TECHNOTE

U.S. Department of Transportation
Federal Highway Administration

Experiences from Early Implementations of UHPC Overlays

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Introduction

Ultra-high performance concrete (UHPC) overlays have been used since 2004 with the first implementation in the U.S. in 2016 [1]. UHPC overlays have been installed on more than 30 bridges in the U.S. as of 2023 [2] and more than 150 bridges worldwide as of 2020 [1]. The objective of this technical brief is to summarize some of the experiences of four different entities with their recent installation of UHPC overlays. Meetings were held with the Delaware River & Bay Authority (DRBA), Federal Lands Highway (FLH), New Jersey Department of Transportation (NJDOT), and Iowa Department of Transportation (Iowa DOT) to discuss their experiences with UHPC overlays including lessons learned and future recommendations.

This technical brief does not contain complete recommendations for all aspects of UHPC overlays. Specific recommendations for UHPC overlays are provided in FHWA-HRT-22-065 [1]. The information provided in this technical brief should be used to supplement the recommendations in FHWA-HRT-22-065.

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Key Words — ultra-high performance concrete (UHPC), UHPC overlays, bridge deck, rehabilitation, construction, lessons learned.

Benefits of UHPC Overlays

UHPC exhibits many behaviors that are beneficial for overlay applications. Some of these include: very low permeability, good freeze-thaw resistance, good abrasion resistance, high strength and stiffness, and good bond strength to conventional concrete [1]. UHPC overlays have also been shown to have a lower life-cycle cost than other overlay options or a full reinforced concrete deck replacement [3]. Recognizing that UHPC overlays may have a higher initial cost due to the costs of the constituents and the construction process involved, owners specifying UHPC overlays often do so with an expectation that the installed solution will provide superior longevity and reduced maintenance [1]. Additionally, recent projects have demonstrated that, as compared to some other specialty overlay solutions, UHPC overlays may be able to be installed across a wider range of weather conditions and largely with a general contractor's workforce, thus providing both cost and schedule benefits.

General Feedback

UHPC overlays are different than other types of overlays and require some additional planning and expertise. While any contractor that has experience with overlays can likely perform the work required for UHPC overlays on a smaller project, it can also be beneficial to involve people with prior experience with UHPC overlays. Past experience has shown that smaller projects may be successfully completed with only the additional expertise of a knowledgeable UHPC supplier. Larger projects would likely benefit from also involving contractors and consultants with UHPC overlay expertise. This document aims to provide some feedback from owners and contractors, but it may still be beneficial to involve experts in at least pilot projects until more in-house or local contractor experience is gained.

One key method for systematically addressing a wide range of potential challenges with UHPC overlays is to include a mockup or pilot phase overlay installation well before the primary construction project begins. This forced demonstration of process and performance can help identify and solve any site-, seasonal-, and project-specific challenges. The mockup should be a reasonable scale with similar grade, substrate preparations, and site conditions to the actual bridge deck. Some successful projects required a full-lane-width mockup using the equipment that was to be used during the actual bridge deck rehabilitation. If grinding and grooving is to be performed on the actual bridge deck, these steps should also be considered on the mockup as the grinding process 1) is a key step in the overlay installation, and 2) may expose defects in the demonstration installation that would otherwise be difficult to detect.

Specific Feedback on Different Aspects of UHPC Overlay Construction

The feedback from owners and contractors is broken into several different categories based on typical steps in the process for constructing a UHPC overlay. These include the following:

- **Project selection**: UHPC overlays are a viable solution for certain types of projects for both rehabilitation of existing decks and new construction. Some feedback is provided on what types of projects may make good candidates for UHPC overlays.
- **Project planning**: Proper planning of when the UHPC overlay is installed with respect to other rehabilitation efforts is important. Typical overlay thicknesses are also discussed.
- **Surface preparation (including demolition)**: For bridge deck rehabilitation projects, the first stage in the UHPC overlay construction process is to remove a portion of the existing deck or overlay. There are different techniques available and associated recommendations for proper demolition are discussed. Demolition is not required for new construction applications, but proper surface preparation of the substrate is still required.
- **UHPC mixture design**: UHPC suppliers will typically provide the mixture design appropriate for a UHPC overlay. Considerations applicable to mixture designs in general are discussed.
- **UHPC mixing**: Mixing of a thixotropic UHPC mixture appropriate for overlays may require special considerations when compared

with self-consolidating UHPC mixtures used for other applications.

- **UHPC placement**: Placement of the UHPC overlay material often differs from other types of overlays and other applications of UHPC (e.g., field-cast connections, bridge girders).
- **Construction joints**: It is not always practical to cast the entire bridge length or width in a single pass. Construction joints can be used to break the casts into reasonable sizes and to help with traffic management plans.
- **UHPC finishing**: Proper curing of the UHPC overlay is essential for good performance. Grinding can be performed using traditional equipment to create the final profile. Grooving is commonly required to provide appropriate vehicle skid resistance. Asphalt overlays have been used instead of grinding and grooving for some projects, however these can add costs and create long-term maintenance issues.
- **UHPC removal and repair**: Different size repairs can be performed on UHPC overlays using grinding and hydromilling equipment to remove part of the UHPC overlay. UHPC or UHPC slurries can be used to fill these areas.

