MATERIAL PARAMETERS AND DIGITALLY INFORMED FABRICATION OF TEXTURED METALS

ABSTRACT

The research represented in this paper proposes to reinvestigate the relationship between structure and appearance through a performative analysis of textured stainless steel, as verified through full-scale prototyping. The work takes a scientific design approach while incorporating a computational workflow that is informed by the material’s physical parameters, and draws a connection between the scales of molecular composition to large-scale geometric systems. Furthermore, the work attempts to provide evidence for thin-gauge textured metals as a high performance and adaptive material, by identifying structural rigidity and particular specular quality as inherent characteristics born from the texturing process. In addition, through close collaboration with the sponsoring manufacturer of textured stainless steel, we are able to gain access to material expertise and large-scale fabrication equipment not readily available to designers, thereby forging a mutually beneficial relationship surrounding the research.

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1 Project 2xM T - rigidized metals pattern samples
INTRODUCTION

Beyond the well-established digital, computational, or manual design methods that have worked to integrate manufacturing and fabrication into architectural practice and research, is direct exposure to specialized processes of working with materials that is otherwise unavailable to most practitioners and academics (Kieran, Timberlake, 2004). This kind of knowledge share of proficiencies between designers and material experts allows academic research to move off-campus by incorporating real-world contingencies, and in the process, broadens the computational capabilities of the manufacturing facility with the hope of expanding the scope and marketability of their products. When this relationship is symbiotic, huge opportunities arise for both parties to develop new expertise and experiment with a given material through full-scale prototyping and implementation.

This text introduces an ongoing research collaboration between the authors and the Rigidized Metals Corporation that is attempting to examine the performative potential of deep-textured metals, namely stainless steel, by reinforcing the relationship between structure and appearance. This relationship is made direct through the rigidizing process that will be described in more detail in the coming paragraphs (Figure 1). The material study is scientifically empirical; a nod to Viollet-Le-Duc who laid a foundation for scientific analysis and enthusiastic use of industrially produced materials with the intention to exploit their inherent qualities (Heam, 1990). Following this tradition, the intention is to submit our current research regarding the discovery and architectural application of innate material performances of textured stainless steel, and to provide some qualitative data about the material itself.

MATERIAL CONDITIONING AND DESIGN WORKFLOW

Since 1940 the Rigidized Metals Corporation based in Buffalo, NY has been one of the world leaders in the development and production of textured metals used in architectural, industrial, and transportation applications. The value-adding process of texturing (rigidizing) ordinary sheet metals increases the cross-sectional depth of thin gauges by distributing metal above and below the neutral axis, resulting in a much stronger and stiffer material (Figure 2). This cold-forming process is the result of work-hardening, which is also commonly defined in the scientific world as plastic deformation (Figure 3). At a molecular scale, plastic deformation breaks the inner atomic bonds and rearranges the atoms within a solid material. This irreversible deformation is carried out by defects called dislocations. Before work-hardening, the atomic lattice of the material exhibits a regular, nearly defect-free pattern. Post work-hardening, the material becomes saturated with dislocations, the more of which produces interaction and entanglement between them, resulting in a decrease of the mobility...
of future dislocations and a strengthening of the material (Figure 4). In mathematical terms, increasing the number of dislocations is a quantification of work-hardening, leading to an increase in yield strength (Degarmo et al., 2003).

Another advantage resulting from the added strength of the rigidizing process is “down-gauging” that generally results in thinner, lighter surfaces and a more economical use of the material when compared to “plain stainless”. In addition to the corrosion resistance (allowing experimentation with long-term exterior applications), we believe the luster of the material combined with the geometric pattern found in the texture is the most intriguing material characteristic and one that has not been previously studied or exploited. Once textured, the surface appearance is never static, and through a combination of light diffusion and specular reflection, activates the surface with varying intensities of color, brightness, shadow and depth; all variables of the distance/location of the observer and daily/seasonal weather conditions. This specular effect along with the conceit that the rigidizing process is unique only to metal and cannot be separated from its inherent characteristics, frames the approach to the research. To summarize, both specular quality and surface rigidity result from the same geometric conditioning and molecular composition, before the material is re-worked into architectural forms/shapes. This process identifies the very character of rigidized stainless steel that makes it a “high performance material”; one that does not change its properties but has “selected and designed” properties exhibiting extremely high strength or stiffness [and] particular reflectivity, both seen as optimized properties via the use of internal material structures or compositions (Addington, Shodek, 2005). The process also identifies the first “scale” within the proposed part-to-whole relationship governing the design of the research proposals (Figure 5).

