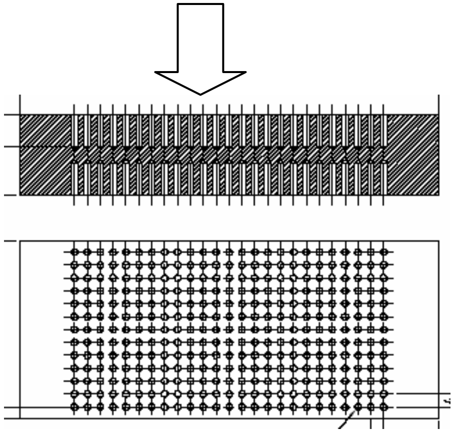
RESEARCH PERFORMED

1) RESEARCH CAST IRON MACHINABILITY :

PARTNER INVOLVED: CIM/UPC and F.RODA			
SAMPLE Nº	FOUNDRY code		MATERIAL (by standard UNE-EN 1560)
	Heat number	Internal code	
2	15OC	06420	EN-GJS-400-15
2	09OC	06404	EN-GJS-400-15
2	08OC	06402	EN-GJS-400-15
6			EN-GJS-400-15
2	11OC	07261	EN-GJS-450-10
2	09OC	07261	EN-GJS-450-10
4			EN-GJS-450-10
2	11OC	08214	EN-GJS-500-7
2	10OC	08215	EN-GJS-500-7
2	05OC	08215	EN-GJS-500-7
2	09OC	08214	EN-GJS-500-7
2	08OC	08214	EN-GJS-500-7
2	08OC	06402	EN-GJS-500-7
2	04OC	08214	EN-GJS-500-7
2	04OC	08215	EN-GJS-500-7
2	03OC	08215	EN-GJS-500-7
18			EN-GJS-500-7
TOTAL	28 SAMPLES		

Moulding sample



Drawing sample after

Machinability test

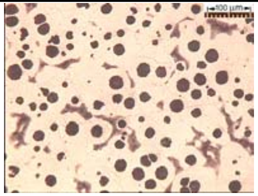
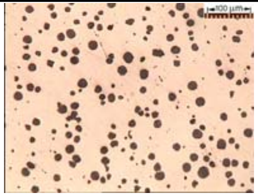
RESEARCH PERFORMED

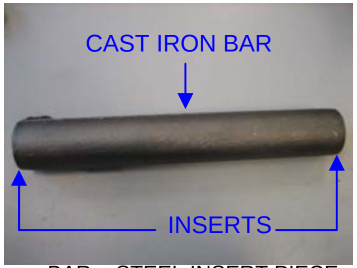
MECHANICAL PROPERTIES - SAMPLES SENT TO THE PARTNER UPC/CIM								
PROHIPP code	FOUNDRY code		MATERIAL (by standard UNE-EN 1560)	Rm (Mpa)	Rp0,2 (Mpa)	A (%)	HARDNESS (HB)	% FERRITE
	Heat number	Internal code						
PH-T-350/1	15OC	06420	EN-GJS-400-15	431,5	285,89	23,4	-	90%
PH-T-351/1	15OC	08214	EN-GJS-500-7	676,44	407,95	14,1	-	30%
PH-T-352/1	11OC	07261	EN-GJS-450-10	694,48	406,49	12,9	-	30%
PH-T-353/1	11OC	08214	EN-GJS-500-7	672,66	398,17	11,5	-	30%
PH-T-354/1	10OC	08215	EN-GJS-500-7	717	423	12	-	30%
PH-T-355/1	09OC	06404	EN-GJS-400-15	472,05	311,12	19,4	-	70%
PH-T-356/1	05OC	08215	EN-GJS-500-7	745	427	11	-	10%
PH-T-357/1	09OC	07261	EN-GJS-450-10	701,48	410,78	13,3	-	30%
PH-T-358/1	09OC	08214	EN-GJS-500-7	618,56	374,69	14	-	30%
PH-T-359/1	08OC	08214	EN-GJS-500-7	634,09	387,57	10,5	-	45%
PH-T-360/1	08OC	06402	EN-GJS-450-15	490,88	334,01	20,3	-	70%
PH-T-361/1	04OC	08214	EN-GJS-500-7	726,86	424,93	12,9	-	30%
PH-T-362/1	04OC	08215	EN-GJS-500-7	744	440	13	-	30%
PH-T-363/1	03OC	08215	EN-GJS-500-7	728	428	12	-	30%

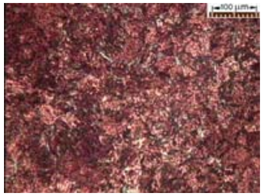
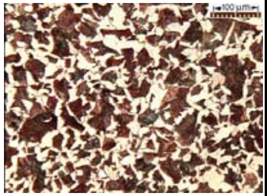
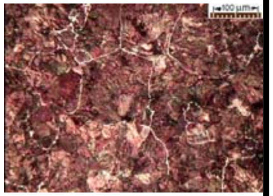
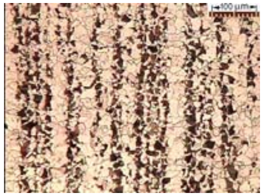
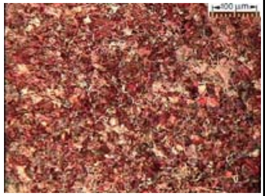
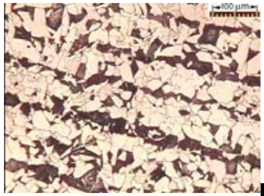
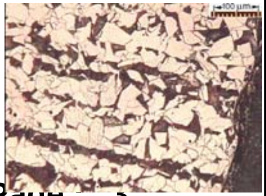
RELATION MECHANICAL PROPERTIES vs MACHINABILITY

RESEARCH PERFORMED

2) RESEARCH WELDING IN CAST IRON :

<table>
<tr><th colspan="2">TUBES</th><th>Nº SAMPLES</th><th>DESCRIPCION</th><th colspan="2">MICROSTRUCTURE</th></tr>
<tr><td colspan="2"></td><td>7</td><td>MATERIAL: EN-GJS-400-18LT
NODULUS DENSITY: 590/mm^2</td><td></td><td></td></tr>
<tr><th colspan="2">BARS + STEEL INSERTS</th><th>Nº SAMPLES</th><th>DESCRIPCION</th><th colspan="2">MICROSTRUCTURE</th></tr>
<tr><td rowspan="4">

PATTERN


BAR + STEEL INSERT PIECE</td><td>A</td><td>6</td><td>MATERIAL: C 45
HEAT TREATMENT:
CARBURIZING HYPEREUTECTIC
TEMPLE Y REVENIDO
TINNING</td><td></td><td></td></tr>
<tr><td>B</td><td>12</td><td>MATERIAL: C 45
HEAT TREATMENT:
CARBURIZING HYPEREUTECTIC
SLOWLY COOLING
TINNING</td><td></td><td></td></tr>
<tr><td>C</td><td>12</td><td>MATERIAL: C 11
HEAT TREATMENT:
CARBURIZING HYPEREUTECTIC
SLOWLY COOLING
TINNING</td><td></td><td></td></tr>
<tr><td>D</td><td>6</td><td>MATERIAL: C 11
HEAT TREATMENT: -
TINNING</td><td></td><td></td></tr>
</table>