More details on each aspect of UHPC overlay installation are provided in the following sections.

Summary of Feedback

Project Selection

UHPC overlays are a potential solution for any rehabilitation project where an alternate overlay type may be considered. These include where an existing overlay is being replaced or where deterioration is primarily toward the top face of the deck with sound concrete in the lower portion of the deck. The owner will gain the most benefit from installing a UHPC overlay when the potential remaining service life of the underlying components is greater than the expected service life of the UHPC overlay, which is expected to be more than 50 years. UHPC overlays could also be used to maintain or reduce the dead load of the rehabilitated structure due to the possibility of installing a thinner structural overlay. UHPC overlays can also be used as a very low permeability topping on newly constructed reinforced concrete bridge decks.

For rehabilitation projects, it is important that the substrate (the remaining portion of the bridge deck that is prepared for installation of the overlay) be in good condition. UHPC overlays and overlays in general are appropriate for substrates composed of sound concrete with minimal cracking. A full deck replacement should be done if there is major cracking and unsound concrete throughout the entire depth of the deck. One owner used ground penetrating radar (GPR) to assess the condition of the deck and the likelihood of extensive rebar corrosion, to determine concrete cover and existing overlay thickness, and to locate the existing deck reinforcement, facilitating the decision of whether a UHPC overlay would be appropriate for the project. Coring of an existing overlay and/or deck has also been used to gain more knowledge of the existing deck condition and chloride levels. Half-cell potential testing can be considered to help detect reinforcement corrosion.

The use of a UHPC overlay may allow for more flexibility in the project schedule as its installation may sometimes be performed by the general contractor. One owner had a contractor propose using a UHPC overlay instead of a polyester polymer concrete (PPC) overlay. In this case, the PPC overlay required a specialty contractor for installation while the UHPC overlay could be installed using the contractor’s crews for this smaller project.

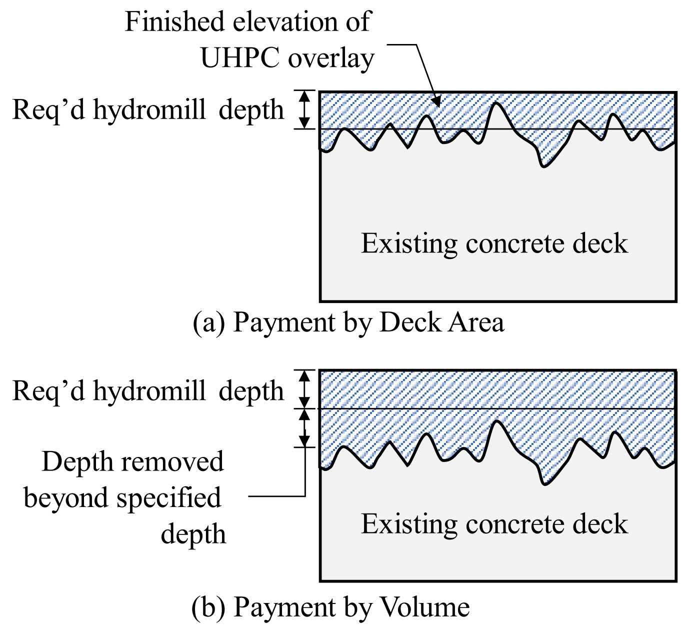
UHPC overlays can also be a good solution for new construction where the deck is composed of precast concrete elements. In one case an owner chose to install a UHPC overlay to create a nearly impermeable layer that would inhibit ingress of salt-laden moisture to the precast elements and field-cast connections. Another owner is considering using UHPC overlays for new construction, with plans to use a 7-inch-thick, cast-in-place, conventional concrete deck and 1-inch UHPC overlay.

Project Planning

Robust statements of work for contractors to bid on are always necessary. In terms of UHPC overlays, one issue that is frequently debated is how to deal with payment units. Prior contracts have specified payment by either cubic yard of UHPC or by square yard of deck area, with each providing advantages and disadvantages. In the context of payment units, it is important to recognize that the condition of the existing deck and the method of substrate preparation are critical considerations that will affect bid price and the final cost to the owner. As will be discussed later in this document, hydromilling (also commonly referred to as hydrodemolition) is commonly used for substrate surface preparation.

Hydromilling presents two challenges when it comes to bidding: (1) estimating accurate volume is difficult given the large variation in surface texture, and (2) the variability in deck condition can lead to over- or under-removal relative to the estimate. To counter these two dilemmas, the owner may opt for a deck area unit price. Since the true cost to the contractor is a direct result of the removed volume of existing concrete and the installed volume of replacement UHPC, the contractor may perform these construction tasks in a way that offers them monetary advantages. For instance, if the payment unit is specified to be based on deck area, Figure 1 (a) shows a situation where the contractor might argue that the achieved profile met specified removal depth on an average sense despite localized peaks that do not meet specification. This interpretation is to the contractor's advantage since they performed less concrete removal and will install less UHPC. Alternatively, if the payment unit is specified to be based on volume of UHPC installed, the contractor might choose to remove extra concrete thus leading to the installation of extra UHPC and added cost to the owner (see Figure 1 (b)). Neither scenario is ideal, and with either method, the owner needs to define how they will sample the deck and assess the removal depth: whether it is the average depth in an area, the depth to the highest peak in an area, etc. Using a combination of traditional milling for most of the required removal depth and hydromilling for the last 0.5-inch of removal depth may also help to decrease the variation in removal depth.

