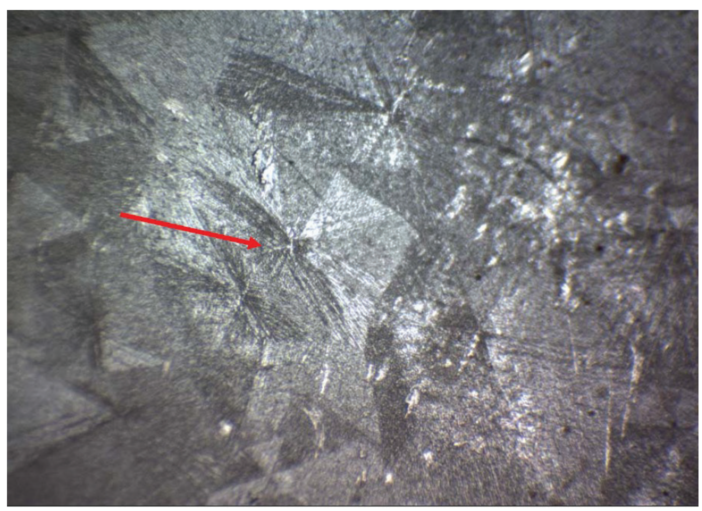

Figure 6. *A view of a 2-inch steel ball impact point center under 80x magnification. The red point indicates a coating scuff.*

TABLE 3. Summary of salt spray testing

Specimen	Results								Comments
	After 72 hours		After 162 hours		After 252 hours		After 336 hours		
	Within dent.	Outside of dent.	Within dent.	Outside of dent.	Within dent.	Outside of dent.	Within dent.	Outside of dent.	
1¼ in. dent on rib surface	10	10	10	10	10	10	10	10	
1¼ in. dent on flat surface between ribs	10	10	10	10	10	10	10	10	
1½ in. dent on rib surface	10	10	10	10	10	10	10	10	
1½ in. dent on flat surface between ribs	10	10	10	10	10	10	10	10	
1¾ in. dent on rib surface	10	10	9-S	10	9-S	10	9-S	10	Isolated rust-colored spots observed after 162 hours
1¾ in. dent on flat surface between ribs	10	10	10	10	10	10	10	10	
2 in. dent on rib surface	10	10	10	10	10	10	9-S	10	Very slight rust-colored spots observed after 336 hours
2 in. dent on flat surface between ribs	10	10	10	10	10	10	10	10	
Scribed on rib surface	10	10	10	10	10	10	10	10	
Scribed on flat surface between ribs	10	10	10	10	10	10	10	10	
Footstep on rib	9-S	10	9-S	10	9-S	10	8-S	10	Isolated rust at scuffed area first observed after 72 hours

Note: *Data from Madhani (2017). For dents, 10 = <0.01% surface rust; 9 = >0.01% and <0.03% rust; S = spot per ASTM D610-08 (2012). For scribes, 10 = 0 in. creepage per ASTM D1654-08 (2016).*

"the absence of corrosion of the carbon steel demonstrates the galvanic protection provided by the coating on exposed areas of the substrate." **Fig. 7** is an excerpt from Madhani[8] showing the scribed area after 336 hours of salt spray (fog) testing with no evidence of corrosion. However, at the crimped area of the foot-pressure-created rib buckle, corrosion was evident after 162 hours in the salt spray at the crimped area of the footstep buckle. **Fig. 8** shows the corrosion at the footstep buckle after 162 hours.

Madhani[8] concluded, "The various metallurgical tests and evaluations of the simulated cracks and hail impact dents in the GALVALUME® carbon steel panels … performed satisfactorily and disclosed no evidence of any corrosion to the substrate carbon steel material" even after exposure to 336 hours of salt spray (fog). The metallurgical testing did reveal corrosion occurring in the sample damaged by the footstep and within a mechanically scuffed portion. This indicates that the salt spray testing was sufficient to cause corrosion to portions of the panel at which the Galvalume coating sustained significant damage.

