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The Specialized use of Additive Manufacturing Techniques to Prototype and Evaluate Next Generation Spacer Grids

Paper by: William Cleary, Uffe Bergman, Oleksiy Riznychenko, Edward DiLoreto, Jacob Lydick

Presentation: William Cleary, Jan Höglund

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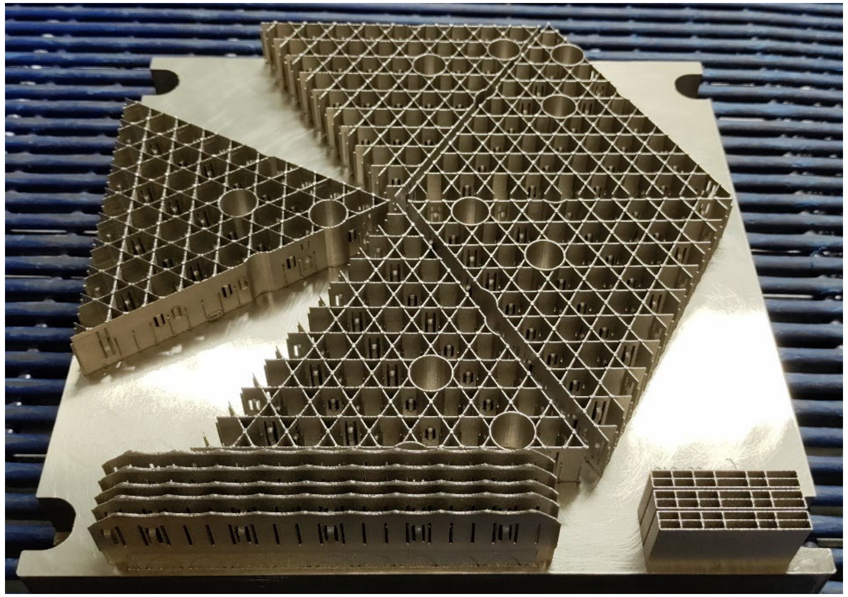
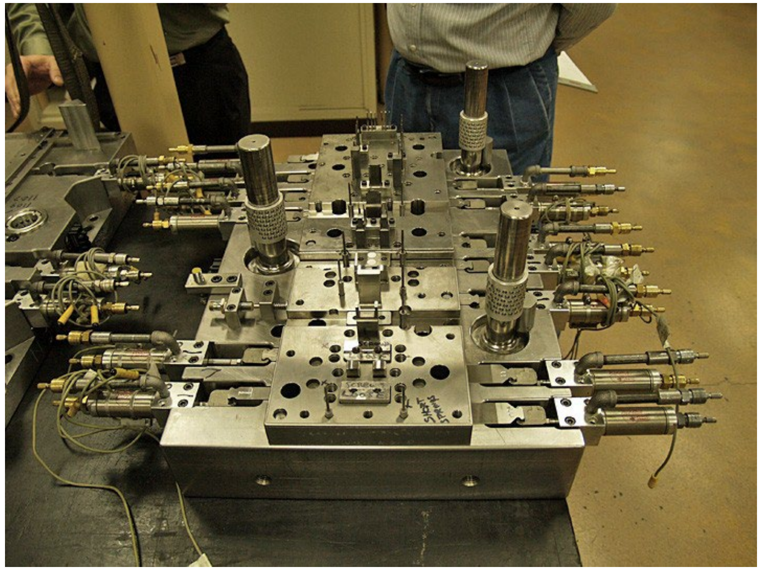


