HIP Modeling and Design of Large Complex Shape Parts Close to the Size of the HIP Furnace Accounting Capsules Manufacturing Technology and their Movement Inside it During the Cycle

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Abstract. The size of the parts needed to be HIPed for critical applications, especially in nuclear, is growing and very often the HIP capsules become so large that they take not only the entire diameter of the HIP furnace, but almost all its volume. Often, these parts weigh thousands of pounds, do not have axial symmetry and cannot stand by themselves in the furnace requiring complex shape supporting frames. For such parts additional problems need to be solved in the HIP tooling design and HIP process itself due to: (1) difficulties in maintaining dimensional accuracy, (2) non-uniform temperature field inside the HIP during heating and ramping the pressure, (3) different mechanical properties in HIP capsule elements and (4) HIP capsule movement during deformation inside the supporting frame. HIP modeling allows to approach these problems. Several examples of the solutions allowing HIPing of complex shape non-symmetrical parts up to 70" in size are analyzed.

Introduction

The two major tasks for HIP of large parts are:

1. Densification to 100% and formation of properties. This is well understood, though requires substantial efforts in enhancing powder manufacturing, powder storage and handling, and pre-HIP processing.

2. Shape control to NNS during densification. This is provided through HIP process FEM modelling and capsule design and "freezing" of the powder tap density and PSD.

However, exceptional uniformity of temperature (10-25F) and isostatic pressure at the end of the HIP cycle is combined with a large non-uniformity (100-200F) at the ramp stage of it. Also, no (or very little) densification happens at the end of the hold temperature when the material is practically 100% dense, but initial deformation of the large cans with powder occurs in a non-uniform temperature field.

HIP of NNS Large Parts

The size of the NNS PM HIPed parts needed for critical applications is growing and very often the HIP capsules become so large that they take not only the entire diameter of the HIP furnace, but almost all its entire height. Very often, these parts are heavy, weigh thousands of pounds, do not have an axial symmetry and cannot stand by themselves in the furnace, requiring complex shape supporting frames (Fig. 1). This leads to the non-uniformity of the powder temperature at the most important stage of the HIP cycle when densification of powder and shape changes mostly occur, and deformation pattern is defined.

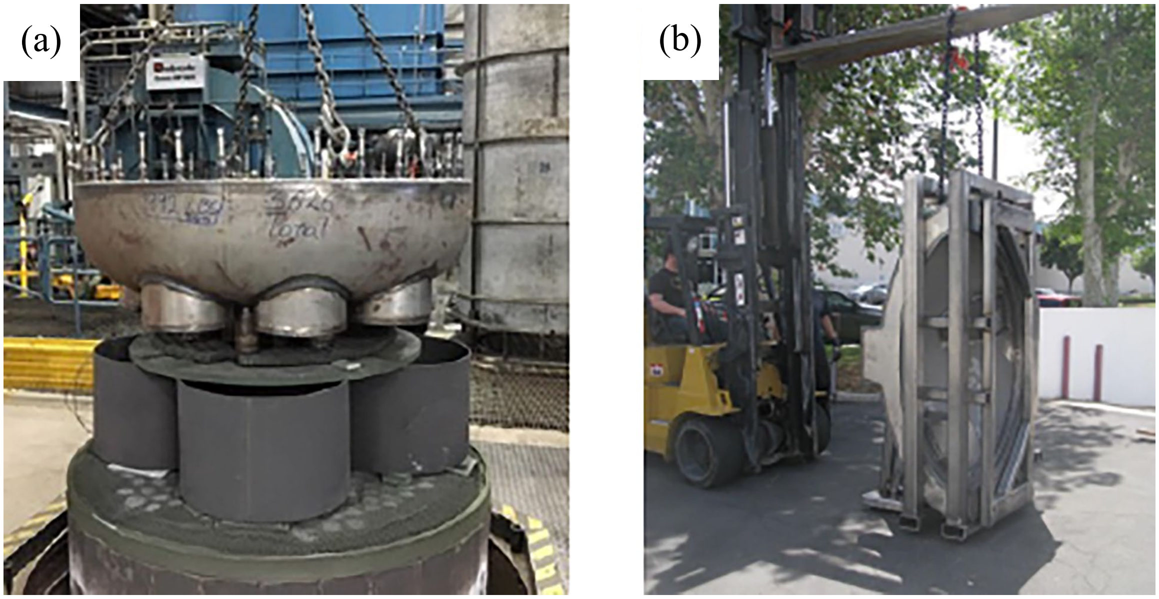

Figure 1. Large HIP capsules taking the entire (a) diameter and (b) volume of the HIP furnace.