RESEARCH PERFORMED

3) FATIGUE TENSILE TEST IN CAST IRON

PARTNER INVOLVED: ROQUET and F.RODA			
SAMPLE Nº	FOUNDRY code		MATERIAL (by standard UNE-EN 1560)
	Heat number	Internal code	
1	08PC		EN-GJS-400-18LT
1	08PC		EN-GJS-400-18LT
1	08PC		EN-GJS-400-18LT
1	08PC		EN-GJS-400-18LT
1	08PC		EN-GJS-400-18LT
1	08PC		EN-GJS-400-18LT
1	08PC		EN-GJS-400-18LT
1	01DD		EN-GJS-400-15
1	01DD		EN-GJS-400-15
1	01DD		EN-GJS-400-15
1	01DD		EN-GJS-400-15
1	01DD		EN-GJS-400-15
1	01DD		EN-GJS-400-15
TOTAL	13 SAMPLES		

CAST IRON TUBE

STATIC FATIGUE TEST BENCH

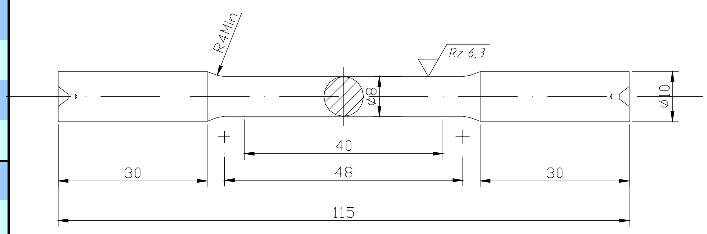
BY ROQUET

RESEARCH PERFORMED

3) FATIGUE TENSILE TEST IN CAST IRON

PARTNER: ROQUET and F.RODA			
SAMPLE Nº	FOUNDRY code		MATERIAL (by standard UNE-EN 1560)
	Heat number	Internal code	
5	01OC	03816	EN-GJS-400-18LT
5	28MC	03816	EN-GJS-400-18LT
3	21BC	03816	EN-GJS-400-18LT
3	15EC	03816	EN-GJS-400-18LT
4	16EC	03816	EN-GJS-400-18LT
4	18OC	05523	EN-GJS-500-7
1	22OC	08211	EN-GJS-500-7
2	22OC	08212	EN-GJS-500-7
1	15OC	08214	EN-GJS-500-7
1	11OC	08214	EN-GJS-500-7
1	09OC	08215	EN-GJS-500-7
1	16OC	06295	EN-GJS-500-7
1	17OC	06295	EN-GJS-500-7
1	04OC	08214	EN-GJS-500-7
1	10OC	08215	EN-GJS-500-7
1	09OC	08214	EN-GJS-500-7
1	09OC	07261	EN-GJS-500-7
1	03OC	08215	EN-GJS-500-7
1	12MC	07601	EN-GJS-500-7
1	21MC	07565	EN-GJS-500-7
1	13MC	08127	EN-GJS-500-7
TOTAL	40 SAMPLES		

Moulding sample



Fatigue tensile test SAMPLE

Fatigue tensile test BENCH

By ROQUET

FUNDICIONES DE RODA, S.A.

RESEARCH PERFORMED

MECHANICAL PROPERTIES - SAMPLES SENT TO THE PARTNER ROQUET S.A.									
MATERIAL (by standard UNE-EN 1560)	SAMPLE NUMBER	FOUNDRY code		Rm (Mpa)	Rp0,2 (Mpa)	A (%)	R_{mean} (J)	HARDNESS (HB)	% FERRITE
		Heat number	Internal code						
EN-GJS-400-18LT	5	01OC	03816	421	285	24	11/13/13	-	90%
	5	28MC	03816	425	295	23	12	-	90%
	3	21BC	03816	404	280	24	12	-	90%
	3	15EC	03816	423	322	20	14	-	90%
	4	16EC	03816	422	307	20	14	-	90%
EN-GJS-500-7	4	18OC	05523	680	402	13	-	-	30%
	1	22OC	08211	501	341	9	-	-	70%
	2	22OC	08212	520	341	15	-	-	70%
	1	15OC	08214	676	408	14	-	-	30%
	1	11OC	08214	673	398	12	-	-	30%
	1	09OC	08215	592	363	15	-	-	45%
	1	16OC	06295	733	421	11	-	-	10%
	1	17OC	06295	673	394	13	-	-	30%
	1	04OC	08214	727	425	13	-	-	30%
	1	10OC	08215	717	423	12	-	-	30%
	1	09OC	08214	619	375	14	-	-	30%
	1	09OC	07261	701	411	13	-	-	30%
	1	03OC	08215	728	428	12	-	-	30%
	1	12MC	07601	752	432	13	-	-	10%
	1	21MC	07565	673	409	14	-	-	30%
	1	13MC	08127	736	427	13	-	-	10%

RESEARCH PERFORMED

4) MECHANICAL PROPERTIES RESEARCH

5) MICROESTRUCTURE RESEARCH

6) IMPROVE CURRENT KNOWLEDGE ABOUT MANUFACTURING PROCESS

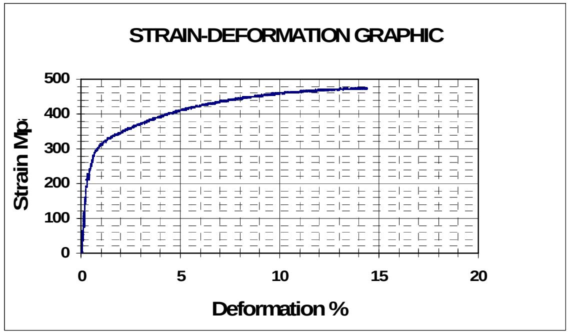
1. MODEL LINEAL FOR CONNECTION:
- CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES
- MICROSTRUCTURE AND MECHANICAL PROPERTIES
- MECHANICAL PROPERTIES AND MACHINABILITY
- EFFECT OF THE GEOMETRY IN MECHANICAL PROPERTIES
- OTHERS...

2. STATISTICAL-MULTIVARIABLE MODEL

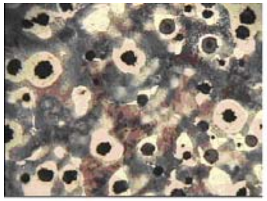
3. DEVELOPMENT NEW TECNOLOGY FOR PREDICTION
- CONECTION MICROSTRUCTURE VS MECHANICAL PROPERTIES IN THEORICAL WAY (CENAERO)
- PREDICTION OF DUCTILE CAST IRON QUALITY BY ARTIFICIAL NEURAL NETWORKS