REAL-WORLD CASE STUDY

Background

One of the most damaging hailstorms in history occurred in Fort Worth, Texas, on May 5, 1995. The storm caught 10,000 people outside without shelter at a spring Mayfest event. More than 400 of those attending Mayfest were injured, including 60 who required hospitalization. There was widespread

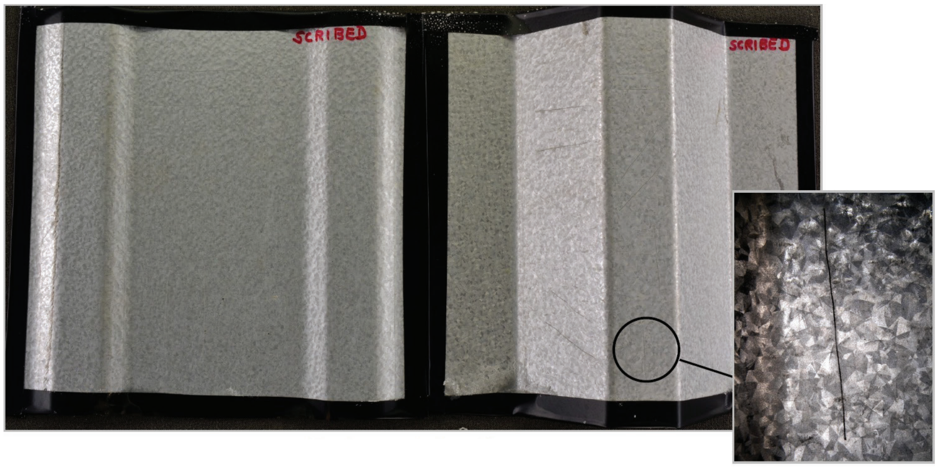

Figure 7. *Photograph of the scribed samples of Galvalume roof panel sample showing the lack of visible evidence of corrosion following 336 hours of test cycle. Reproduced with permission from Madhani (2017).*

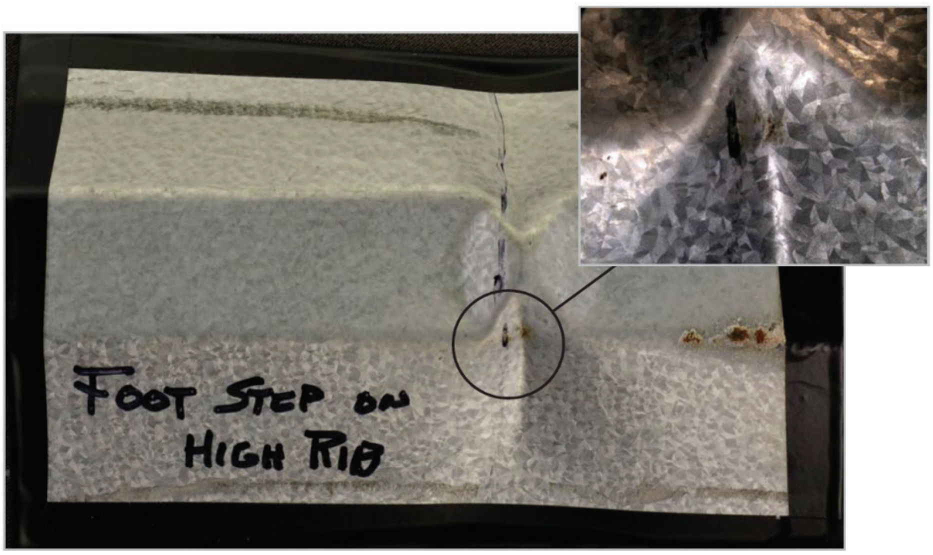

Figure 8. *Photograph of footstep buckle showing corrosion after 162 hours of salt spray testing. Reproduced with permission from Madhani (2017).*

Figure 9. *Photograph of the case study roof taken in 2013, approximately 18 years after the hail event, when the roof was 27 years old.*

softball-sized hail across Fort Worth that caused an estimated $2 billion in damages, and the hailstorm became known as the "Mayfest Storm."[9] According to the National Centers for Environmental Information's Storm Events Database, there were several reports of hail within Fort Worth (the location of the subject case-study building), including reports of 2.75-, 3.5-, and 4-inch hailstones.[10]

The building that is the subject of this case study is a one-story strip shopping center built in 1986 and located on the east side of Fort Worth. The general construction consists of a slab-on-grade foundation with pre-engineered metal building framing and a 26-gauge Galvalume steel R-panel roof. The roof panels were attached to Z-purlins approximately 5 feet apart using screws with rubber washers. There were stitch screws at the side laps approximately 24 inches on center.