Other stochastic technological factors and instability of the process parameters and material properties that can increase random geometrical scatter during HIP are:

- Mechanical properties of the steel sheet used for fabrication of capsule elements (chemical analysis, yield strength, thermo- mechanical processing, thickness).
- Powder variation in tap density / particle size distribution (PSD).
- Welding process, especially in hand welding (stiffness, distortions due to thermal stresses).
- Variations in the HIP cycle trajectory.
- The value of the powder tap density and its variations within the capsule. Need to "freeze" the parameters of atomization process.
- Location of a capsule in a HIP furnace may be important due to non-uniform radiation heating followed by preferential deformation of the areas getting hot first.

An important role of HIP Modeling is to help to determine the sensitivity of the final geometry to these parameters through multiple virtual HIP iterations and to provide the design of the capsule the least sensitive to these variations.

HIP tooling design is the core operation in the development of the NNS parts. Since HIP takes place in a freely plastically deformed tool that is not well supported by the densifying powder at the initial stages of HIP, when the yield strength of the capsule material is still relatively high, the balance of the stiffness of the capsule elements is essential. While the axial deformation (for the parts with a kind of axial symmetry) is like stable uni-axial densification, the radial deformation can lead to macro-bending and other macro-distortions, if the capsule is not properly balanced. At the later stages of HIP, when the powder material is partially densified and behaves as a compressible rigid plastic media, the deformation pattern becomes much more uniform, but the distortions introduced at the beginning of the process cannot be compensated and will progress. Sometimes, as will be shown below, the specific conditions of the capsule manufacturing require introduction of the gradient properties of the capsule material that are essential for the HIP deformation of large NNN parts. Therefore, the behavior of the HIP tooling at the beginning of the process has the greatest influence on the final shape and dimensions of the part. Any macro-non uniformity of the initial capsule is inherited further, can evolve and progress during HIP. Also, a capsule design must provide full and uniform filling with powder leaving no “pockets” or area of lower density.

Three Development Stories for HIP of Very Large Parts of SMR

1. 44% Top Head Development - Impact of the Capsule Manufacturing Technology.

The 44% Top Head (Fig. 2) is 51” Ø which is the max size that can fit in the existing largest US HIP (62” Ø) accounting the shrinkage of capsule with A 508 powder.