To obtain competitive bids, owners might also consider providing a supplemental, volume-based pay item for UHPC as a contingency item. This way, if large variations in hydromilled surface necessitate more UHPC than the contractor anticipated, then there is a pay item to capture this variation. Via this contingency item, the contractor has the opportunity to have more confidence in the construction process and thus bid less risk into the primary pay item.



Source: FHWA.
Figure 1. Illustration. Typical hydromilling depths based on payment units.

A UHPC overlay is often part of a larger rehabilitation effort for a bridge. The way different aspects of the rehabilitation affect each other should be considered. As an example, there may be runoff from the hydromilling or casting of the UHPC that may stain the superstructure or substructure beneath the deck. Therefore, the execution of the overall rehabilitation should begin from the top and move downward across the various bridge systems. As an example, one owner had painted their steel superstructure prior to the UHPC overlay installation, then runoff from the hydromilling marred portions of the newly painted steel, necessitating cleaning after the overlay was complete.

The finished overlay thickness should be greater than 1.0 inch or 1.5 times the maximum fiber length with a minimum clear cover over the reinforcement of 0.625 inch (Haber et al., 2022). Some states will add 0.5 inch to this thickness for tolerance for a 1.5-inch total specified thickness. This minimum thickness should create a nearly impermeable layer to improve the durability of the bridge deck. The overlay does not need to get under the top mat of reinforcement to be effective. Overlays may be up to several inches thick; thicker overlays can be tied into the top mat of reinforcement, which can lead to a greater increase in the capacity of the deck.

The overlay thickness installed should consider the thickness that will be removed during the grinding and grooving process. The grinding and grooving process will typically remove between $^{1}/_{4}$ and $^{3}/_{8}$ inch. Overfilling and grinding has also been shown to remove small surface cracks and defects that may occur during construction of the overlay.

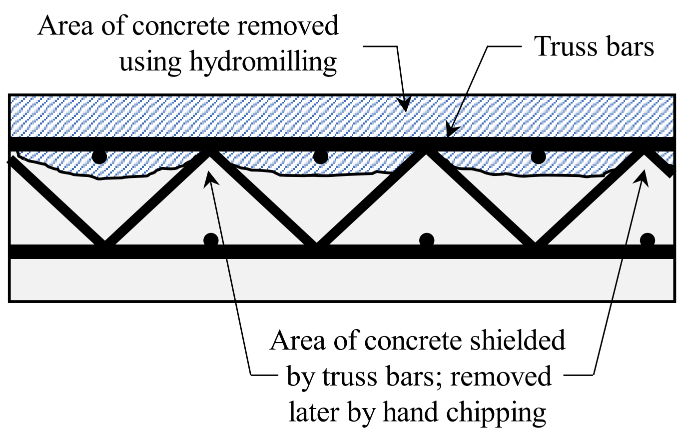
Surface Preparation (Including Demolition)

Proper demolition and preparation of the substrate can be one of the more challenging aspects of a UHPC overlay installation. In order to bond well and create a single, composite bridge deck, the UHPC overlay needs a roughened and sound concrete substrate with minimal macro- or microcracking. The surface preparation is typically done using hydromilling. Hydromilling leaves a roughened surface by removing portions of the existing concrete in relation to their proximity to the hydromilling nozzle and their structural competency. A photograph of a bridge deck after the hydromilling process is shown in Figure 2.

Source: FHWA.
Figure 2. Photograph. Example of bridge deck after hydromilling process.

Hydromilling will also remove any soft spots in the substrate. However, there are several challenges associated with the hydromilling process.

- The discharge from hydromilling will typically need to be collected during the process or special environmental permits need to be obtained. The slurry created by the hydromilling process can be removed using a pump and tank truck. Although successful execution is quite feasible, planning for project-specific conditions related to hydromilling runoff water is crucial and should be considered in the project contractual provisions.
- The top mat of the deck reinforcement may shield some of the concrete removal underneath depending on the reinforcement detail and desired depth. This occurred in one bridge with a truss bar detail in the deck where the initial desired hydromilling depth was specified to extend below the top mat of reinforcement, as shown in Figure 3. In the mockup phase, concrete shielded by the truss bars had to be manually chipped away, adding a significant amount of manual labor. Since this situation was identified during the mockup phase, the owner was able to revise the specified hydromilling depth to stop above the top mat of reinforcement.

