METALMORPHASIS: CHANGE AND TRANSITION

Thomas E. Prucha

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Abstract

Change is constant, as nothing stays the same. Consider the words of the Chinese philosopher Lao Tzu, “Life is a series of natural and spontaneous changes. Don’t resist them—that only creates sorrow. Let reality be reality. Let things flow naturally forward in whatever way they like.” Some changes are the result of biology and the passage of time, within the natural cycle or order of things. Others are self-generated, under our own control and resulting from willful efforts, or dependent upon encounters with significant others—family, friends, colleagues, and others close to us. Still, other changes occur because of circumstance or fate, a proverbial “date with destiny” and often beyond what we feel is our control. Whether it is our personal life

or occupational, like metalcasting, this change can facilitate transition and transformation. I have coined the term metalmorphosis and this lecture as reflection of how to embrace change, recognize the opportunities presented and utilize it as a vehicle for new beginnings. This is not just philosophical but also a look how we as metallurgist and metalcasters apply and control input variables (time, temperature, pressure, chemical reactions, etc.) to transform metals and create metalmorphosis.

Keywords: change, transformation, transition

Introduction

Change is constant, as nothing stays the same. Consider the words of the Chinese philosopher Lao Tzu, “Life is a series of natural and spontaneous changes. Don’t resist them—that only creates sorrow. Let reality be reality. Let things flow naturally forward in whatever way they like*.”

Some changes are the result of biology and the passage of time, within the natural cycle or order of things. Others are self-generated, under our own control and resulting from willful efforts, or dependent upon encounters with significant others—family, friends, colleagues, and others close to us. Still, other changes occur because of circumstance or fate, a proverbial “date with destiny” and often beyond what we feel is our control. Whether it is our personal life or occupational, like metalcasting, this change can facilitate transition and transformation. I have coined the term

metalmorphosis and this lecture as a reflection on how to embrace change, recognize the opportunities presented and then utilize it as a vehicle for new beginnings. This is not just a philosophical dissertation, but also a look how we as metallurgist and metalcasters practice the application and control of input variables (time, temperature, pressure, chemical ingredients, reactions, etc.) to change and transform metals, creating a metalmorphosis.

The Personal Nature of Change

The world is in a constant state of flux. Whether we recognize it or not, everything around us is changing. Our experiences with this can be externally or internally focused; that might follow a linear pattern, regulated by chronology of time, space, and the social structure, or transcend ordinary time and emerge from the depths of our psyches and our own internal strivings. While these changes may be subtle and gradual, easy, and welcomed, or difficult and demanding; we are presented the option to meet them with acceptance and grace, or with protest, denial, and resistance (Figure 1).²

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* Based upon the Hoyt Lecture given during the 125th AFS Metalcasting Congress, published in 2021 AFS Transactions.¹

Figure 1. Open ² source image—metamorphosis.

The personal significance that each change has upon us occurs when we decide to make something from what is offered. This means we move from the passive state of just watching how things unfold to taking some action that enables us to utilize what unfolds to create an outcome of our own making. Shifting our focus from what happens (the events themselves) to what we do with what happens is another way to describe transition. Ultimately, how we embrace change is our own personal choice and responsibility.²

The danger of going through this phase without allowing ourselves to truly experience it, is that transition and transformation through change may not actually occur. If we are too uncomfortable to stay the course through transition, become too anxious to fix the problem, we may ultimately lose the message and its accompanying transformative effect. Change without transition may only serve to recreate old scenarios and reinforce old patterns of behavior. For change to have a meaningful and beneficial effect upon us, we need to learn to effectively work with it and not to run the other way when it presents itself.

