Sintering tests using a dental oven

Here is a page of what we found out during sintering, what the manufacturer recommends, my thoughts on it, and what to try in a possible future.

Used material: PolyMIM 316L, water debinding feedstock
Used sintering furnace: Mimh Vogt HTS-2/METAL

First of all, here are the debinding and sintering parameters recommended by the manufacturer:

Debinding process *Entbinderungsprozess*	Solvent *Flüssigkeit*	Water or distilled water
	Additive *Badzusatz*	Corrosion inhibitor: Inhibitor 4000 (Zschimmer & Schwarz, Quantity added : 2Vol%)
	Debinding temperature *Entbinderungstemperatur*	40– 60°C
	Debinding time *Entbinderungszeit*	depending on part thickness (eg 4mm part approx. 10 h at 60°C)
	Drying *Trocknung*	to constant weight, approx. 2 h at 100°C (drying under vacuum preferable)
	Weight loss *Gewichtsverlust*	> 3,7 weight%
	Equipment *Anlagentechnik*	Water bath or debinding equipment
Sintering processs *Sinterprozess*	Sintering atmosphere *Sinteratmosphäre*	100% dry hydrogen
	Sintering substrata *Sinterunterlage*	Non-metallic base (e.g. Al_2O_3)
	Sinterzyklus *Sintering cycle*	RT – 3K/min – 600°C, 2h hold 600°C – 5K/min – 1350°C, 3,0h hold 1350°C – 15K/min – 80°C, cooling

Now, to start with, there are some issues here.
Firstly, the Mimh Vogt sintering oven we got for these experiments can't ramp below 5 K/min, and working with pure hydrogen just isn't feasable in the FabLab.
Therefore we agreed on some compromises, namely ramping with 5 K/min or faster, and using forming gas (95% N2, 5% H2) as a reducing atmosphere.

After some experimenting this is the most reliable sintering procedure we settled on:

Ramp K/min	Target Temp °C	Hold time min	Reason / Comment
5	100	10	Drying
5	600	120	Burning off Binder
15	1350	180	Sintering
40	200	0	Cooldown

Gas is turned on at 200 °C, and the Cooldown step is necessary to keep gas flowing during cooldown, otherwise the oven would close its valve as soon as the 180 min sintering step is over.
The oven only opens back up once it has reached 200 °C.
Gas flow should be at least 2.0 SLPM, as below that oxidation becomes very evident and parts become brittle.
At ~2.5 SLPM parts come out with partially metallic looking surfaces, maybe testing at even higher flow rates will yield interesting results.

In all experiments so far there has not been a visible difference between parts that underwent a debinding process before sintering, and untreated parts.
Debinding has been done at various temperatures and times, with and without corrosion inhibitors, but at least on the small parts we have sintered so far there has been no noticeable difference.
The biggest influence lies in the temperature ramps, both for drying and burning off the binder. If the risetime is too high parts will bend unde uneven heating, as there is no time to reach thermal equilibrium, beyond that they will crack open or burst.
All experiments have been done with the parts just lying on the included sintering beads, maybe burying them under a layer will improve the thermal distribution.

Sintering under vacuum instead of the reducing atmosphere yields good results, but the parts are even more prone to breaking.
Presumably the carbon crucible used in the DIY SIntering Oven V1 creates a reducing atmosphere by consuming all remaining oxygen.
When sintering under vacuum it is evident that some copper boils off the alloy, not sure how that affects mechanical strength or similar.