Introduction

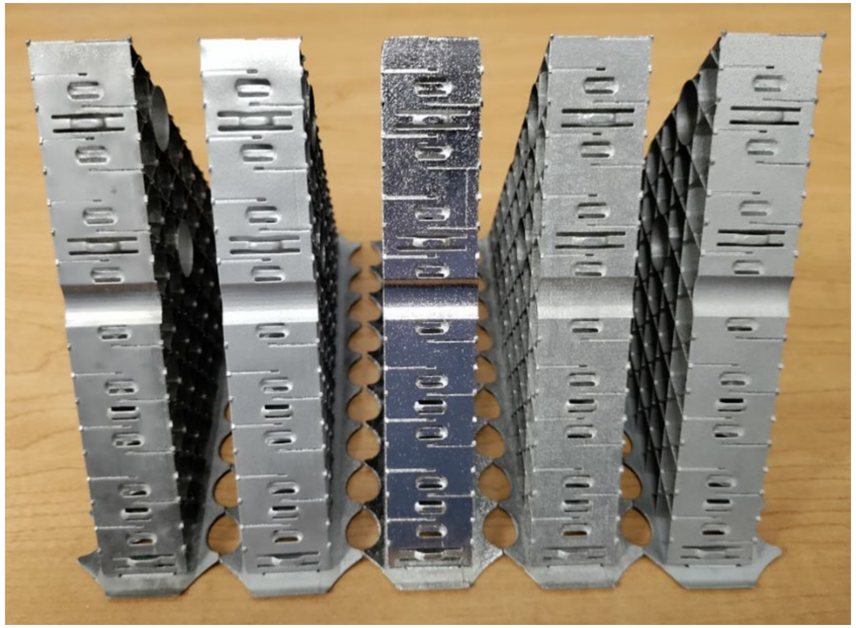
- Utilizing Additive Manufacturing to prototype a spacer grid offered the potential to rapidly screen various new concepts while reducing the costs associated with building them conventionally.
- Conventional manufacturing requires fabrication of expensive stamping dies

- This effort required several challenging attributes to be produced to adequately represent what could be produced conventionally in production



Surface Finish

- The AM-LPB process typically produces surface finish roughness in the 6 to 8 µm.
- Cold rolled coil stock is normally in the 0.8 µm or less range.
- To achieve a comparable surface finish several post processing techniques were evaluated
- Sample geometries were printed and sent to four post processing companies utilizing different methodologies for evaluation
- Each post processing technique required varying amounts of material removal



U.S. Customary Units

Location	Surface Finish (µin.) RA	Surface Finish (µin.) RZ	Wall Thickness (in.)	Location	Surface Finish (µin.) RA	Surface Finish (µin.) RZ	Wall Thickness (in.)	Location	Surface Finish (µin.) RA	Surface Finish (µin.) RZ	Wall Thickness (in.)	Location	Surface Finish (µin.) RA	Surface Finish (µin.) RZ	Wall Thickness (in.)	Location	Surface Finish (µin.) RA	Surface Finish (µin.) RZ	Wall Thickness (in.)
A	158	958	0.009049	A	231	1794	0.011398	A	116	662	0.008315	A	247	1841	0.013088	A	177	1573	0.013376
B	143	860	0.008270	B	232	1444	0.010208	B	104	526	0.009938	B	224	1850	0.011833	B	167	1197	0.012284
C	171	954	0.008374	C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.011187	C	218	1162	0.011052	C	181	1187	0.012837
D	132	841	0.008930	D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.013733	D	219	1474	0.013604	D	176	1197	0.013485
E	130	833	0.008673	E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.011302	E	212	1387	0.013718	E	152	1066	0.013242
F	130	831	0.008892	F	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.011041	F	217	1750	0.013856	F	187	1325	0.013180
G	123	667	0.009061	G	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.010962	G	60	298	0.012175	G	236	1555	0.013524
H	105	709	0.008829	H	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.011354	H	194	1264	0.013617	H	191	1266	0.013591
I	120	744	[illegible]	I	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.012960	I	168	1050	0.013078	I	182	1340	0.013195
J	118	729	0.008726	J	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.013020	J	208	1316	0.012799	J	174	1198	0.013142
Max	171	958	0.009061	Max	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.013733	Max	247	1850	0.013856	Max	236	1573	0.013591
Min	105	667	0.008270	Min	180	1234	0.010208	Min	94	491	0.008315	Min	60	298	0.011052	Min	152	1066	0.012284
Avg.	133	813	0.008736	Avg.	215	1420	0.011777	Avg.	129	708	0.011381	Avg.	197	1330	0.012877	Avg.	182	1290	0.013186
K	177	1182		K	250	1784		K	236	1647		K	16	94		K	235	1608	
L	160	1061		L	246	1737		L	274	1848		L	14	109		L	220	1418	

Location	Surface Finish (µin.) RA	Surface Finish (µin.) RZ	Wall Thickness (in.)
A	158	958	0.009049
B	143	860	0.008270
C	171	954	0.008374
D	132	841	0.008930