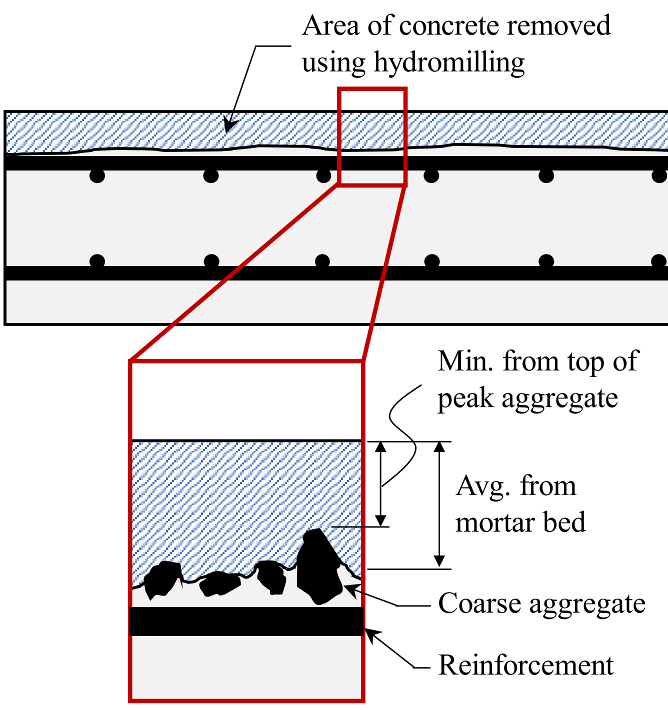


Source: FHWA.
Figure 3. Illustration. Area of concrete shielded by truss bars during hydromilling.

- Specifying hydromilling to extend below the top mat of reinforcement for conventional deck reinforcement details will create a free-floating top mat of reinforcement no longer connected to the bridge. This can create some difficulties with overlay placement and would generally only be considered if a new top mat of reinforcement is to be installed or if required to further increase the structural capacity to the deck.
- There can be some difficulty in removing a consistent depth of concrete over the entire bridge deck. The pressure of the water and speed at which the water jets are moved will control the depth of concrete removed. Lower strength

concrete will be removed at a greater depth if the pressure or speed are not adjusted. Very soft spots in the deck may lead to a blowthrough, where the hydromilling creates a hole through the existing deck. A contractor experienced with hydromilling can quickly adjust the pressure and rate of traverse to obtain the desired removal depth. Using a multi-jet head (e.g., five-jet nozzle) compared to a single-jet head may also lead to a more uniform demolition depth but may be more costly, labor intensive, and be less available in the current marketplace. The ability to deliver a consistent removal depth may become more challenging on decks with numerous existing repair patches of different ages and material types.

- Hydromilling commonly removes hydrated cement paste and aggregates and leaves protruding coarse aggregates exposed. The specified depth for hydromilling should be the average depth from the mortar bed, not a minimum removal depth from the peak of the aggregate, as shown in Figure 4. Details on how the depth is measured should be included in the project specifications to help improve estimates of the volume of UHPC required for the overlay.

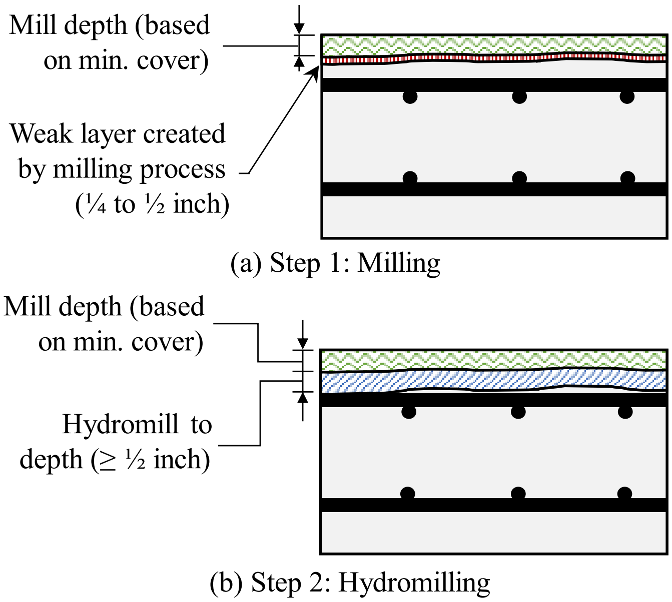


Source: FHWA.
Figure 4. Illustration. Recommended depth to specify for hydromilling process.

- The concrete substrate should have a roughened surface with a minimum profile of at least 0.25 inches measured as the average distance between the peaks and valleys. This magnitude is dependent on many factors including coarse aggregate size but will often be much greater than 0.25 inches when using hydromilling. A very large surface roughness may lead to more air being trapped under the UHPC surface during overlay placement, resulting in air bubbles rising through the UHPC overlay during and soon after placement. The UHPC mixture and the casting procedure will affect whether these bubbles can be largely or fully released. This topic is further discussed in the Placement section.

As a construction process for removing existing concrete from a bridge deck, traditional concrete milling is generally heavily preferred by contractors over hydromilling. However, a major issue with milling is that it will leave micro cracks along the exposed surface of the remaining concrete [4]. This weak layer created by the milling process is generally thought to be about $^1/_2$ inch deep. Several UHPC overlay projects have utilized milling to remove most of the desired concrete and then removed the last $^1/_2$ inch to 1 inch using hydromilling, as shown in Figure 5. This process helped to minimize the amount of material removed using hydromilling, which helped 1) mitigate concerns with the volume of water that had to be collected, 2) eliminate the need for multiple hydromilling passes over the same concrete, and 3) enable the creation of a relatively consistent substrate surface profile. More research is needed to investigate if other methods of removal can achieve the needed surface texture without the detriment of microcracks.