4. IMPROVE CURRENT KNOWLEDGE IN CAST IRON
- TO FIX MECHANICAL PROPERTIES FOR A DIFFERENTS MATERIALS

INTENSIVE EXPERIMENTAL TESTING
- CHEMICAL COMPOSITION
- HARDNESS TEST
- TENSILE TEST

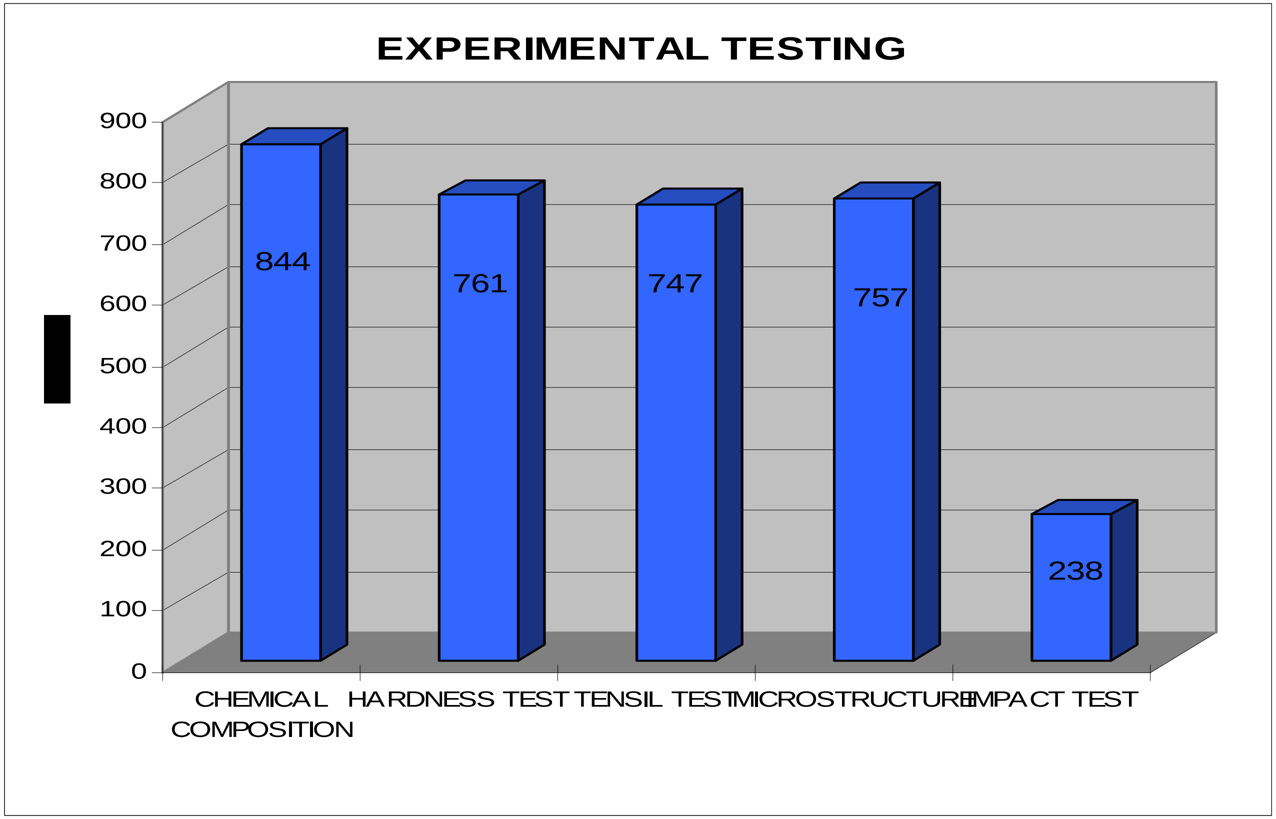


- IMPACT TEST
- MICROSTRUCTURE



RESEARCH PERFORMED

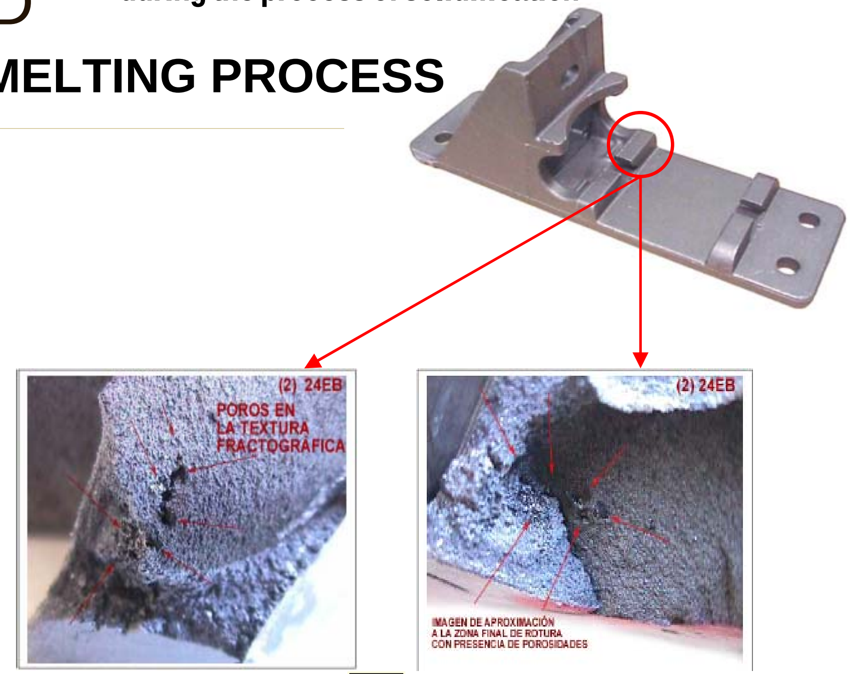
INTENSIVE EXPERIMENTAL TESTING



RESEARCH PERFORMED

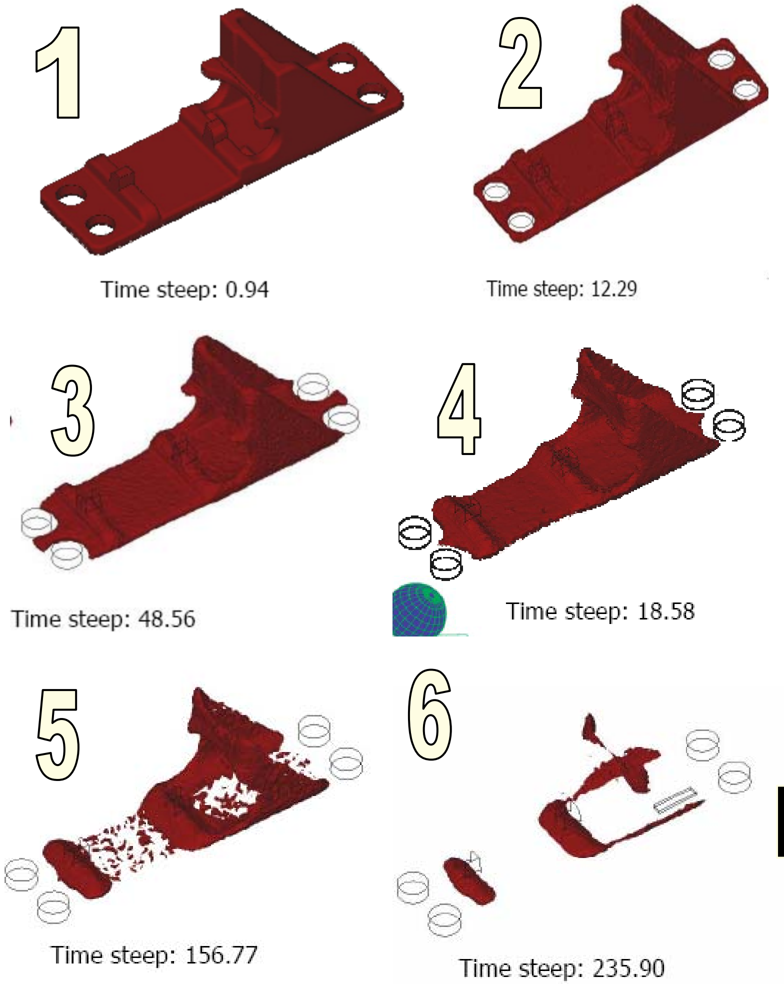
7) PREDICTION OF FAULTS IN MELTING PROCESS