STRUCTURAL AND AESTHETIC POTENCY

Thus far we have worked under the general assumption that in panelized assemblies, material + form = structure. We propose creating a more comprehensive part-to-whole relationship, one that includes texture as part of the tectonic equation. Texture in our equation adds a great deal of structural capacity and overall dimensional rigidity due to its pattern depth and pattern geometry. We are currently in the process of developing metrics that begin to quantify the rigidity, strength, and specular quality of a particular pattern and hope to use this data as a way to calibrate future design proposals (Figure 6). In addition, we are exploring the idea of texture/pattern at a range of scales. At every scale there is a relationship to both physical and visual performance. That is to say at each scale, both scenarios are amplified, rigidity is added to the system and the specular effects are enhanced. While a more typical use of the material is in non-structural façade elements or interior panels backed by substrates, the intention of the current project 2xlnT - texture is understood as a performative “scale” in the part-to-whole relationship.

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5 Project 2xlnT - texture is understood as a performative “scale” in the part-to-whole relationship.

TEXTURED METALS
Project 2XMt - three-point load testing of pattern, grain direction, and gauge of rigidized metals

Project 2XMt - 'Karamba' structural analysis revealing areas of maximum strain

Project 2XMt - load testing of full-scale mockup
design schemes is to develop self-supporting architectural systems that make evident the existing but underutilized structural potential of the material while exhibiting the specular quality of the texture. As previously mentioned, one of the underlining interests of the research is to directly link structure and appearance; a goal that has been exemplified by both Le-Duc and Semper, who respectively championed the expression of material through functional efficiency and drew principles from systems, structures and manufacturing techniques as the basis for external appearance (Moussavi, 2009). This is a powerful idea with respect to the rigidizing process, since functional efficiency, material expression, and external appearance are very much interrelated, allowing a single material to accommodate a range of architectural goals. Perhaps more important to the research at hand, is the visibility of structural capacity through geometric patterning. Because the pattern is embossed into the steel (thereby adjusting its molecular composition), the aesthetic visual result is the structural capacity. At the same time, the material is very thin and relatively lightweight, requesting it be worked into forms or assemblies that allow it to resist bending moments. In doing so, the overall perception of structural capacity of textured sheet steel is expanded into the design of the assemblage, where depth and orientation produce shadow and controlled specular reflection in addition to strength. In other words, sheet metal folds are complimented and strengthened by the rigid and textured surfaces between them. What is made clear is that the rigidizing process simultaneously creates a visual and structural potency, making large scale thin-gauge assemblages possible (Picon, 2003).

To elaborate on the connection between molecular composition and performance of the material, we can look toward Buckminster Fuller’s notion that structure is “not a thing – it is not a solid.” Fuller notes that architecture is an “assemblage of visible modular structures out of subvisible modular structures”, suggesting that the principles describing structure operate at the molecular level within the material in a pattern “inherently associative within the local regenerative dynamics of chemical structure” (Fuller 68, 1965). Here we find inspiration and align our research to the relationship between the visible and subvisible modules by suggesting that the results of the work-hardening process (subvisible), in concert with designed forms with architectural purpose (visible) is a reflection and appreciation of these concepts (Figure 7). For example, the textures resulting from the rigidizing process play an important role in the part-to-whole relationship, since they determine the rigidity of the parts that are combined to perform as the whole. It is also worth noting a particular alignment of our attitude towards rigidized stainless steel as an “adaptive material” using
similar terms that could otherwise describe the subtle shape-shifting behavior of wood veneers when exposed to moisture. In both cases, the visible structures (grain direction, scale, physical parameters) are subject to external conditions (moisture, sunlight, etc.), and respond based on the subvisible makeup of the material (molecular composition). On one hand, the response is exhibited as a tropism, while on the other, as structural and visual potency.