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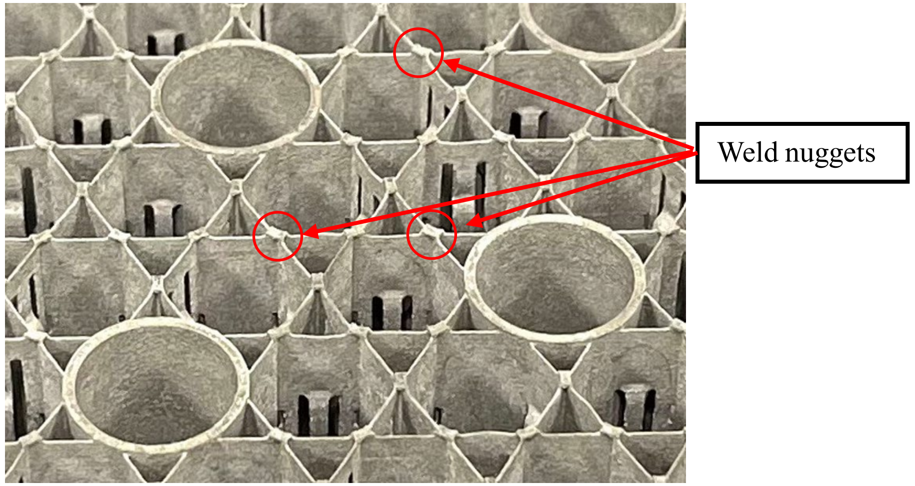
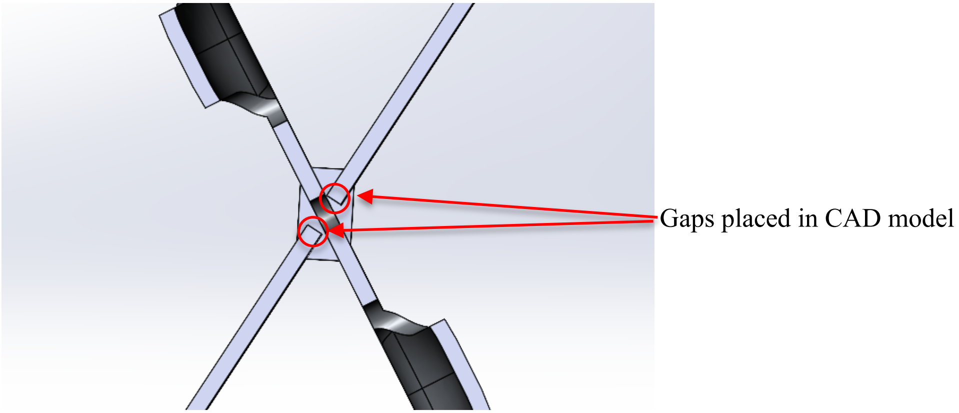
Weld Nugget Geometry

- Pressure drop testing was a major consideration in selection of a new spacer grid geometry
- Weld nuggets produced when fabricating conventional grids needed to be printed
- Significant contribution to pressure drop
- Must be present to avoid “masking” of other geometry changes



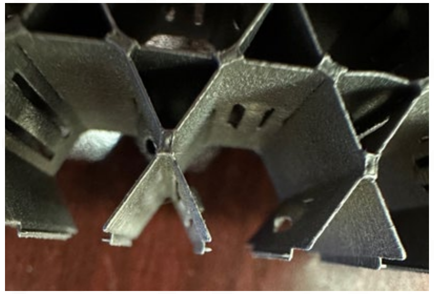
Intersection Variables

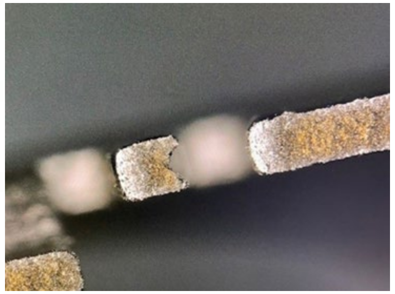
- Conventional grids are only welded at the tops and bottoms of where straps intersect
- The AM grid crush strength and stiffness would be much greater if the intersections are completely joined
- Placed a gap in the CAD file partially solved the issue
- Weld pool physics prevented a perfect solution

