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Application of steel as an alternative tool material for field assisted sintering in SPA

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Application of Steel as Alternative Tool Material for FAST/SPS

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Graphite as a tool material

- Appropriate electrical and thermal conductivity
- Low dependence mechanical strength on temperature up to 2500°C
- Good machinability
- Low compressive strength particularly at low temperatures (<200MPa)
- Chemical interaction with many materials

Alternative tool materials

Material	Temperature, °C	Application
Hot working steel	600°C	Al-alloys
Superalloys (Ni-based)	950°C	Ti-alloys
Molybdenum alloys (TZM)	1100°C	Ni-alloys
Ceramics (SiC, Si_3N_4, composites)	2500°C	Ceramics

Steels as a tool material

- High strength (at low and moderate temperatures)
- No thermal shock problem
- Good machinability
- Small wear during exploitation
- Electrical conductivity much higher then conductivity of graphite, which can result problem in control of temperature profile
- Is it possible to avoid application of graphite foils without welding of tool elements?
- Are strength and hardness of a steel tool during Field Assisted Sintering stable enough?

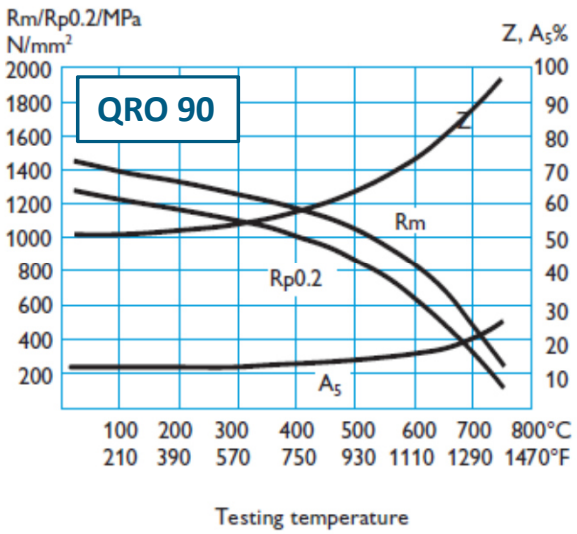
Promising candidates: hot working steels

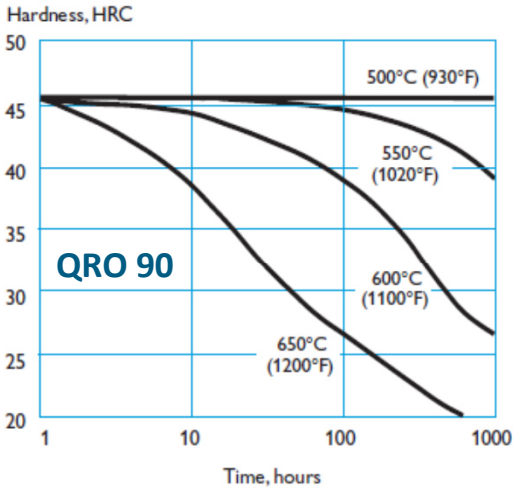
Udeholm QRO 90 Supreme

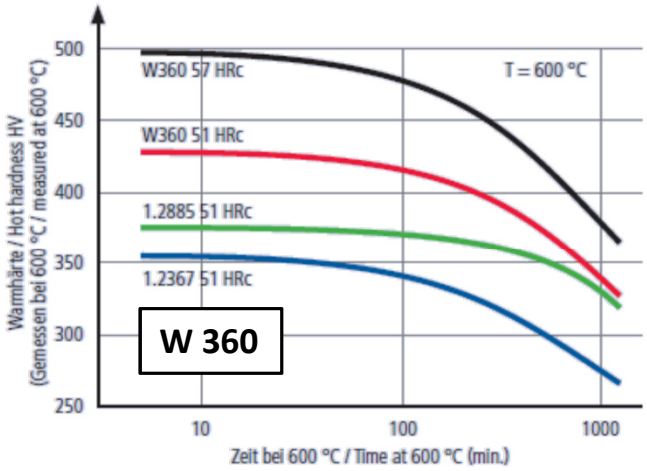
C	Si	Mn	Cr	Mo	V
0.38	0.30	0.75	2.6	2.25	0.9