Metallurgy, Metalcasting, Metalmorphosis

Taking metals and elements from the earth, combining, and subjecting them to extreme heat, changing that mixture from solids to a liquid, and then directing the molten mass into cavities that contain its transformation into new shapes and forms, this is the essence why those involved with the foundry industry are true agents of change. As I mentioned, as metallurgist and metalcasters, we also apply numerous input variables (time, temperature, pressure, chemical reactions, etc.) to try to intelligently control this change

and transform metals, creating what I term as a ‘metalmorphosis’. Sometime this effort is the result of insights gained from a series of planned and carefully conducted experiments, where these variables are controlled and varied in a methodical approach to obtain observable and quantifiable outcomes. This can then lead to better understanding of the nature of these changes, the mechanisms and kinetics and thus the development of new algorithms and predictive models. Other times we are presented with what can be considered unintended outcomes—serendipity—in discovering and advancing new technology. I feel it is appropriate to briefly look at some examples of these technological developments that were a result of both planned and unplanned circumstances.

The Role of Serendipity

The first example is the basis for invention of ductile iron conducted almost 80 years ago in 1942. Note, this did not start out as an effort to develop treatment techniques to produce a new type of cast iron with its graphite solidifying in the form of spheroids (Figure 2).³ Rather it was research conducted at the INCO (International Nickel Company) labs in New Jersey at the start of WW2 out of availability concerns to find replacement alloying elements for Cr in Ni-Hard irons by the additions of various carbide stabilizers. As Keith Millis, one of the young investigators and co-founders recounted, after a less than exhaustive literature review of elements that could form carbides with C, they decided on series of heats that included additions of Cr (chromium), Zr (zirconium), Bi (bismuth), Ce (cerium), Cu (copper), Pb (lead), Te (tellurium), Mg (magnesium) and Cb (columbium). Ignoring the advice of his co-researcher, Albert Gagnebin, and warnings about incompatibility of Mg in molten iron, the test heat was made with the Mg addition which resulted in significant violent flaring. Thinking this approach of Mg addition was useless, Millis had the metal poured off and tagged with the notation in his 13 February 1942 lab book that the sample was “...tough to break, surface rather crappy.” The tagged sample was not sectioned at that time but was catalogued and stored. While the depth of chill was noted as was the ability for Mg to effectively reduce the S content, it was not until January 1946 when Millis, out of curiosity, got that chill block out of storage, polished it, and discovered that the graphite formed in the top half was spheroidal in appearance. This and other work conducted by INCO at Jamestown Foundry resulted in the INCO patents and the dramatic announcement by T. H. Wickenden (INCO) of their developments of a Mg treatment for production of an as-cast spheroidal graphite iron during the Question and Answer session at the end of Henton Morrogh’s (BCIRA—British Cast Iron Research Association) 1948 AFA (American Foundry Association) Casting Congress presentation “Production of Nodular Graphitic Structure in Gray Cast Irons” concerning the use of cerium to create

Figure 2. Ductile iron spheroid.³

graphite nodules. Except for that fortunate turn of events when Keith Millis first added magnesium to a bath of molten iron back in 1942, and the subsequent curiosity he displayed, who could have predicted that the incredible reaction that took place would reverberate to this day.

I also recall another similar experience and discussion, also relating to ductile iron, that I had with Brian Turner, Parkfield Foundries, Stockton, England, who was the father of Andrew Turner, WFO General Secretariat, about his initial discovery of in-mold ductile treatment with co-inventor Cliff Dunks, Materials and Methods, Surrey,

England (Figure 3).⁴ At the time, I was a young metallurgist implementing the relatively new in-mold treatment technique at the CMI International Cast South greenfield foundry in Marion, Alabama and Brian was visiting us. He told me the story of how Cliff was up at his foundry trying a new Mg-FeSi treatment alloy. They were doing some playing around at the end of the shift before heading off to the pub for a few pints, and they decided to put some of the finer sized alloy into a pocket hand carved into the drag

Figure 3. Test casting for in-mold, C dunks AFS 74-84.⁴

runner of a sand mold and ‘see what happened’. The resultant high nodule count and carbide-free structure in the casting produced surprised them both. Cliff quickly called back to Surrey about these unexpected results and his bosses at M&M replied, ‘stop everything, till we can file a patent.’