For situations where the UHPC overlay is being installed on top of a newly constructed conventional concrete deck, it may be possible to use a spray-on chemical to retard the setting of the concrete, after which the concrete surface would be washed to achieve the required surface roughness. Similar paste retarders are commonly applied to precast component formwork to achieve the necessary surface roughness for field-cast UHPC connections between prefabricated conventional concrete elements.



Source: FHWA.
Figure 5. Illustration. Possible two-step demolition process using milling and hydromilling.

UHPC Mixture Design

Self-consolidating UHPC mixtures used for field-cast connections, link slabs, and structural elements are not appropriate for overlays because the material will flow away along any road grade or superelevation. Several UHPC suppliers have thixotropic mixture designs for UHPC overlays that resist flow on a grade. A photograph of a thixotropic UHPC mixture being placed for an overlay is shown in Figure 6.

Source: FHWA.
Figure 6. Photograph. Example of thixotropic UHPC mixture being placed for a UHPC overlay.

A UHPC overlay mixture will be sensitive to local climate (e.g., temperature, sun exposure, humidity), so the supplier should understand how to adjust the mix design on site based on the climate conditions the day of casting and be able to modify the mix if conditions change throughout the day (e.g., as the sun rises and temperatures change from the morning to afternoon). Different suppliers will have different methods for making these adjustments. Every effort should be made to ensure that the mockup construction process closely resembles the conditions of the actual bridge deck being rehabilitated or constructed.

UHPC overlay mixtures have traditionally used a steel fiber content of over 3 percent (by volume). This steel fiber content has been thought to provide additional tensile strength and ductility for the thin overlay and help to stiffen the mixture to allow for placement on a grade. More recently, UHPC overlay mixtures are being used successfully with 2 percent (by volume) fiber content. Higher fiber contents can lead to an increased likelihood of issues during mixing and placement (e.g., fiber balling), so tailoring the fiber content in light of many competing considerations is necessary.

Semi-thixotropic mixtures are also available for use in the construction joints in a UHPC overlay where the UHPC needs to consolidate around the reinforcement in the joint region. These semi-thixotropic mixtures (and self-consolidating mixtures) should not be subjected to the same controlled vibration as thixotropic mixtures, as the vibration can lead to fiber settlement.

UHPC Mixing

The mixing procedure, required equipment for mixing, and mixing time will depend on the specific UHPC material being used. There were several general observations from the mixing process that should be considered regardless of the specific UHPC mixture.

- The proper storage of the UHPC materials before mixing should be considered. Like any other cementitious material, UHPC materials should generally be stored away from moisture. One project had issues with stacking super sacks of UHPC premix where workers poked holes in the bags during stacking to facilitate the rapid escape of trapped air. These holes led to moisture entering the sacks. For a large overlay project, a warehouse space may be necessary to store the materials until needed for the project. Recognize that extended storage durations, such as four months or longer, can result in degradation of fresh and hardened material properties.

- Steel fibers should be added slowly and should be dispersed as they are being added. Sufficient mixing time should be provided after the steel fibers are added to ensure uniform dispersal. The steel fibers may clump and create fiber balls, as shown in Figure 7, in the overlay if the fibers are added too quickly or if enough mixing time is not provided after they are added. Dependent on the mixer and the fiber addition process, it may take up to 20 minutes of mixing time after the fibers are added to properly distribute the fibers; this time needs to be factored into the placement schedule. The process for adding fibers and the mixing time needed to prevent fiber balling can be investigated during the mockup construction.

Source: FHWA.
Figure 7. Photograph. Example of fiber ball in finished overlay after grooving.

- The mix timing and output should match the placement rate for the overlay. The volume of the mixers, number of mixers used, and time required for mixing can be used to calculate the output from mixing to align with the desired placement rate. It is important that the mixing output allows for continuous placement of the overlay; one owner observed bumps in the finished surface at locations where the paving equipment had to be stopped to wait for the deposition of additional fresh UHPC.
- Mixing procedures may need to change throughout the day as weather conditions change, with late morning into early afternoon often being particularly important. The UHPC supplier should be able to provide guidance on what changes need to be made to account for changes in weather conditions. Ice can be substituted for mix water to help compensate for warming air temperatures.
- For long duration UHPC overlay placements, mixers will likely need to be cleaned periodically throughout the day. This time should also be factored into the mixing procedure and schedule.

UHPC Placement

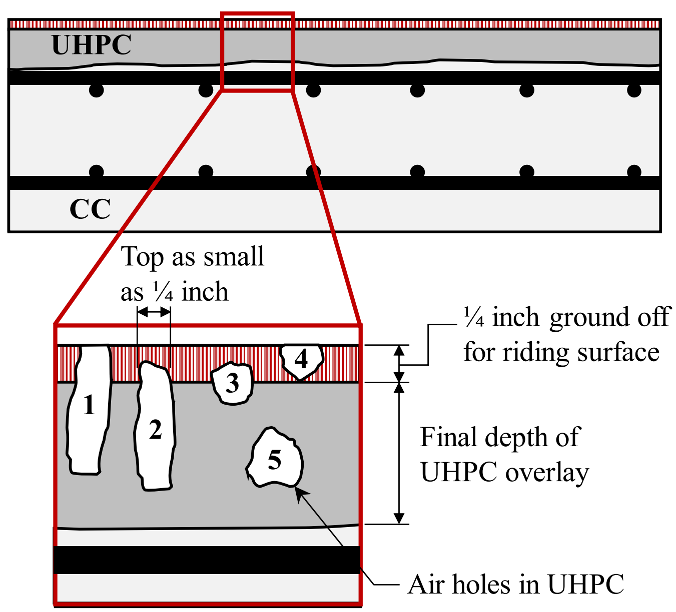
The environment, equipment, and procedure for placement are dependent on the UHPC material used for the project. A photograph of UHPC being placed for an overlay using specialized equipment is shown in Figure 8.