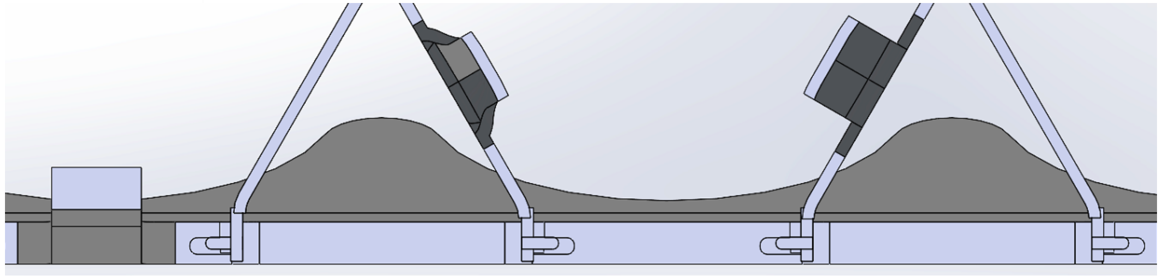


Outer Strap Attachment

- The envelope of the entire grid fell outside the build plate volume
- The outer straps extend below the build elevation relative to the inner straps creating an unacceptable overhang
- A hook and loop concept was designed to allow outer straps to be printed separately and then joined later
- Able to use the printer laser to make the connection secure







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EMBLA Pressure Drop Testing

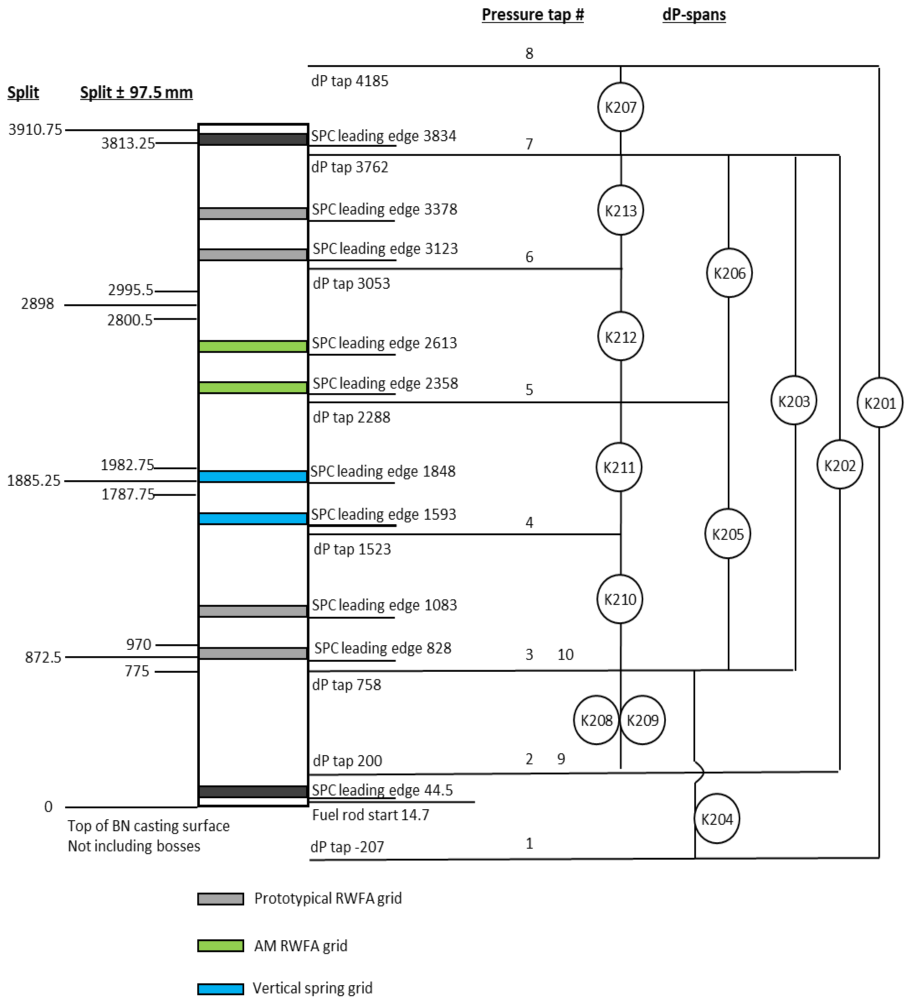
Parameter	Range
Flow	5-150 kg/s (~100-2400 gpm)
Temperature	20-150°C (68-302°F)
Operating pressure	~7-13 bar (~100-190 psi)

- EMBLA is a new loop built in the Västerås T/H lab for pressure drop testing of full-size VVER and PWR fuel assemblies