So, are these technological advances the result of carefully planned and researched experiments or just plain luck? From my observations, while serendipity can often involve what is often called luck, it differs in that the unintended consequences are not just stumbled upon but the result of identifying and utilizing that unplanned benefit. In the case of metallurgy, it might sometimes require becoming a ‘scientific serendipitist’ which I define as “one who finds technically valuable or beneficial things not sought for.”

The Power of Metallurgical Transformations

The application of heat and time to change the structure and the resultant properties of a product after the ‘die is cast’, is a method that has been applied to metals that have been cast, forged and otherwise manufactured for millennium. This forms the basis of what we call heat treatment. It is one of those extraordinary aspects where change can be obtained via the rearrangement of atoms and the exact nature of that transition can result in unique and remarkable transformations. How this process is controlled allows for chemical elements to be taken into and out of solution, precipitates to be dissolved or formed, phases to be eliminated or created, their shapes to be changed, and all this and more through the power of these metallurgical transformations.

As with many of those who have received AFS Gold Medals or Awards of Scientific Merit, this year’s recipient of the John Whiting Gold Medal, Kathy L. Hayrynen, has spent her career first at Michigan Tech and then at Applied Process, investigating, understanding, applying and controlling the variables of chemistry, temperature, time, rate of cooling and understanding metallurgy to advance and iso-thermally transform the morphology of the microstructure that forms in this ductile cast iron into a highly engineered material, Austempered Ductile Iron. The basic concepts of heating a ferrous carbon containing metal into the austenitic region to allow the matrix to transform to austenite, cooling it rapidly enough to avoid pearlite formation but also to stop the cooling before martensite forms, and then to austemper that matrix at an iso-thermal temperature in a media to allow for its complete transformation into the desired final microstructure was generally known, but not completely understood (Figure 4).⁵ To then throw into the mix a cast iron material like ductile iron with its variations in chemistry, nodule count, alloying elements, and starting matrix structure and the result was almost mysterious. As Kathy told me when she started graduate

Figure 4. A schematic of austempering process.⁵

school, that while components were being produced in ADI for the past 10–15 years, no one exactly knew what to call what they saw in the structure. How to characterize or identify it, aka name it, at the various steps and then accepting precise terms for the morphology of the end products were needing agreement.

But by applied research, careful control, and application of metallurgical principles our industry has been able to double and triple the strengths obtained from these alloys while still maintaining toughness and ductility, creating custom engineered microstructures with numerous grades and international specifications (Figure 5).⁶ This has then opened new markets available to casters and provided the casting user community an expanded array of options not even envisioned those 80 years ago to help make products lighter and stronger through the use of this family of cast metals

But even as the base metal reaches a level of maturity, the investigations, understanding, learning and advancement continues. You just need to look at the recent number of

Figure 5. Fracture toughness and yield strength values of nodular cast irons, indicating the excellent combination of mechanical properties of the ADI grades.⁶

papers and issues dedicated to cast iron in the IJMC (International Journal of Metalcasting), like the Carl Loper Cast Iron Symposium issue and the Keith Millis Symposium focus section from last year, to see that change and growth comes from investigation, discussion, and technology transfer.

Transformational and Disruptive Change

Change, transition, and transformation is not just relegated to metals development when looking at our industry. Many advancements have been made in how we convert and cast that molten metal into functioning, sellable and near net shaped products. Lost foam casting, semi-solid metal, squeeze casting, ablation and vacuum die casting are but just a few examples that come to mind.