Böhler W360 Isobloc

C	Si	Mn	Cr	Mo	V
0.50	0.20	0.25	4.5	3.00	0.55



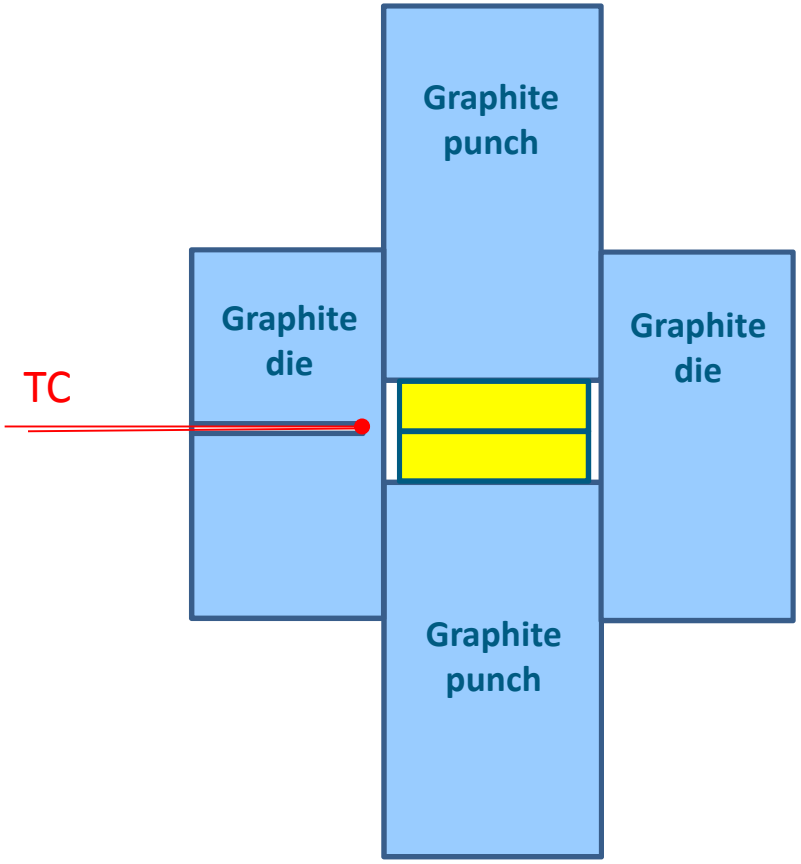




Preliminary experiments

Goal: Determination of welding temperature between steel elements

Temperature control by thermocouple (TK)

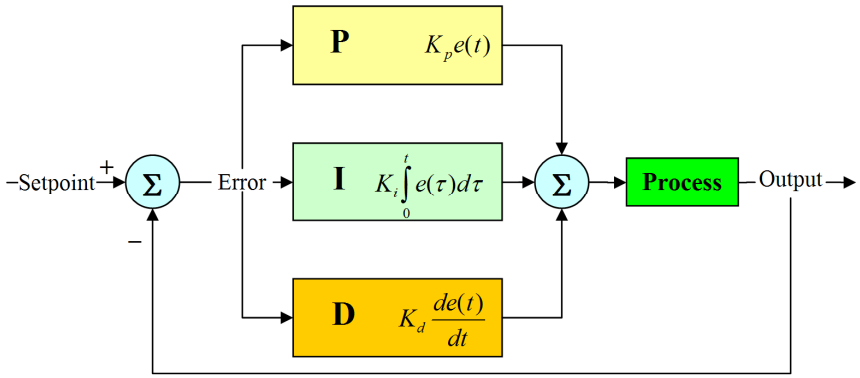


Case #1. Two uncoated steel discs

Case #2. Both steel discs coated by TiN

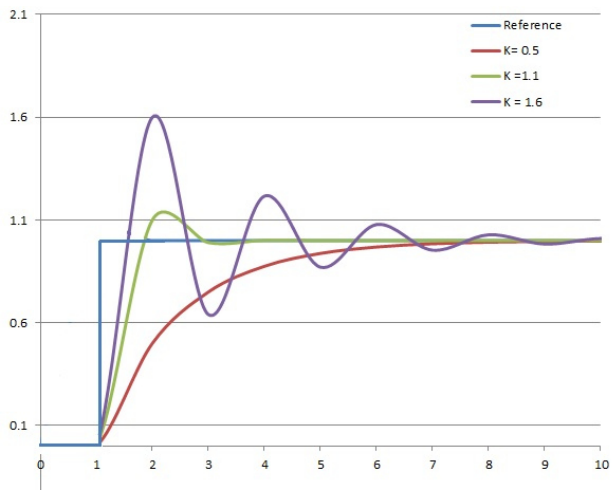
Case #3. One steel disc coated by TiN

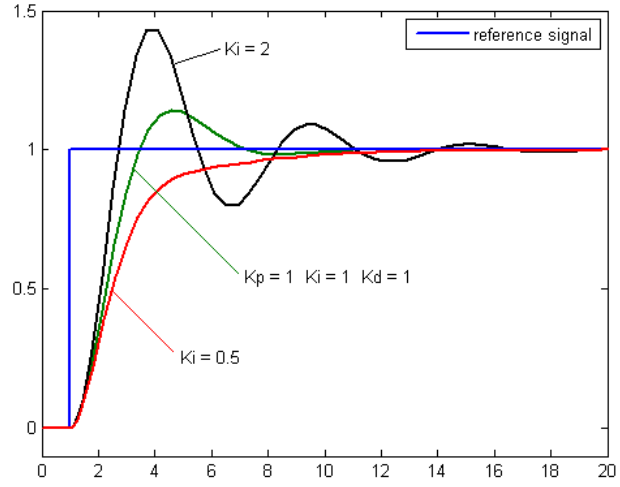
Change of tool resistivity: Adaption of PID-controller