Problems inside the railway piece due to shrinkage made during the process of solidification

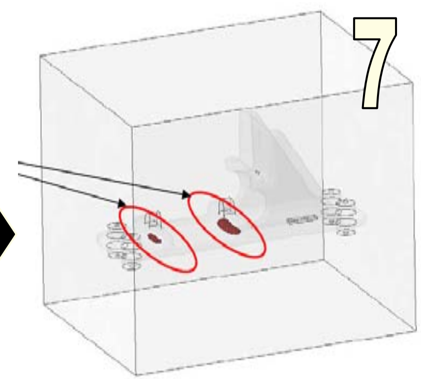


Filling simulation

Solid Fraction Evolution – Prediction of Faults



Prediction of faults



The component can present porosity problems in the shown area if some riser is not consider

FUNDICIONES DE RODA, S.A.

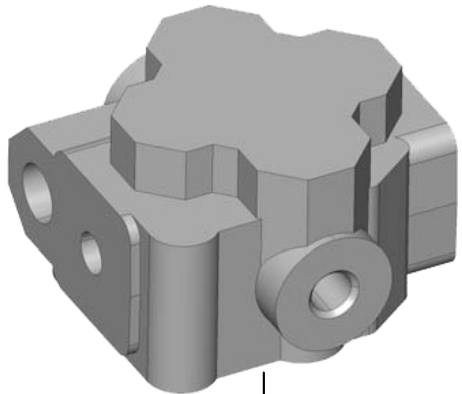
RESEARCH PERFORMED

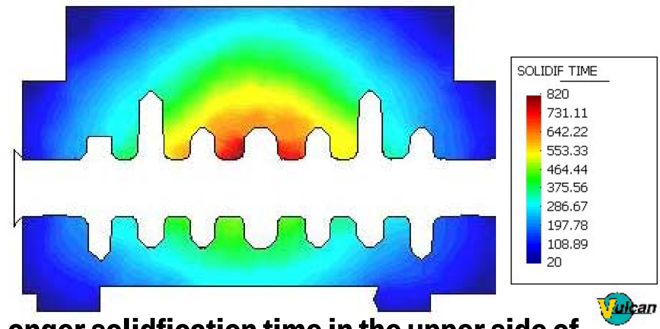
7) PREDICTION OF FAULTS IN MELTING PROCESS

Cooling simulation

Problems in the foundry of a hydraulic distributor due to the core burning inside the piece during the process

Simulation of the solidification time in the original distributor

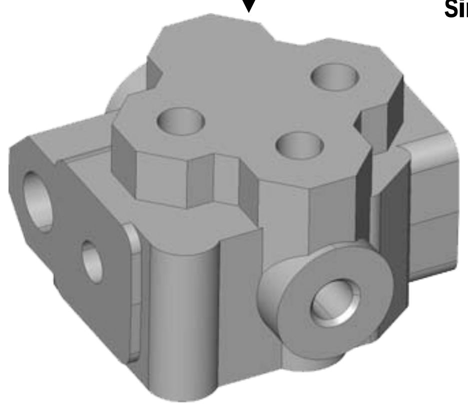




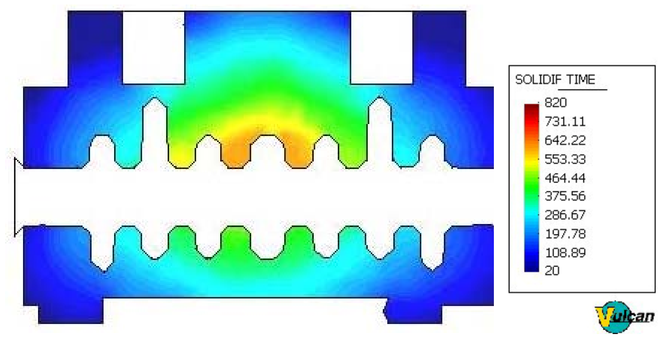
Longer solidfication time in the upper side of the piece so this area is submitted to high temperature during more time causing the burning core

Holes made for mass reduction and less solidification time

?



Simulation of the solidification time in the modified distributor



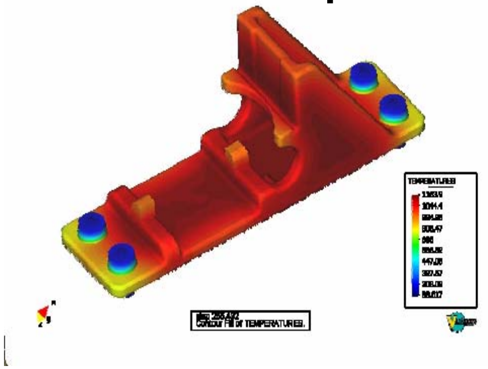
Reduction of the solidification time of the critical area, therefore the time length at high temperature

RESEARCH PERFORMED

7) PREDICTION OF FAULTS IN MELTING PROCESS

Cooling simulation

Thermal simulation – Temperature evolution

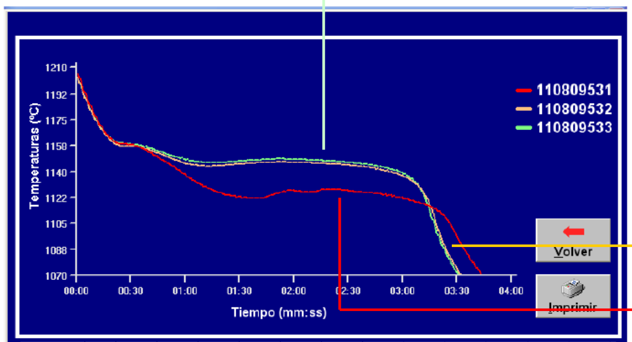


Rm = 416,17 Mpa; Le = 282,30Mpa; A= 23.2%

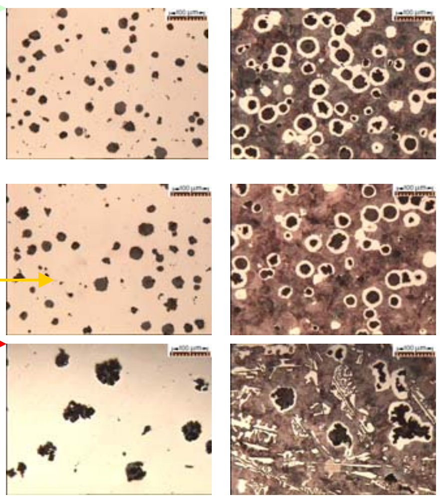
Rm = 402- 412 Mpa; Le = 277-279 Mpa; A= 10,4-13,2%