Source: FHWA.
Figure 8. Photograph. UHPC overlay being placed with specialized paving equipment.

Some of the general feedback on placement is as follows.

- Environmental conditions (e.g., temperature, humidity, wind) will affect the UHPC during the placement process. For example, increased temperatures can cause the UHPC to become stiffer leading to difficulty with placement and consolidation. Direct sunlight, low humidity, and wind can each lead to desiccation of the UHPC, causing it to both stiffen before placement and exhibit plastic shrinkage cracking after placement.

- UHPC mixes tend to include a very low water-to-cementitious materials ratio; therefore, the substrate should be prewetted to a saturated surface dry (SSD) condition to prevent the substrate from soaking up mix water from the UHPC. This can generally be achieved by spraying the substrate using a water truck with soaker hoses then covering the substrate with a tarp. Wet burlap could also be used to help maintain consistent and uniform moisture in dryer climates. Water should be applied to the surface for several hours to ensure that it soaks into the concrete substrate; this can be done overnight for morning casts. Leaf blowers and compressed air can be used to remove any standing water prior to UHPC placement.
- Typical bridge finishing equipment may not work because the UHPC overlay mixture is stickier than conventional concrete. Form-release agent may need to be applied frequently on any tooling that contacts the UHPC because of its stickiness. Typical finishing equipment, such as vibrating screeds, also have been found to have extremely slow finishing rates.
- Thixotropic UHPC does not readily move without vibration. The UHPC material should be placed as close to the overlay finishing equipment as possible to minimize the distance it needs to be moved by hand. Ideally, the hoppers, buggies, or ready-mix trucks would be able to place the material right next to the finishing equipment so that no movement by hand is needed. The contractor may need to practice with the placement equipment and process to gain experience with how the thixotropic UHPC flows.
- The placement equipment must impart vibration to help consolidate the overlay and allow trapped air to rise to the surface. The amount of vibration needed will depend on the UHPC mixture, thickness of the overlay, amount that the UHPC needs to be moved from initial deposition to final location, roughness and condition of substrate, and weather conditions. Stiffer UHPC mixtures, thicker overlays, further distances from deposition to final locations, and rougher substrates will all contribute to a higher likelihood of air voids being left in the placed UHPC. Specialty UHPC pavers are available for placement of UHPC overlays. These pavers are designed to level the thixotropic UHPC mixture and impart the proper amount of vibration.
- Several different types of trapped air may occur, as shown in Figure 9. Types 1 and 2 are deeper vertical air voids with depths that can be up to several inches and diameters that can be less than a $^{1}/_{2}$ inch or so. These voids may need to be repaired if they extend from the top surface to close to the top mat of reinforcement. Types 3, 4, and 5 are smaller voids that would typically not need to be repaired. Some voids may not be exposed until after the grinding process, see Types 2 and 3. Type 4 would be removed during the grinding process. Type 5 is not exposed to the surface. The size, type, location, and number of air voids will depend on the factors highlighted in the previous bullet point. To avoid later conflict, the owner should state within their project specifications the acceptance and rejection criteria for geometry of holes which will be considered defects. The acceptable number of holes per unit of surface area should also be stated. The owner and contractor can also benefit from clarity in the acceptable repair procedure for these types of defects.



Source: FHWA.
Figure 9. Illustration. Sample of different types of air voids observed in one project.

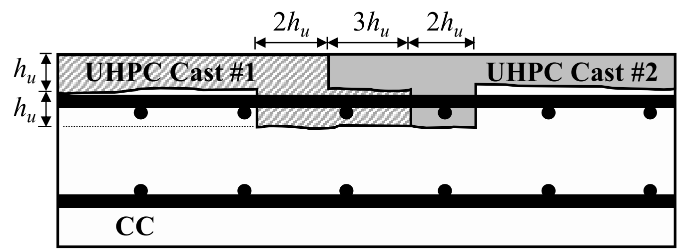
- Depending on the flexibility of the bridge and the type of traffic loading, there can be concern about allowing live traffic adjacent to the casting of UHPC overlays. However, it is not always possible to restrict traffic during casting on high traffic volume bridges or bridges requiring extensive detours. One project only closed traffic in the lane immediately next to the UHPC overlay during casting. Another project closed traffic on the bridge during casting but opened the lanes adjacent to the UHPC overlay cast back to traffic within 36 hours after casting. Neither project saw any cracking, issues with bonding of the overlay to the substrate, or fiber settlement due to the vibrations caused by traffic in adjacent lanes.
- Construction surveys should be used for each interim stage in the hydromilling and UHPC placement process. Acceptance criteria for the desired profile at different stages can be included in the plans.