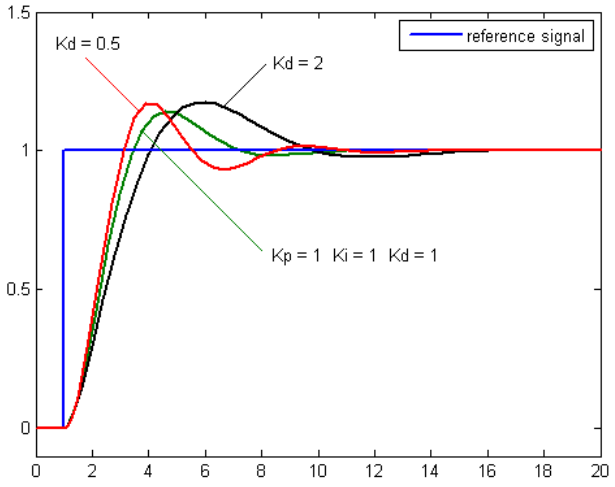


$$U(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$

K_p (P), K_i(I), K_d(D) - proportional, integral and derivative terms







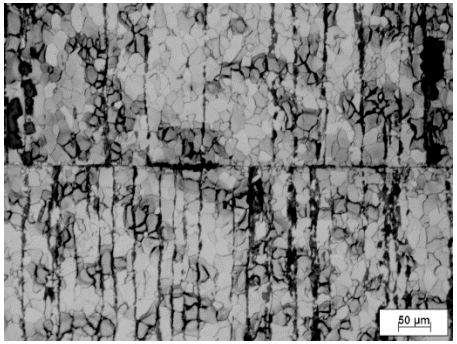
Uncoated steel discs

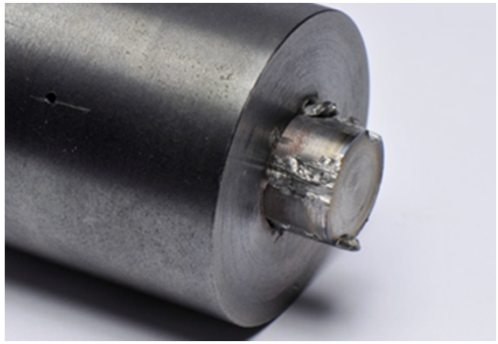
No coating						
Temperature, °C Dwell, min	Heating rate, °C/min	PID controller			Temperature control	Adhesion
		P	I	D		
100/ 5	50	7.5	7.0	1.17	TC / bad	No
200/5	50	7.5	7.0	1.17	TC / bad	No
300/5	50	3.5	50	0	TC / bad	No
400/5	25	10	50	0	TC / moderate	No
500/5	25	10	50	0	TC / moderate	Low
600/5	25	10	50	0	TC / moderate	Strong

Tuning parameters:

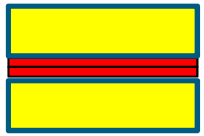
P = proportional gaine
I = integral gain
D = derivative gain

TC = thermocouple





Strong adhesion of punch and die during SPS at 400°C



Both discs coated by TiN

Both discs coated by TiN						
Temperature, °C Dwell, min	Heating rate, °C/min	PID controller			Temperature control	Adhesion
		P	I	D		
500/5	20	15	50	0	TC / moderate	No
600/5	20	15	50	0	TC / bad	No
600/5	50	7.5	7.0	1.17	TC / good	No
650/5	50	7.5	7.0	1.17	TC / good	No
700/5	50	7.5	7.0	1.17	TC / good	Low
750/5	50	7.5	7.0	1.17	TC / good	Low
800/5	50	7.5	7.0	1.17	TC / good	Low

Tuning parameters:

P = proportional gaine
I = integral gain
D = derivative gain

TC = thermocouple

One disc coated by TiN

One disc coated by TiN						
Temperature, °C Dwell, min	Heating rate, °C/min	PID controller			Temperature control	Adhesion
		P	I	D		
500/5	50	7.5	7.0	1.17	TC / good	No
550/5	50	7.5	7.0	1.17	TC / good	No
600/5	50	7.5	7.0	1.17	TC / good	Low
650/5	50	7.5	7.0	1.17	TC / good	Moderate

Tuning parameters:
P = proportional gain
I = integral gain
D = derivative gain

TC = thermocouple

Conclusions

- The strength of hot working steel allows its use as an alternative SPS tool material at temperatures until 600°C.
- The application of steel tool needs an adjustment of parameters of PID controller. These parameters can be different when coating of tool elements is used.
- Uncoated steel tool without application of graphite foil apparently can be used until 400°C.
- Coating of one contacting surface by TiN increases this critical temperature to 550°C.
- Coating of both contacting surfaces by TiN further increases critical temperature to 600°C.

Thank you for your attention!