- EMBLA is a new loop built in the Västerås T/H lab for pressure drop testing of full-size VVER and PWR fuel assemblies
- Surface finish and weld nuggets contribute significantly to pressure drop
- Test objectives: Measure relative differences in pressure drop of
  - **(AM) New Grid Design** vs. **(AM) RWFA grid**
  - **(AM) RWFA grid** vs. **prototypical RWFA grid**

AM process/design adds 10% pressure drop vs. prototypical

Pressure taps with transducers are located at various heights through the test loop



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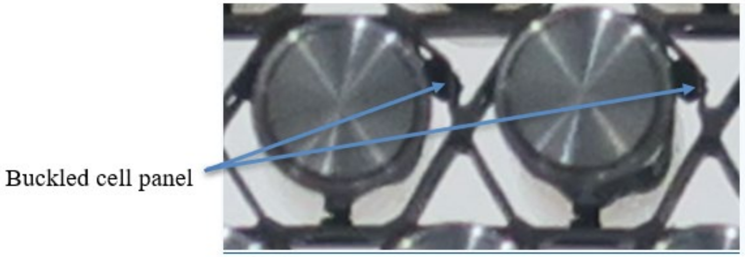
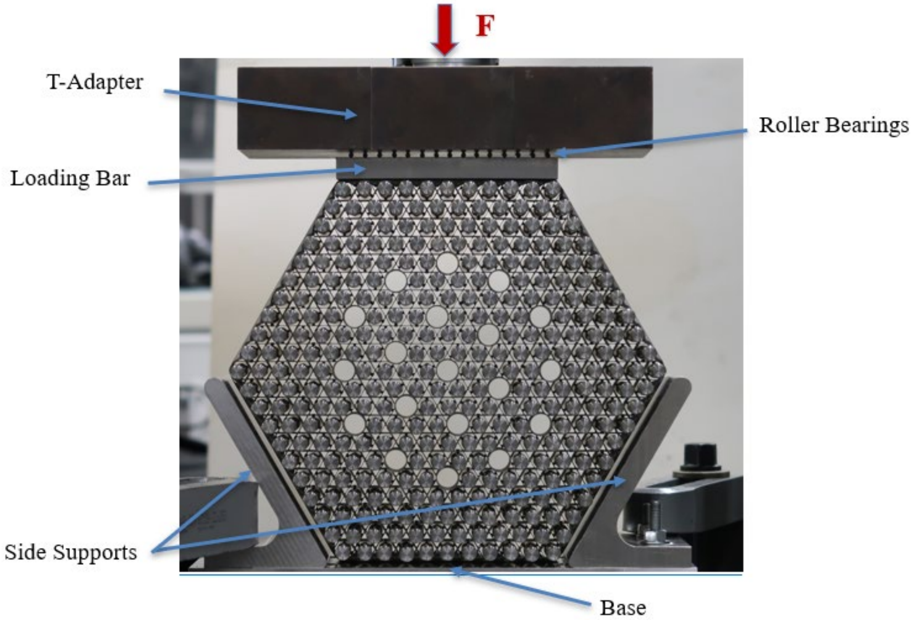
Crush Strength

- Spacer grids need to withstand loads during shipping and handling, normal operations as well as maintaining coolable geometry during a seismic event
- Crush strength testing was performed to obtain the lateral static strength characteristics
- A conventional grid was tested alongside an AM grid with the same geometry to understand differences not due to geometry. Test included:
  - Prototypical RWFA grid
  - AM RWFA grid
  - AM New Grid Design Concepts
  - Grids were fully loaded with rodlet to simulate fuel rods
  - Compressive load was applied until grid failed (straps buckled)
  - AM vs. prototypical RWFA showed similar loads for onset of buckling





Tolerance Metrics

- Spacer grids have tight cell size and positional tolerances
- Well known for conventional grids but limited experience with an AM grid
- AM grids demonstrated to have exceptional positional control and better than conventionally fabricated grids
- Secondary processing was performed to achieve acceptable surface finish results requiring additional material stock be printed in anticipation
- Surface finishing operations were demonstrated to be very repeatable allowing cell sizing and wall thickness to meet requirements

Conclusions

- Designing and evaluating new products can be very expensive and time consuming
- When the new product requires expensive or long lead tooling to produce prototyping methods should be evaluated
- The final choice for prototyping needs to be representative of a production process for scalability
- Additive manufacturing has been shown to be appropriate for prototyping spacer grids
- Using AM for this use case saved ~ 1.5 years and ~ $1M

Thank You for the Attention