Inspection and Analysis

The roof on the building was subjected to impact from hailstones up to at least 2. inches in diameter, with some hailstones possibly reaching 4 inches. The roof was not replaced after the Mayfest Storm. The roof on the building had numerous dents but no hail-related leaks. The building has a history of minor leaks occurring at the end laps of the metal panels and at screws. In 2013, one of the authors reinspected the roof to evaluate its performance. **Fig. 9** is a photograph of the roof taken in 2013, approximately 18 years after the hail event, when the roof was 27 years old. The roof leaks were minor and in generally the same locations, related to end laps and screws, as they were in 1995. There were a few repairs to the screws and penetrations.

Numerous hail-caused dents were visually examined, including examination at 10x to determine if there had been any deterioration as a result of the hail-caused dents. **Fig. 10** shows typical hail-caused indentations with stains in the dents that were randomly spaced across the roof.

The larger hail-caused dents were stained with sediment in the dents. **Fig. 11** shows a close-up of one of the larger hail-caused dents with stains. **Fig. 12** shows the hail-caused dent cleaned. There was no evidence of corrosion or other evidence of deterioration. **Fig. 13** shows a 10x view of the impact area. There is no visible corrosion or deterioration of the Galvalume coating at 10x.

Stains at the screws and end laps of the panels had stains similar to the stains at the hail-caused dents. This type of staining is normal and commonly occurs on these types of metal

Figure 10. *Photograph of the dents in the case study roof caused by the Mayfest Storm.*

Figure 11. *Photograph of typical hail-caused indentations with stains in the dents.*

Figure 12. *Photograph of a cleaned hail-caused dent—note the absence of evident corrosion.*

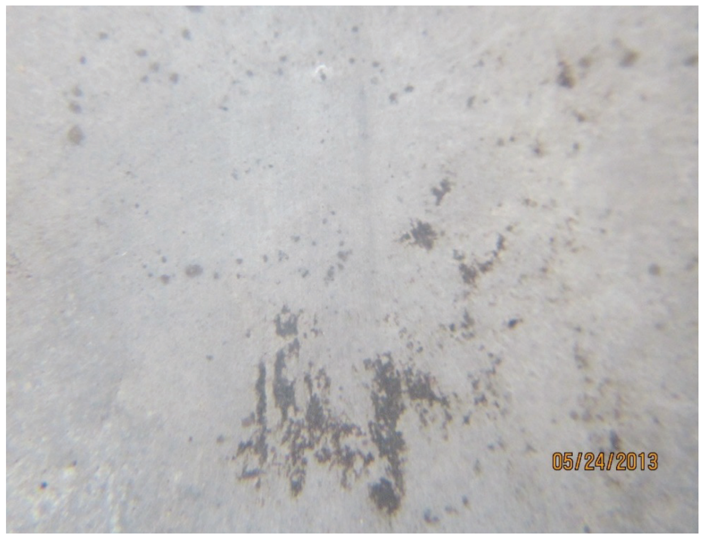

Figure 13. *Photograph of a cleaned hail-caused dent under 10x magnification—note the absence of evident corrosion.*

Figure 14. *Photograph of case study roof taken in 2022 approximately 17 years after the Mayfest Storm.*

roof. There was no evidence of corrosion in the Galvalume panel. There was, however, corrosion on the screw. At the end lap panels, the overlap results in a shallower slope (with slower drainage and evaporation) and, consequently, staining similar to the staining in the hail-caused dents. There also appeared to be some evidence of slight pitting of the Galvalume coating at the end lap.

In 2022, one of the authors again reinspected the roof to evaluate its performance. **Fig. 14** shows an overview of the roof on the building taken in 2022 approximately 27 years after the Mayfest Storm. The roof was approximately 40 years old at the time of this inspection. Overall, the appearance of the roof was in a substantially similar condition to its condition at the previous inspection.