The cooling is not symmetrical and uniform along the process

There are differents microstructures and mechanical properties depending on the area due to differents coolings



Curva	Tipo	Colada	Pieza	Inoc.	T liq	T min	Recal.	T sol	Esf.	K	%C	%Si	%Mg
110809531	1			Te	1128,6	1122,1	5,9	1101,5	0	0,73	0	0	0
110809532	1			Inocula	1157,8	1143,9	2,7	1112,4	0	0,8	0	0	0
110809533	1			Inocula	1159,7	1146,1	2,6	1118,7	0	0,81	0	0	0



Intensive Research

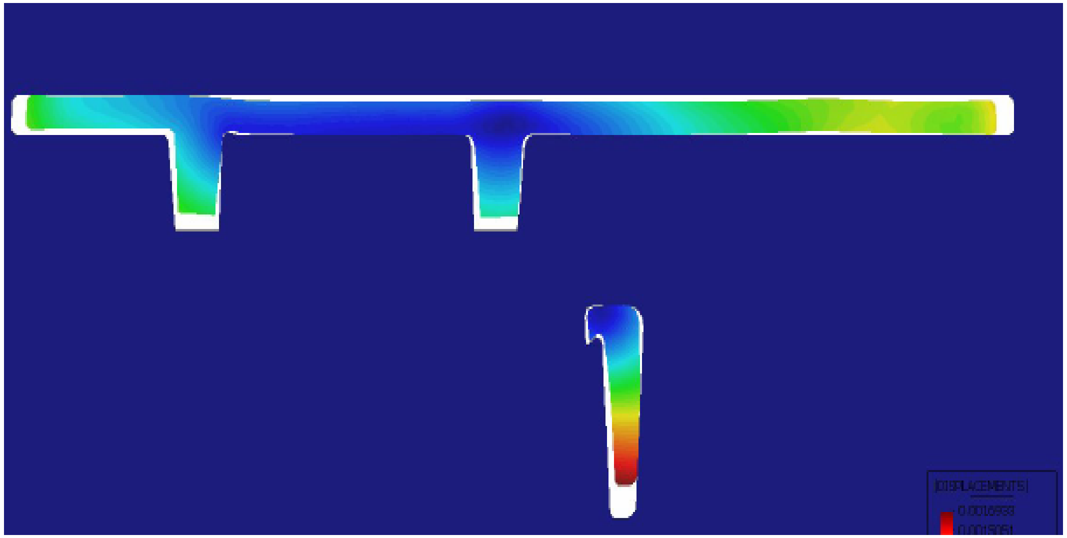
Real cooling curves of nodular cast iron comparing two inoculants (yellow and green curves) and with no inoculant (red curve) connection with their microstructures

FUNDICIONES DE RODA, S.A.

7) PREDICTION OF FAULTS IN MELTING PROCESS

Thermo mechanical analysis

Final deformation on the part



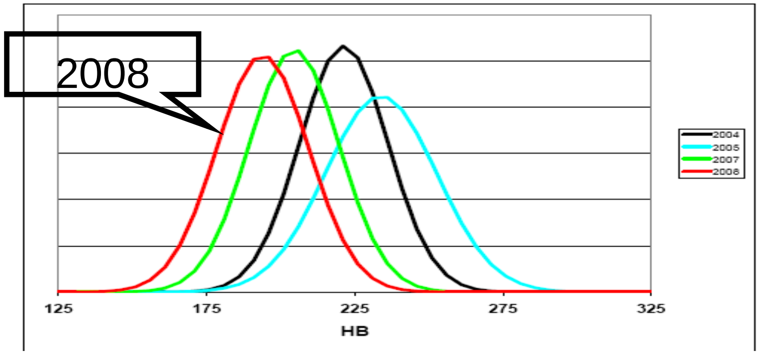
Validation through real piece

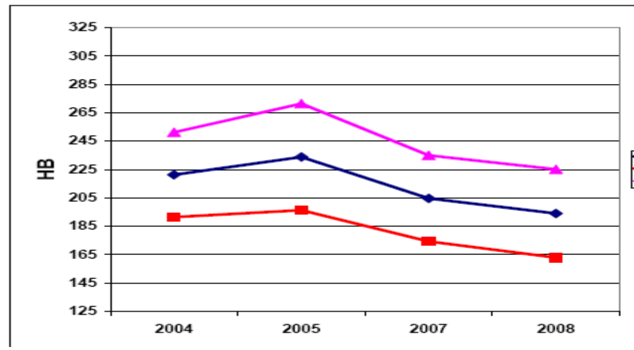
The deformation due to thermal contraction affect the original shape of the geometry

ACHIEVEMENTS OF THE RESEARCH

A. IMPROVE QUALITY OF CAST IRON

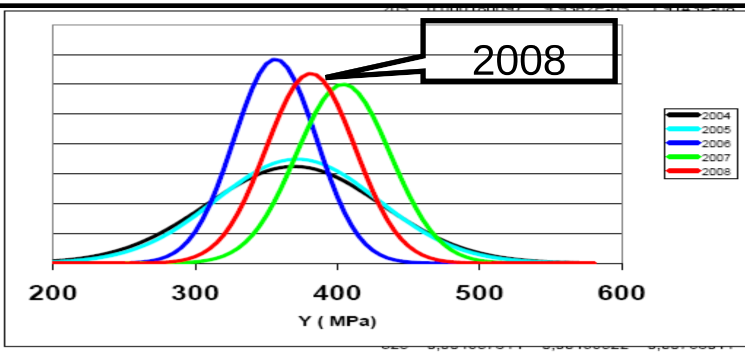
Evolution of EN GJS 500

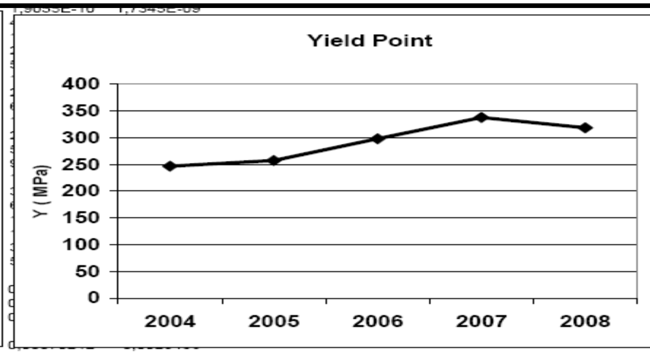




Machinability:

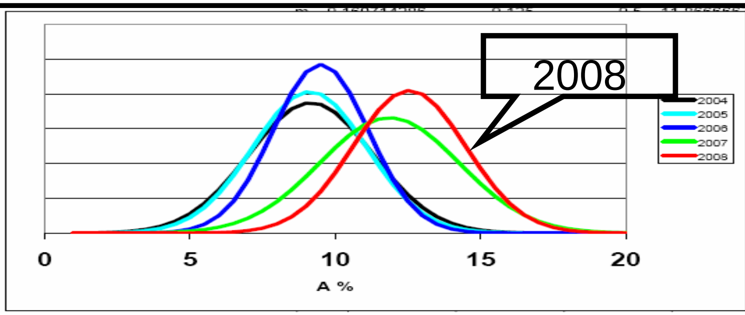
lower hardness= better machinability

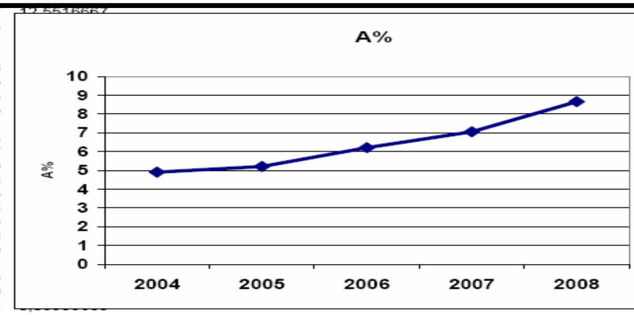




Yield Point:

Higher Yield P
Higher elastic resistance





Elongastion:

Higher Elongation
Higher ductility

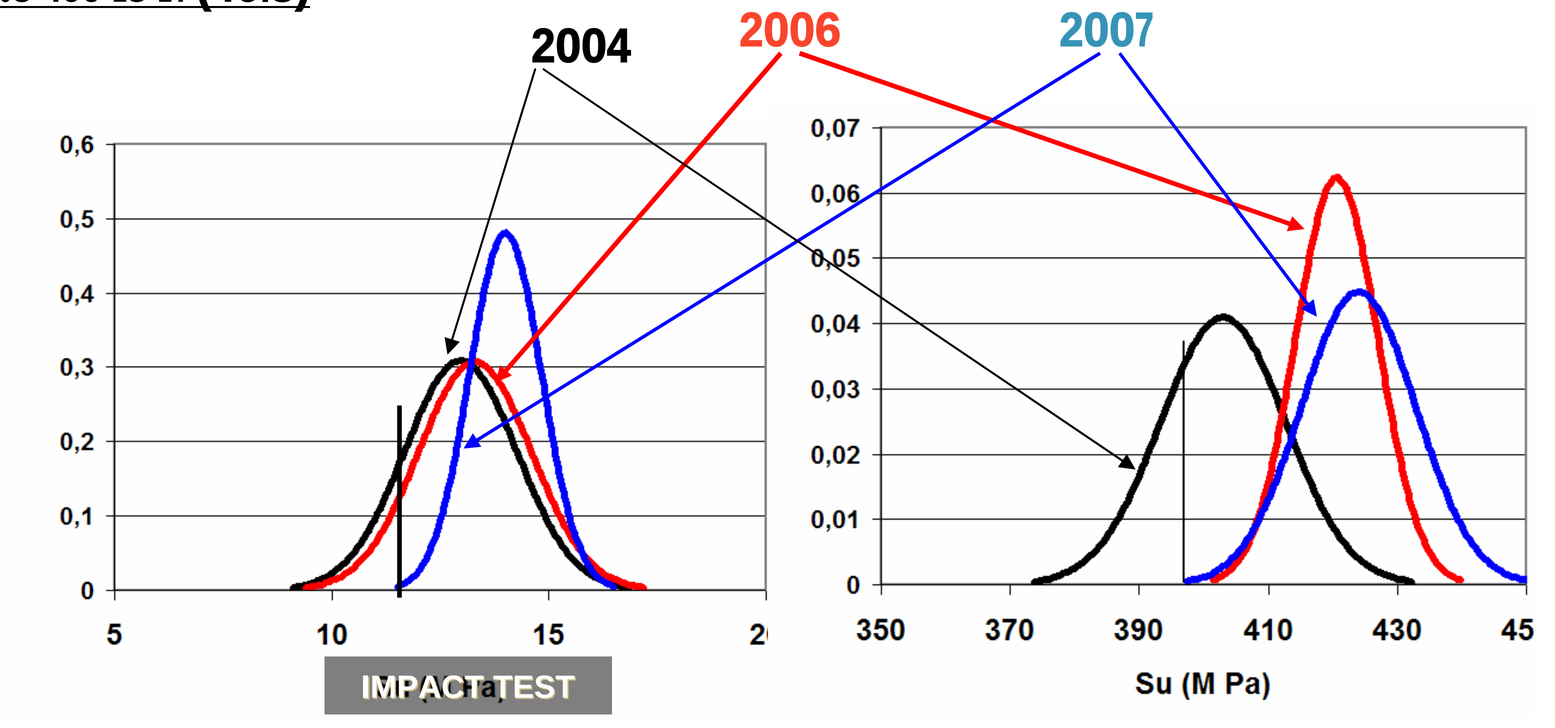
ACHIEVEMENTS OF THE RESEARCH

A. IMPROVE QUALITY OF CAST IRON

Evolution of EN GJS 400-18LT

Enhancing of mechanical characteristics during the project

EN-GJS-400-18-LT (40.3)



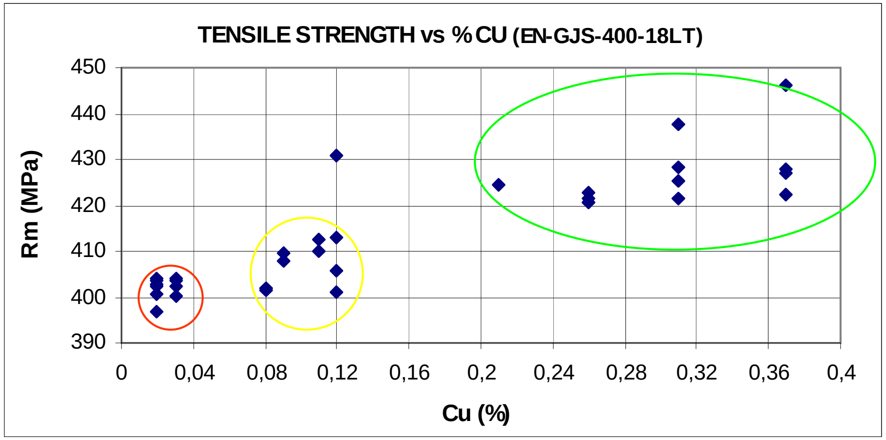
ACHIEVEMENTS OF THE RESEARCH

B. IMPROVE KNOWLEDGE CHEMICAL COMPOSITION FOR CAST IRON

EN-GJS-400-18-LT (40.3)

- MATERIAL FOR PRESSURE VESSELS (ISO 13445)

- AVOID RISK OF FRAGILITY (in cool areas)

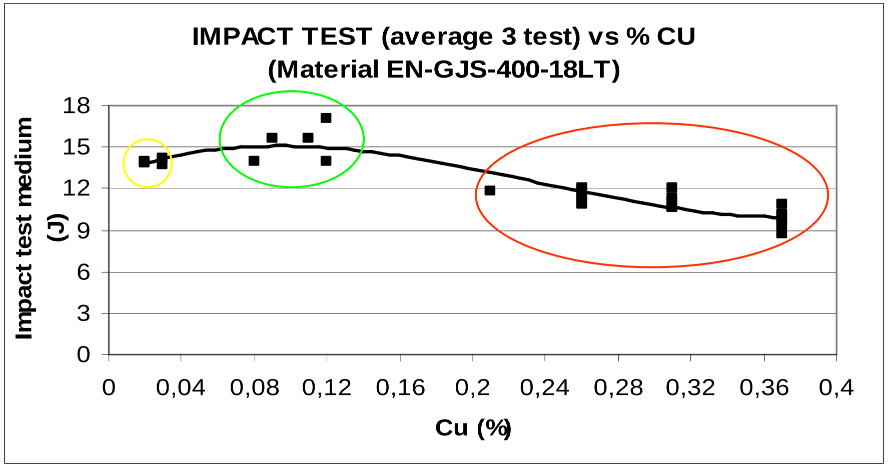


<0.04% Cu – Rm= JUST/ >0.08 To 0.12 – Rm= OK/ >0.20- Rm = TO UP ON

EN-GJS-400-18-LT (40.3)

UP Rm → DOWN ELONGATION / IMPACT TEST

CHEMICAL COMPOSITION ????