TESTING AND PROTOTYPING

Tacit knowledge of fabricators which is often times unwritten, is a form of materials science through empirical study, that is to say, years of first-hand experience. Exposure to this level of expertise through collaboration, coupled with technical information of the material documented a-priori, informs our design proposals based on the expectation of how the material may react under various environmental conditions and during fabrication/assembly (tolerances resulting from the material’s reaction to machine fabrication processes, such as bend radii and material stretching). These expectations or “informed best guesses” filter into the digital design process and are substantiated through full-scale prototyping of our own, before the stainless steel mock-ups are started by the fabricator (Figure 8). In short, knowing what a material may be capable of is part and parcel to an understanding for how it reacts under certain conditions. This thought process influences our material research at every level, from on-screen computation to decisions relating to on-site implementation, and is paramount to the coordination of hundreds of unique bend angles, unit dimensions, and gauge changes all of which require a near-zero tolerance.

Current design schemes are attempting to utilize un-backed, un-framed (self-supported), thin-gauge rigidized stainless steel within vertical, free-standing architectural screens. These systems are mono-material, consisting entirely of stainless steel (including the hardware/tension cables) and consider this to be critical to the clarity of the research and necessary to accurately pinpoint and analyze material behavior. Through texturing and purposefully aggressive folded geometries, loads are transferred through seemingly paper-thin surfaces, an ambitious approach to using sheet materials vertically and without the assistance of linear frameworks. Two schemes are currently in development and at different levels of completion, one of which (project 2XmT) will be described here. Each scheme intends to test the material in a specific and observable manner. In both cases, the textural (stiffening) pattern geometry is complemented by a global geometry of precise folds. Structural capacity continues to scale up where clusters emerge to carry compressive loads along a global geometric trajectory (Figure 9).

An early and inspirational example leading up to the development of project 2XmT, Muqarnas domes utilize a system of mathematical rules governed by a repetition of geometrical figures to produce load-carrying and ornamental surfaces. In this scheme, a base geometric scaffold of octahedrons is designed to accept parametric variations before the actual geometry of the system is applied. This allows for mathematic coordination of the panel orientation that when viewed from the west, creates an illusionary orthographic projection of the surface depth, since the degree of rotation is related to the panel dimensions. In addition, the
system becomes gradually thinner toward the top to reduce the overall dead-load and material quantities. The gradual widening of the base scaffold throws the interconnected diamond shaped panels out of plane. When relieved of their parabolic curvature, the flat panels conform to a subtle diagonal twist toward the south, and reveal much deeper pockets and potential openings toward the north. Here, the logic is that the amount of specular quality helps determine where the structural responsibility should be located – thicker gauges and deeper textures are placed in areas where the load is considered highest. The idea is to highlight the performance of the metal in compression and to animate the surfaces by developing nuanced variations in light reflectance by mixing in complimentary textures (Figure 10). The scheme is further developed along these lines, where unit family types are determined by way of gauge thickness, structural role, and texture. The more deeply pocketed areas within the folds are placed between continuous (shingled) diagonal surfaces that perform as an exterior cross bracing. These units are stitched together from front to back, as are the more aggressively textured panels that connect the coursings of diagonal surfaces. The diagonal elements are the most visually dominate while taking on the responsibility of handling the majority of the load transfer. Here, the structural capacity of the material is put to the test, and has been noted in the load tests of our mock-ups to be the areas of possible buckling (Figure 11). This scheme is currently being fabricated and will be assembled on-site a few weeks following the completion of this paper.

CONCLUSION

Our research proposal has one over-arching goal which is the synthesis of structural performance and appearance; examined at a range of scales from the molecular composition of a material to large scale geometric/formal organizations. In late summer 2013, the research will culminate in the implementation of two self-structuring, stainless steel prototypes (measuring 25'-0" wide x 20'-0" high) to be permanently installed on the grounds of Silo City, a dense collection of historic grain elevators along Buffalo’s waterfront. This siting will enable the team to observe the proposed performative capabilities of the material and designed systems through harsh weather conditions such as strong prevailing winds (due to the site’s adjacency to Lake Erie) and the diffusion of sunlight that activates the surface textures at a varying range of viewing distances, speeds, and cloud conditions. In addition, these prototypes will be useful in framing future material research and allow us to reconnect the designers to the makers: the manufacturer, the material scientist, the product engineer and to seek out material expertise in the region.

ENDNOTES

1 Martin Bressani, in his article entitled “Viollet-Le-Duc’s Optic”, describes the way Le-Duc “envisaged his work as science in his Dictionnaire raisonné de l’architecture francaise which served as a foundation for scientific approach in architecture. Bressani also reminds us that Le-Duc explains his intention to explore medieval architecture like an anatomist examining the human body, providing a ‘structural physiology’ of the cathedral.
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