Figure 15. *Photograph of large dent in the rib of the panel.*

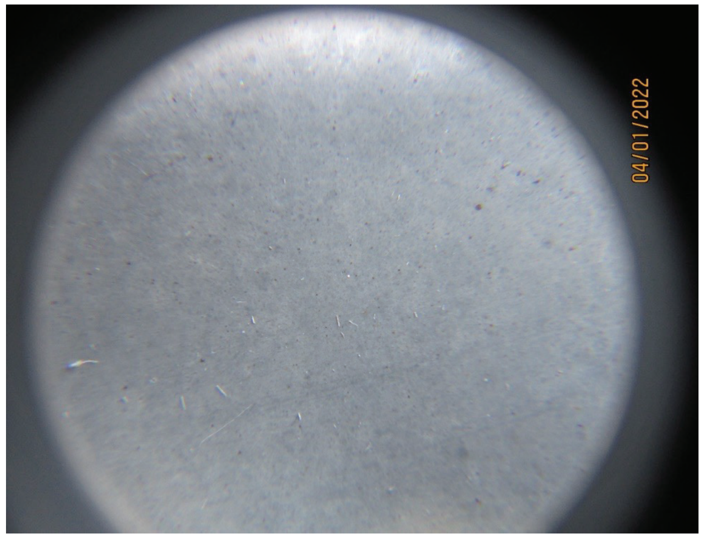

Figure 16. *Photograph of cleaned dent in the rib under 10x magnification.*

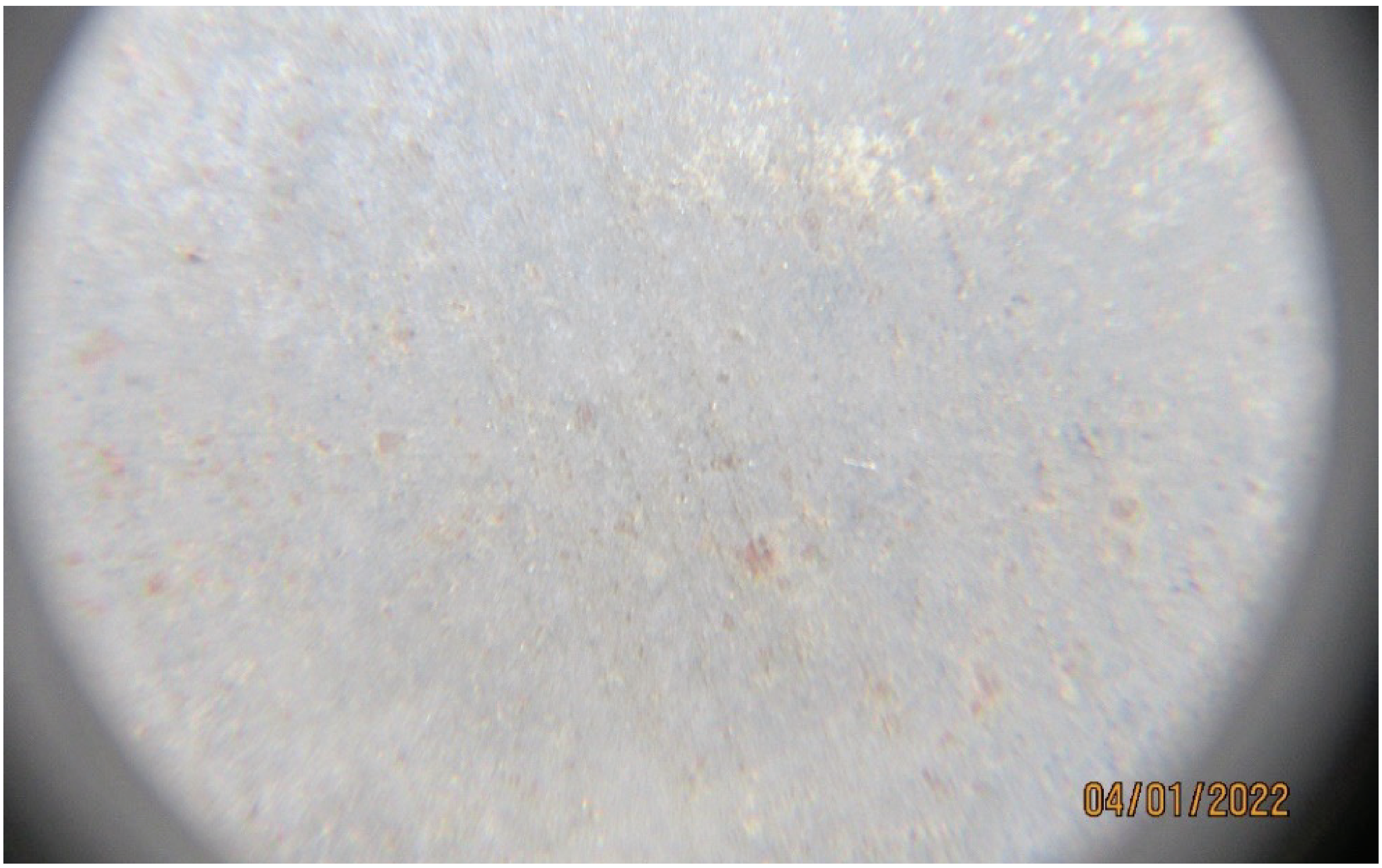

Figure 17. *Photograph of small spots of corrosion at the eave panels of the 40-year-old roof.*