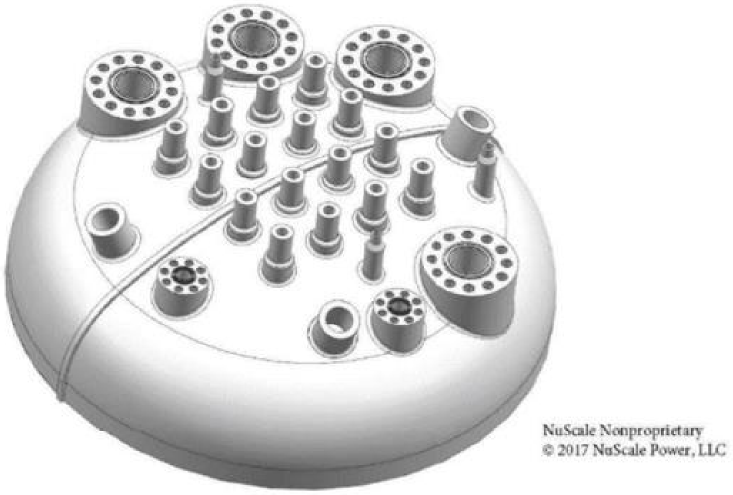

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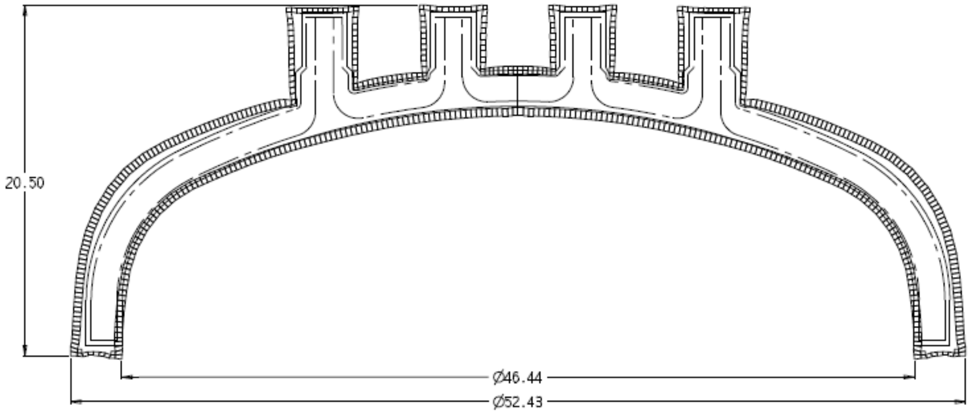
Figure 2. A508 Top Head of a SMR with integral nozzles

HIP modeling and design of the HIP tooling were based on the developed rheological properties for the capsule steel and A508 powder (Fig. 3).



Result of Simulation for Mild Steel Can: Cross-section 2 with Central Bosses

Figure 3. HIP modeling for the 44% Top Head providing a machinable blank.

Capsule elements were manufactured through several operations: die forming, spinning of the flanges, laser cutting, welding. The welded capsule can be seen in Fig. 4.

Figure 4. Welded capsule for 44% Top Head

As a result of HIP, the material was fully consolidated, but the periphery of the HIP can has not shrunk to the desired values (green) (Fig. 5). It has turned out that during cold spinning the material of the capsule flange has acquired substantial strain hardening that had not been accounted during modeling. As result, the flange had higher strength than the rest of the capsule, that had impacted the shrinkage. HIP modeling accounting the Strain Hardening of the Capsule Flange has confirmed the received dimensions. The new capsule material properties have been introduced into the data base for this type of capsules.

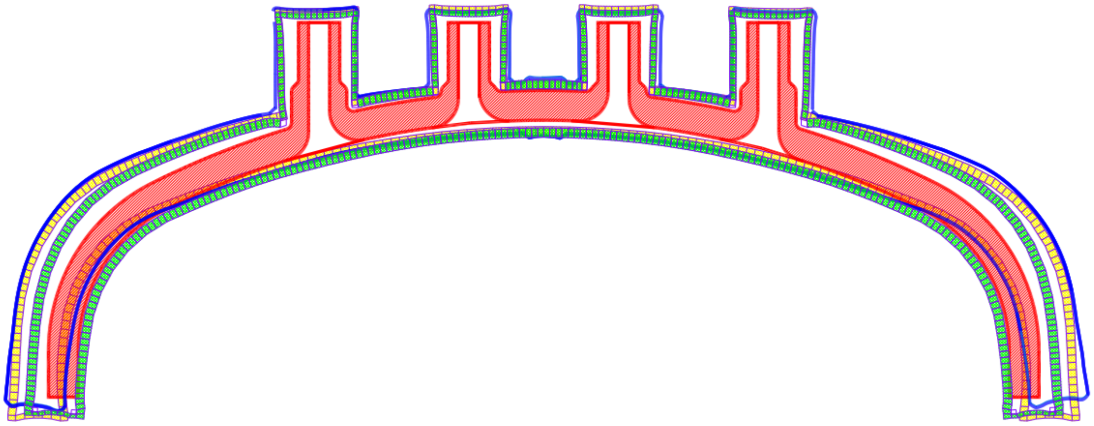


Figure 5. Dimensional analysis of modeling and actual shrinkage

2. 67% ½ Lower Head - HIP of a non-symmetrical capsule in a frame.
The 89" Ø 67% lower head could be manufactured only in two halves in vertical position in the supporting frame (Fig. 1b). HIP modeling was done accounting capsule deformation in the frame with local friction and sliding (Fig. 6a). The manufactured lower head can be seen in Fig. 6b.