Construction Joints

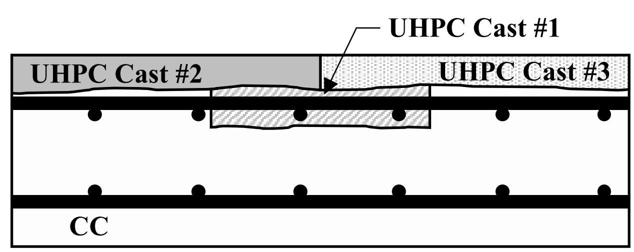
Construction joints can be used to divide the placement of UHPC overlays as needed based on mixing output rates, placement equipment being used, traffic management plans, etc. Construction joints are often required in the longitudinal direction. One owner tried to place these joints away from the typical wheel path in the lanes, since these joints may be more susceptible to localized failure than the rest of the overlay.

Two different general construction joint details are shown in Figure 10. The detail that has been most frequently used to date in the U.S. is shown in Figure 10 (a). This detail is based on a detail the Swiss have promoted in their document SIA 2052 [5]. The detail includes a larger overlay thickness in the joint region. A portion of the first UHPC overlay cast needs to be underneath a portion of the second UHPC overlay cast. One owner that previously used this joint detail commented that the joint can be difficult to form and there can be challenges related to achieving good consolidation of the thixotropic UHPC mixture around the reinforcement and in the underlying portion shown in UHPC Cast #1.

The second detail shown in Figure 10 (b) is starting to be used for UHPC overlays in Switzerland [6] because of its easier fabrication than the first detail. This detail has the same general geometry as the detail described above but has a first UHPC cast in the deeper portion of the joint underneath the two overlay casts. This first UHPC cast can use a more fluid UHPC mixture than the overlay, which helps with the consolidation around the reinforcement. The two UHPC overlay casts have a butt joint between them. This joint is relatively new so there is no data on its long-term performance. However, the detail is expected to offer a similar performance to the detail shown in Figure 10 (a).



(a)



(b)

Source: FHWA.

Figure 10. Illustration. Examples of construction joint details: (a) proposed in SIA 2052 [5] and (b) emerging detail from Switzerland [6].

Both construction joint details require an exposed fiber finish on the UHPC-to-UHPC interfaces. One owner had specified on one project that this could be done by either using a paste set retarder and pressure washer or sandblasting the surface afterwards. The contractor tried both ways and found that using the paste set retarder and pressure washer resulted in a surface with exposed fibers. The sandblasting to create an acceptable surface finish was difficult on the hardened UHPC even just 24 hours after casting.

Formwork

Formwork used for construction joints should be constructed with a nonabsorbent finish so the formwork does not pull moisture from the UHPC. Plywood products with resin coatings have been found to be the most effective. Oiled plywood is not fully non-absorbent and should not be used. Formwork also needs to be designed and installed to be watertight and able to withstand the hydrostatic pressure of UHPC. The strength and tightness of the formwork can be validated during the mockup.

Headers

UHPC headers can also be utilized to reduce the number of materials used in the rehabilitation. A partial depth of the header can be removed, exposing the top mat of reinforcement and ties in the header. All unsound concrete should be removed during this process. New joint armoring elements with the armoring anchorage embedded in the UHPC header can be installed at this time as well. Some states are installing UHPC headers without the armoring angle and seeing good performance to date; elimination of the armoring angle simplifies construction and may enhance the longevity of the header.

UHPC Finishing (Curing, Grinding, and Grooving)

Proper curing of a UHPC overlay is essential to its long-term performance. UHPC mixes tend to include a very low water-to-cementitious materials ratio; therefore, it is essential to retain the mixing water within the UHPC and not lose it through evaporation. There are several spray-applied curing compounds that have been observed to facilitate good performance of the freshly placed UHPC. Curing compounds should be applied as soon as possible to the placed overlay; this can be done a few feet behind the paving equipment based on reach of the applicator or a time period not to exceed 5 minutes after placement.

A combination of curing compound and plastic sheeting can be used to achieve proper curing of the overlay. If plastic sheeting is used, it is important to minimize the contact of it with the overlay surface. Contact with the overlay surface will lead to impressions in the surface (i.e., “wrinkles”) potentially then leading to cracks; however, small impressions might not be a concern if the surface will ultimately be ground and grooved. It is also important to ensure the plastic sheeting is sufficiently secured so as not to move when subjected to windy conditions. One project experienced dehydration and cracking of the UHPC when plastic sheeting was blown off the overlay by windy conditions. Airborne plastic sheeting can also pose a safety concern to nearby live traffic.

Proper curing of the overlay can be achieved using a sufficient amount of the curing compound alone. Using only curing compound is preferred as it eliminates the challenges associated with the plastic sheeting. An example of the UHPC overlay surface after the application of a curing compound is shown in Figure 11 (a), where the curing compound was applied using two sprayers from the back of the paving equipment. An example of a UHPC overlay mockup with the curing compound being applied is shown in Figure 11 (b). Plastic sheeting may still be required in cold weather concrete conditions. At least one project was performed in cold weather, and plastic sheets and heat blankets were required to retain the heat produced by the UHPC during its initial hydration.