Again, numerous hail-caused indentations were visually examined and examined under 10x magnification. **Fig. 15** shows a large dent in the rib of the panel with sediment accumulation. **Fig. 16** shows a 10x view of a rib dent after cleaning with no evidence of corrosion. However, small spots of corrosion were beginning to show at the eaves after 40 years of service, shown in **Fig. 17**.

Case Study Conclusions

There was no evidence of corrosion at the various hail-caused impacts after 27 years of weathering, though there were staining and sediment accumulations at the hail-caused dents. The Galvalume panels were performing well, and there was no evidence of corrosion in the metal panels caused by the hailstone impacts. We found that there was no visible evidence of corrosion at the hail-caused indentations.

We also found that the sediment in at the depressions in the metal panels at the screws and the sediment at the end laps and eaves were similar in appearance to the stains in the hail-caused dents, which is consistent with the findings reported in Dutton and Wilson.[3] In this case study, it appeared that there were some minor pits from corrosion in the Galvalume coating at end-lap seams that were not present in the hail-caused dents.

CONCLUSION

The salt spray metallurgical testing verified that dents caused by impacts from steel balls up to 2 inches (with the approximate energy of a similarly sized hailstone) would not be expected to corrode at a rate that would exceed the rate of other areas of the panel due to normal weathering, such as at end-lap seams or overtightened fasteners, or at areas with mechanical-type damage, such as at rib buckles. The metallurgical study included subjecting the dented samples from the test panel to salt spray testing for 336 hours, which is a significantly more corrosive environment than normal atmospheric conditions, and evaluating the sample before and after the test. This metallurgical evaluation confirmed that there was no corrosion as a result of the simulated hail-caused dents in the metal panels even when subjected to the salt spray testing. The metallurgical study also showed that there was no corrosion in the scribed areas. Moreover, the lack of corrosion in the scribed areas confirmed that the coating performed as designed to prevent corrosion, even if the coating had minor scratches or cracks. The testing was, however, sufficient to cause corrosion in areas of the panel that were buckled by footfall and mechanically scuffed.

The observations of the subject case study found that Galvalume-coated steel panels were not corroded at the hail-caused dent locations, even after 27 years of weathering. The Galvalume-coated panels were performing well, and there was no evidence of any significant deterioration in the metal panels caused by the hailstone impacts. We also found that the sediment in at the depressions in the metal panels at the screws and the sediment at the end laps and eaves were similar in appearance to the stains in the hail-caused dents, which is consistent with the findings reported in Dutton and Wilson.[3] While this study was limited to panels subjected to hailstones up to approximately 2½ inches, larger hail is an extremely rare occurrence and thus, these results are comparable to the large majority of cases of hail-dented Galvalume-coated panels, most of which would have been impacted by smaller hail. This case study was consistent with the authors' experience inspecting thousands of hail-dented Galvalume-coated metal roof panels, none of which have ever exhibited corrosion correlated to the dent locations. Moreover, the authors have never seen photographs of Galvalume-coated panels with corrosion specifically correlated to hail-caused dents (though if such photographs exist, we welcome their production).

Together, the metallurgical testing and case study indicated that metal roof panels will generally corrode at various areas due to normal weathering before they would be expected to corrode at dents caused by impact from hailstones up to 2½ inches. In other words, by the time hail-caused dents corrode, the metal panels will have already corroded elsewhere and, therefore, these hail-caused dents will not result in a reduction of their expected service life. In sum, based on the salt spray testing and the case study, it can be concluded that hail-caused dents from hail 2½ inches or less will not corrode at an accelerated rate such that their expected service life is shortened. With regard to the distinction between cosmetic and functional damage, the authors conclude that unless they cause a vector for moisture intrusion (such as a split panel or seam disengagement), dents caused by hail up to 2½ inches will generally not meet the definition of functional damage and are deemed cosmetic.

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