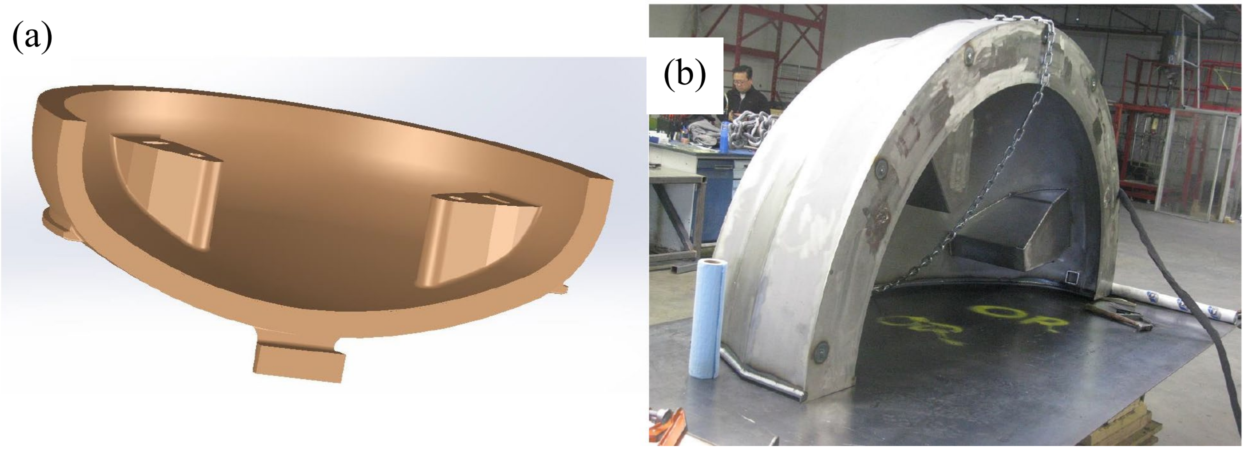


Figure 6. (a) A508 lower head of the SMR and (b) HIP capsule for the lower head

Laser scanning of the HIPed lower head has confirmed the results of modeling (Fig. 7).

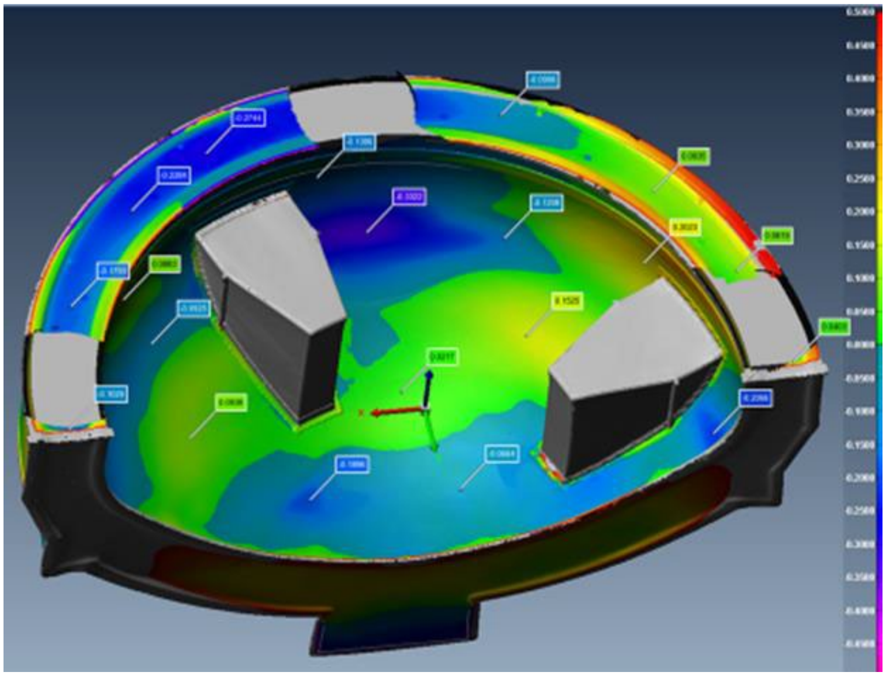


Figure 7. Dimensional analysis of the HIPed lower head

3. 67% ½ Top Head Development.