I would like to relate my personal experiences with cast aluminum and implementing some unique manufacturing processes. Back in the late 1960's most automotive and truck powertrain components like intake manifolds, cylinder heads and blocks, water pumps, etc. were made from gray cast iron. As I previously noted, often the agent of change is not always in our control but is often the result of external forces. We are seeing dramatic examples of that today with the COVID 19 global pandemic forcing changes in how we shop, work, attend school, vacation, celebrate events, and even virtually participate in conferences like this 125th Anniversary Metalcasting Congress and this Hoyt Memorial Lecture. Such was the dynamics during the oil embargo and energy crisis in the 1970's (Figure 6).⁷ This event spawned the need for improved gas mileage and lighter weight vehicles. My former boss Ray Witt saw this as an opportunity. While replacement of these gray cast iron parts was not considered an engineering stretch, as some of the early automotive components were made from cast aluminum, their production in the large volumes, quality and cost demanded by the current automotive industry was a

Figure 6. 1970's oil crisis.⁷

challenge. Some of the internal OEM's own efforts involved producing multiple die cast parts and welding them together. Ray thought that this approach was cumbersome and asked why not use high production green sand mold lines with silica sand like that being used for cast irons (Figure 7). Traditionally aluminum was cast in olivine sand. He also saw that this would require the production of high-volume complex sand cores and the potential application for the recently developed core process called phenolic urethane cold box, aka isocure, for blowing these needed complex cores instead of hot box shell.⁸ What resulted was the ability to produce not just hundreds or thousands of castings but millions of manifolds and cylinder heads in cast aluminum transforming our industry.

Ray also had a saying, "to be successful in business, you need to know when to put yourself out of business and recreate yourself". While vehicles had started to become lighter via conversions in the powertrain by the 1990's, the key potential for more weight savings involved un-sprung weight and its multiplying effect via applications in the demanding structural components used in chassis and suspension.

While not a larger player in ductile iron steering knuckle, control arm and suspension arm market, we observed there needed to be casting techniques to make these high integrity and safety critical parts in high volumes, reliably, repeatably, and cost effectively in cast aluminum. However, the barriers to overcome required that not just implementations of methods to controllably and repeatably cast these parts, but an integrated approach that included unique and focused product designs to account for the differences in elastic modulus, aka stiffness and strength between aluminum and ductile cast iron or steel (Figure 8), process modeling and tool design (Figure 9), melt handling, a new way of filling the mold cavity from below to avoid creation of oxides via counter filling techniques, controlled engineered die thermal management, and real-time x-ray inspection with automatic defect recognition. It

Figure 7. High production green sand line at CMI Industrias Fronterias making aluminum intakes.⁸

Figure 8. Designing for cast aluminium.⁸

Figure 9. Die thermal management in counter pressure casting of aluminum steering knuckle.⁹

cannot be understated the efforts needed to launch the new processes and inspection techniques for parts like the Ford Taurus/Sable steering knuckles, Chrysler NS mini-van front cross member, and the GM Chevrolet Impala/Malibu steering knuckles in cast aluminum (Figures 10, 11).^{8,9}

In the subsequent years, these applications saw broad use across car, SUV and truck platforms for these cast aluminum products dramatically increase and it is witness to power of change, transition and transformation have to a market segment.⁸

Fundamental Shifts—Changing Traditional Business Models

Probably no technology offers to be more transformative and potentially disruptive to our industry than that presented by additive manufacturing. What appears on the

Figure 10. Chrysler NS Min-van Al crosssmember.⁸

Figure 11. Cast aluminum steering knuckles.⁹

surface to just be another manufacturing approach for making a core, mold, pattern, etc., is proving to be an agent to fundamentally change how we interface and collaborate with customers and suppliers and how we do business. The traditional approach is a customer had an application and need for parts to create a component. These were defined is a series of blueprint drawings released to potential suppliers to review and submit quotes. The selected supplier would suggest changes to the drawings to reflect the capabilities and limitations of their manufacturing processes for things like draft (Figure 12),¹⁰ metal fluidity, need for cores, etc. and the approved casting drawings converted into tooling. As I started in our industry this required a cadre of skilled trades people, patternmakers, who transformed the 2D drawing information into 3D tooling (Figures 13, 14).¹¹ With the introduction and widespread implementation of computers we embarked into a digital age, Industry 3.0, integrating hardware and software platforms where designs are generated entirely in 3D and the electronic information is transferred and the associated tooling created in computer numeric controlled machines. While some in our industry embraced this as an opportunity to have larger interface with customers, often using computer aided design, finite element analysis and process modeling tools to drive component design, their

Figure 12. Designing for draft.¹⁰

Figure 13. Traditional pattern shop.¹¹

Figure 14. Blueprint reading.¹¹

efforts were still constrained by those same limitations of the manufacturing processes selected.