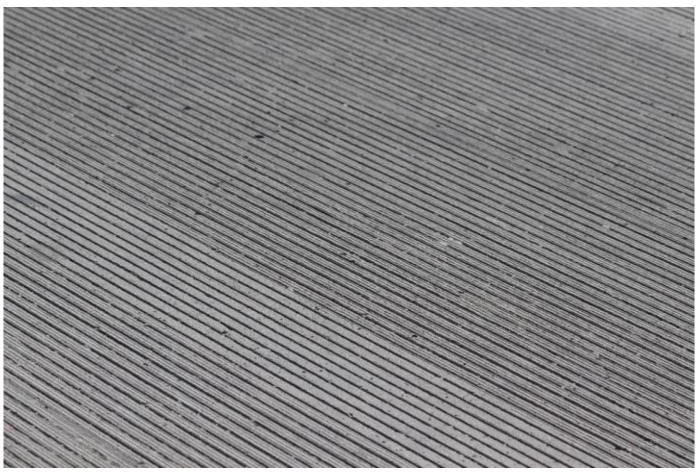
(a) (b)

Source: FHWA.

Figure 11. Photograph. (a) Example of an overlay after a white-colored curing compound was sprayed on the surface of the freshly placed UHPC and (b) white curing compound application on mockup slab.

Curing will be more critical in climates with low relative humidity and when there is sustained wind. It is important to apply a sufficient amount of curing compound as soon as possible to the placed overlay in these cases. Small plastic shrinkage cracks have been observed on some projects, but when sufficient curing is promptly applied, these cracks are rare and do not penetrate deep into the overlay, allowing them to be removed during the grinding phase. Curing methods can be evaluated in the mockup or pilot phase.

Grooving is required to provide the necessary skid resistance. Grinding may also be required to obtain the desired bridge profile. While some suppliers may recommend only grooving and no grinding, grinding will help to improve the rideability and remove some air voids that may be present at the surface. Proper equipment should be used for the grinding process; hand grinding will be very labor intensive for UHPC. One contractor had success by overfilling the deck by $^{3}/_{8}$ inch. They did one pass of bump grinding to remove $^{1}/_{8}$ inch, which removed small undulations. Then they used a profilograph to see high and low points and did a second pass at around $^{1}/_{4}$-inch depth to get the final profile. An example of the finished riding surface after grinding and grooving is shown in Figure 12.



Source: FHWA.
Figure 12. Photograph. Example of a finished riding surface after grinding and grooving.

Specialized grinding equipment is available for attachment to a skid steer to help grind along the curb line. Conventional grinding and grooving equipment can typically be used, but cutting heads will typically wear out faster on the UHPC compared to conventional concrete. There are different cutting heads available for concrete with harder quartz aggregates; if available, these will work better than cutting heads used for concrete with softer limestone aggregates. Additionally, hoses with smooth interior linings may be needed for pumping the recovered slurry, and more water than normal may be required to prevent fibers from clumping in the hose. One owner who had used $^{1}/_{4}$-inch overpours on previous projects plans to increase the overpour and grinding depth to $^{1}/_{2}$ inch to remove more surface defects during the grinding process.

An asphalt overlay can be used on top of a UHPC overlay in place of the grinding and grooving procedure. This was done by one owner on several projects, although the owner was planning to use the UHPC overlay as the riding surface for future projects whenever the bridge profile allowed for it. Leaving the UHPC overlay as the riding surface also allows for easier inspection and evaluation of the overlay condition in the future.

Lastly, a frequent question on UHPC overlays is what happens to the exposed fibers after grinding. The exposed portions of the fibers rust away, but the corrosion ceases at the face of the UHPC. It also takes a couple years to fully progress. An example is shown in Figure 13 of a 6-year-old UHPC overlay showing the brownish hue of the deck not unlike aged conventional concrete. An inset is also provided in the figure showing a close-up view of the ground UHPC surface showing the individualized rusted fibers.

Source: FHWA.
Figure 13. Photograph. Example of a finished riding surface after grinding and grooving.

UHPC Removal and Repair

Different size repairs were required on some of the projects. Some of the repairs that were required include:

- Filling air voids,
- Epoxy injection of cracking from improper curing,

- Removal of fiber balls and casting of new UHPC, and
- Removal and recasting of UHPC damaged by events after construction.

Small voids or cracks can be filled with a UHPC slurry (i.e., UHPC without fibers), epoxy, or other proprietary repair materials. When needed (e.g., to remove fiber balls), portions of the UHPC overlay can be removed using grinders or a hydromilling hand lance and then repaired with new UHPC.

A large patch of overlay needed to be repaired on one project due to fire damage from a truck that stalled and caught fire. The contractor was able to grind out the damaged area to a 1-inch depth using a grinder attachment on a skid steer and then recast the UHPC.

Conclusions

This technical brief summarized the experience and lessons learned from four different owners who have implemented UHPC overlays on projects with different characteristics and scales. In general, UHPC overlays have been successfully installed by several states on a variety of projects and at different scales. Experiences over the past eight years in the U.S. indicate that this bridge deck rehabilitation solution can offer benefits to extend the life of bridge decks.

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