The 80" Ø 67% top head could be manufactured only in two halves also using a supporting frame. The general deformation of the two capsule shells and location of nozzles were defined through HIP modeling. An image of the head following laser cutting can be seen in Fig. 8. The ½ top head after powder filling (Fig. 9a) and in the shape support frame (Fig. 9b).

Figure 8. CNC laser cutting operations.

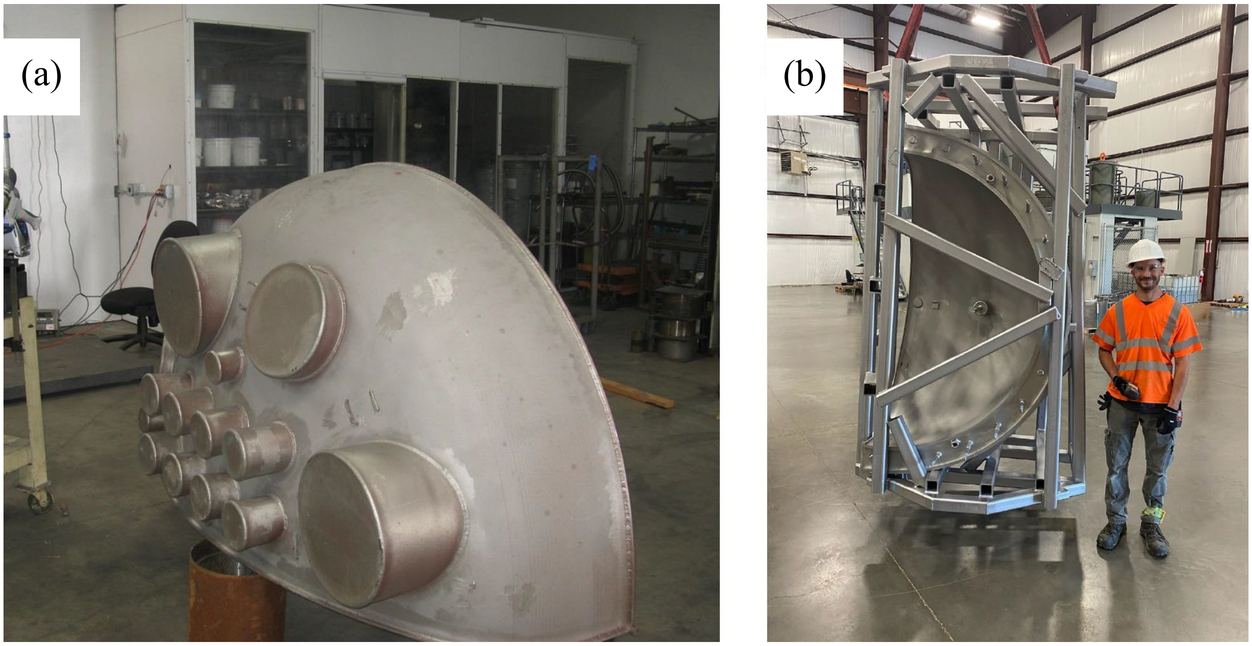


Figure 9. HIPed 1/2 top head (a) after powder filling and (b) in the support structure

Conclusions

Problems to be analyzed and solved for HIP of large parts close to the size of the HIP furnace are:

1. Non uniformity of the temperature field during the HIP ramp leading to non-uniform deformation of capsules with powder.
2. Preferential deformation of the capsules or capsule elements affected by radiation from the heaters.
3. Capsule manufacturing processes that have a strong impact on the deformation during HIP.
4. Large non-symmetrical capsules need frames to position them in the furnace and guide their deformation during HIP.
5. Efficient design and modeling tools, not just modeling art are needed.
6. With all these factors accounted and problems solved it becomes possible to manufacture large NNS parts from the first shot.