It also still required an approach to create the tooling, either by hand, by CNC or a combination of methods to carve, form, machine, assembly, bench, and finish. This tooling also must be verified, sampled, approved, maintained, catalogued, and safely stored.

With additive manufacturing, cores, molds, and wax patterns can be produced, 3D printed, without the concerns of backdraft, draft angles, blind holes, and other features that would require multiple assembled pieces or overly complex tooling. It is also what is called a tooling-less technique (Figure 15).¹⁰

So why is this transformational? This technology not only opens-up the constraints on design flexibility to allow for improved component performance, efficiency, and lighter weight, shortened development and lead times and reduced cost, but it also is changing the dynamics of the customer-supplier interactions. This relationship change cannot be overestimated. It is what I like to call a “fundamental shift” in the nature of business.

I recently read an article which is a great example of this transformation. It was in the January 2021 issue of Additive Manufacturing about one of the leading companies in the implementation of 3D sand printing, Humtown Products (Figure 16).¹² They have been a business model innovator from their early days as they transitioned from being a conventional tooling shop making patterns and core boxes, to utilizing CNC machines to create tooling to making and delivering cores. They saw a need and determined that the best path forward was putting themselves out of the tooling business, which it has done since 1959, and into directly supplying the product of that tooling to

Figure 15. Designing for additive manufacturing.¹⁰

Figure 16. New 3D printing facility at Humtown¹²

foundry customers. While being only a few miles down the road from what became the first National Network Institute for Manufacturing Innovation, the additive manufacturing focused America Makes in Youngstown, Ohio, the Lamomhca family and employees became directly involved in the technology and the potential it offers for our industry and its customers. As is often the case for new technology implementation for smaller companies, this is not always easy and seamless. But they found the ability to work collaboratively, interface and partner with universities, like the University of Northern Iowa and their 3D printing efforts at the Cast Metals Center, and collaborative work sponsored by America Makes afforded them the ability to evaluate the technology and business case before committing significant capital. The result has been the next transformation into a company that now has a stand-alone facility dedicated to the technology with five 3D printers supplying sand cores and molds. While always being a service-based company from its inception, this transformation also has changed that business model from just supplying quality make-to-print product on-time and at good value. To take full advantage it required educating themselves and their customers, both the foundries and the end recipients of the castings, about what making a part designed for the manufacturing flexibility of 3D printing could be and the benefits they can bring. These products are not just substitutions for what was being produced in conventional tooling but entirely new designs that expand what was previously considered manufacturable.

Similar stories are playing out in numerous foundries, suppliers that previously only made tooling, printing service bureaus and even customers that are now implementing the technology. While this has been disruptive to some of the conventional supply chain approaches and manufacturing methods, it has also shown how casting is not only still relevant but the preferred approach opening the doors of opportunity. I leave you with this poem that I wrote back in 1992.

Changes

*Change; is it the beginning or the end?
Perhaps it is the answer that causes us to fear it.
As children we anticipated and welcomed our changes,
Till we realized they ushered us to the end of periods of our life.
Change brings a sense of uncertainty, chaos and anxiety,
Will things ever be the same again?
Then, do we really want them to be?
Even as we enjoy the comfort of the present,
The seeds of the metamorphosis take root.
Relationships, attitudes and the feelings we once felt were secure,
Become the object of endings, new beginnings and change.
Is it something we need to dread or regret,
Relegating our thoughts to memories of what has been?
Or, do we seize the moment and move forward,
Forging new directions for our life, careers and friendships?
But it also brings us the chances for growth.
As difficult as it may be to embrace,
We cannot deny or run from it.
The key is to understand that change will come,
And learn from the opportunities that it presents.*
T. Prucha
6-7-92

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