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Alexander Laptev Forschungszentrum Julich GmbH

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# Application of Steel as Alternative Tool Material for FAST/SPS

A. M. Laptev, M. Bram, O. Guillon, Institute of Energy and Climate Research (IEK-1: Materials Synthesis and Processing)

Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany.



### 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)</li>
- 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 <sub>3</sub> N <sub>4</sub> , 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?



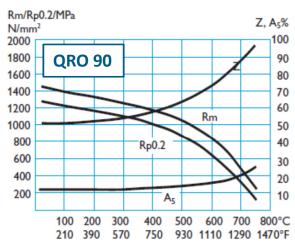
# Promising candidates: hot working steels

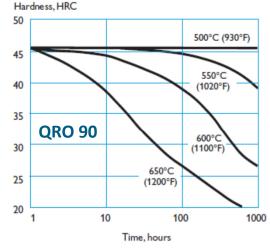
#### **Udeholm QRO 90 Supreme**

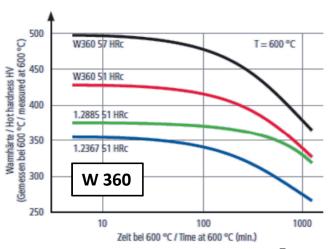
С	Si	Mn	Cr	Mo	V
0.38	0.30	0.75	2.6	2.25	0.9

#### Böhler W360 Isobloc

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







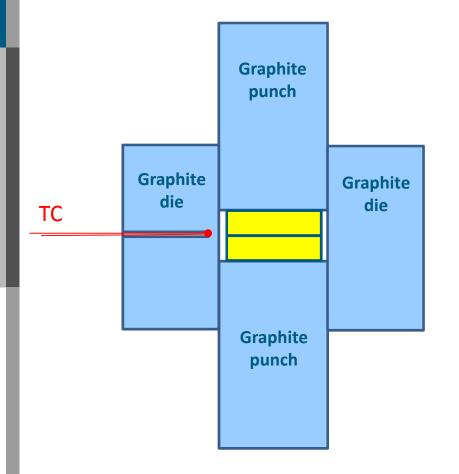
Testing temperature



## **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



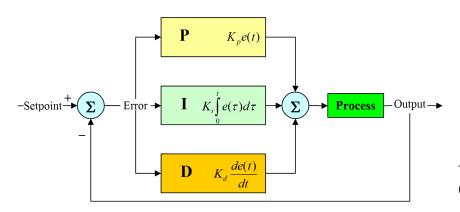
Case #3. One steel disc coated by TiN





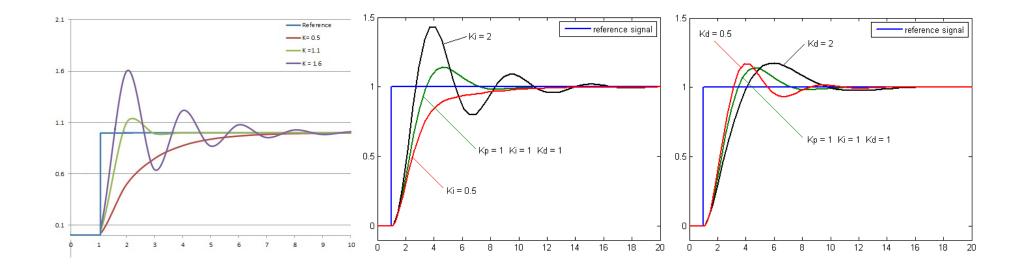


# Change of tool resistivity: Adaption of PID-controller



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

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





### **Uncoated steel discs**



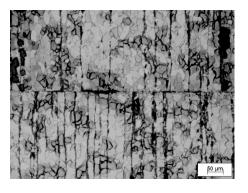
No coating								
Temperature, °C	Heating rate,	PID controller		roller	Temperature	Adhesion		
Dwell, min	°C/min	Р	I	D	control			
100/5	50	7.5	7.0	1.17	TC / bad	No		
200/5	50	7.5	7.0	1.17	TC / bad	No		
300/5	50	3.5	50	0	TC / bad	No		
400/5	25	10	50	0	TC / moderate	No		
500/5	25	10	50	0	TC / moderate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

P = proportional gaine

I = integral gain

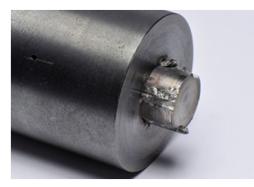
D = derivative gain

TC = thermocouple



Tuning

parameters:



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





## **Both discs coated by TiN**

Both discs coated by TiN							
Temperature, °C	Heating rate,	PID controller			Temperature	Adhesion	
Dwell, min	°C/min	Р	I	D	control		
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 P = proportional gaine TC = thermocouple

parameters: I = integral gain

D = derivative gain





## One disc coated by TiN

One disc coated by TiN							
Temperature, °C	Heating rate,	PID	contr	roller	Temperature	Adhesion	
Dwell, min	°C/min	Р	I	D	control		
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:** 

TC = thermocouple

P = proportional gain

I = integral gain

D = derivative gain



### **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!