LITERATURE: LESS CONTENTS OF % Cu is the BEST

PROHIPP: IS NECESSARY A MINIMUM % Cu TO CARRY OUT MECHANICAL PROPERTIES (Rm and Tensile Test)

<0.04% Cu – Impact test= JUST/ >0.08 To 0.12 – Impact test= TO UP ON/ >0.20- Impact test = TO DOWN ON

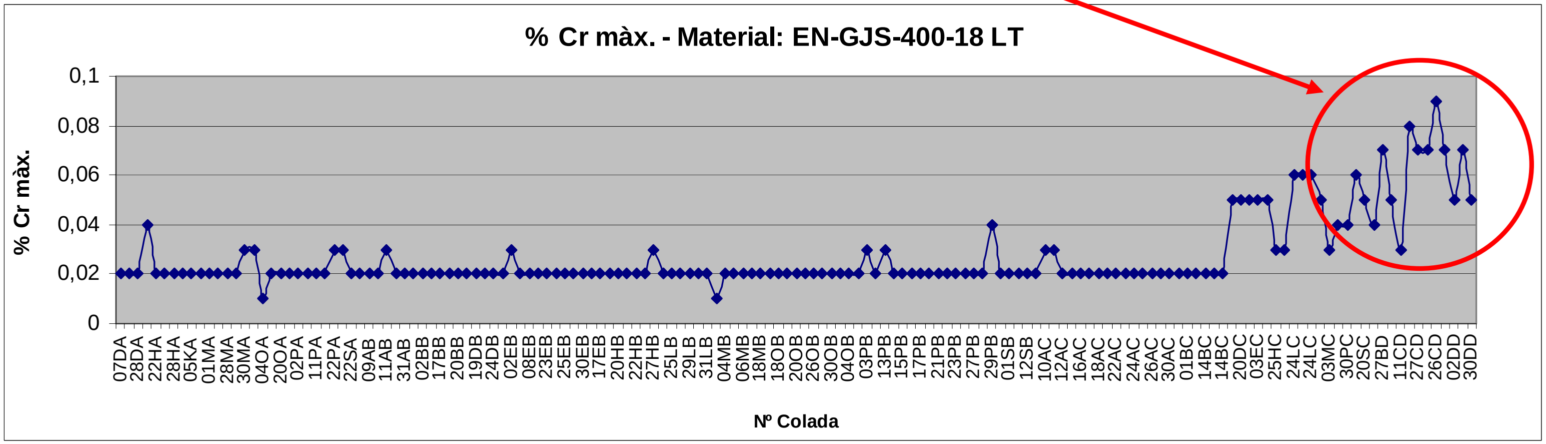
ACHIEVEMENTS OF THE RESEARCH

B. IMPROVE KNOWLEDGE CHEMICAL COMPOSITION FOR CAST IRON

EN-GJS-400-18-LT (40.3)

- RESIDUAL LEVELS SOME CHEMICAL COMPONENTS (Cr, Mo, ...)

- CURRENT STATUS THIS COMPONENTS = UP



LITERATURE: INFLUENCE % Cr in TENSILE TEST

PROHIPP: INFLUENCE %Cr and others in IMPACT TEST

UP %Cr = DOWN IMPACT TEST

ACHIEVEMENTS OF THE RESEARCH

B. IMPROVE KNOWLEDGE CHEMICAL COMPOSITION FOR CAST IRON

STATISTICAL-MULTIVARIABLE MODEL - EXAMPLE

Empirical numerical model of the influence of the chemical composition

SIMULATION OF THE EFFECT OF CHEMICAL COMPOSITION USING MULTILINEAR CORRELATION OF EXPERIMENTAL

$$Su = \alpha_S\ C\% + \beta_S\ Si\% + \chi_S\ Cu\% + \delta_S\ Mg\% + \phi_S\ Mn\%$$

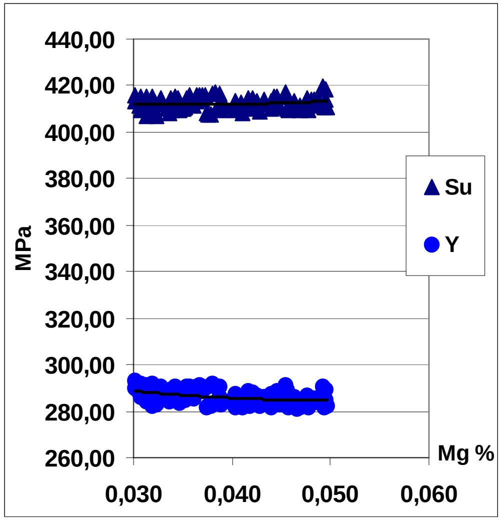
$$Al\% = \alpha_A\ C\% + \beta_A\ Si\% + \chi_A\ Cu\% + \delta_A\ Mg\% + \phi_A\ Mn\% + \lambda_A\ Mn\%^2$$

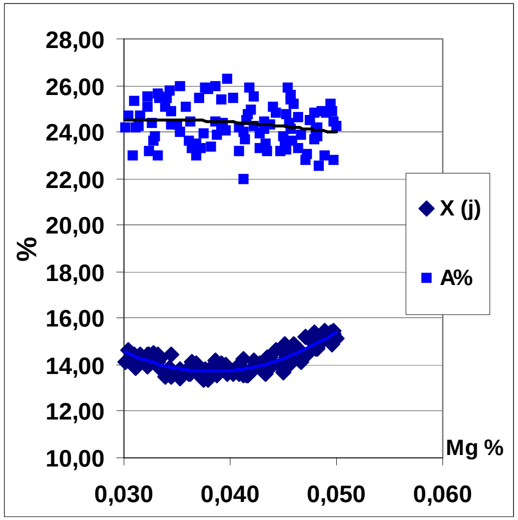
$$X(j) = \alpha_X\ C\% + \beta_X\ Si\% + \chi_X\ Cu\% + \delta_X\ Mg\% + \phi_X\ Mn\% + \vartheta\ C\%^2 + \varphi_X\ Cu\%^2 + \theta_X\ Mg\%^2$$

Su = ultimate strength

C% = Carbon %

Examples of possible plots





Effect of Mg% , given a statistical variability of chemical components (C, Si, Cu, Mn,). Probability analysis (Montecarlo method) (Variability is supposed to be according Normal distributions)

Empirical microstructure prediction

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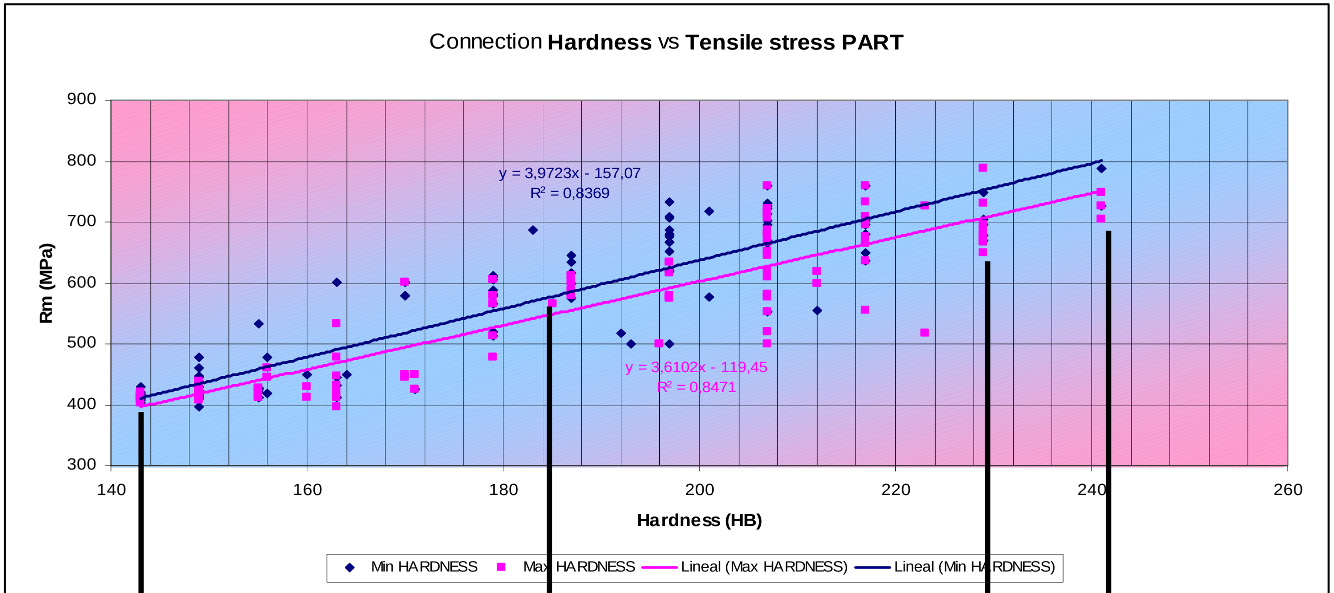
C. IMPROVE KNOWLEDGE MECHANICAL PROPERTIES FOR CAST IRON



HB	Rm	Material
130-175	400	EN-GJS-400-15
170-230	500	EN-GJS-500-75
190-270	600	EN-GJS-600-3
225-305	700	EN-GJS-700-2

NORM UNE-EN 1563

143
EN-GJS-400-15

185
EN-GJS-500-7

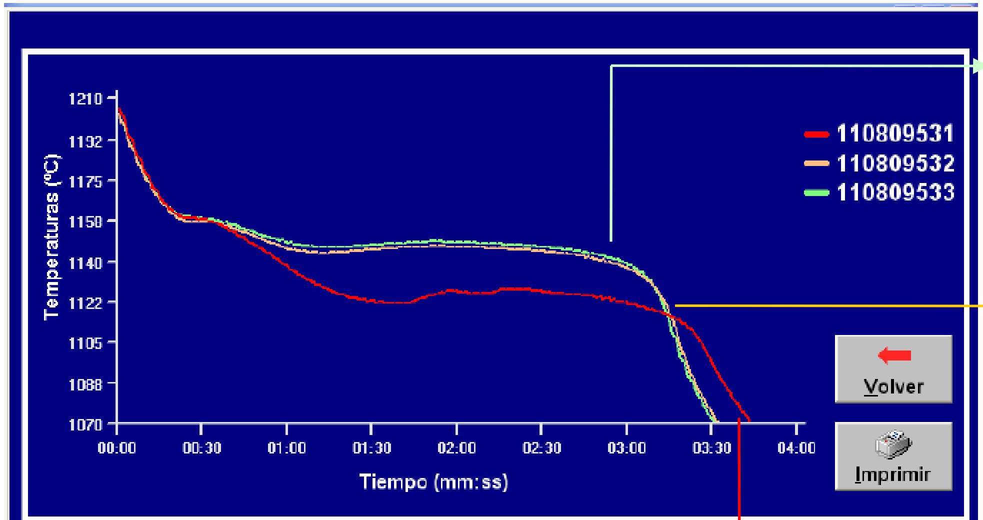
229
EN-GJS-600-3

241
EN-GJS-700-2

ACHIEVEMENTS OF THE RESEARCH

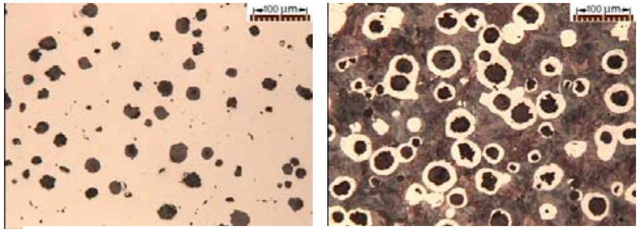
D. INOCULANTS / EXPERIMENTAL COOLING CURVES / MICROSTRUCTURE RESEARCH

EXPERIMENTAL COOLING CURVES

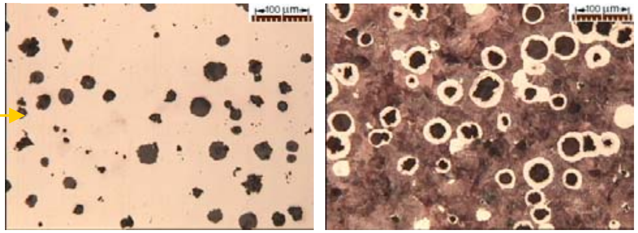


Curva	Tipo	Colada	Pieza	Inoc.	T liq	T min	Recal.	T sol	Esf.	K	%C	%Si	%Mg	T
110809531	1			Te	1128,6	1122,1	5,9	1101,5	0	0,73	0	0	0	
110809532	1			Inocula	1157,8	1143,9	2,7	1112,4	0	0,8	0	0	0	
110809533	1			Inocula	1159,7	1146,1	2,6	1118,7	0	0,81	0	0	0	

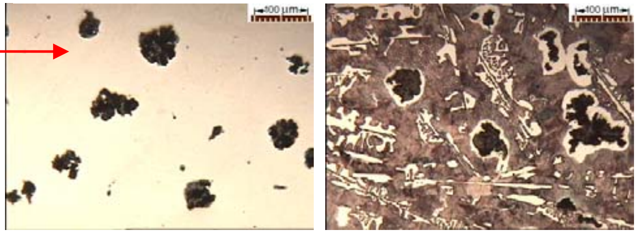
INOCULANT A (CURVE GREEN)



INOCULANT B (CURVE YELLOW)



WITHOUT INOCULANT (CURVE RED)

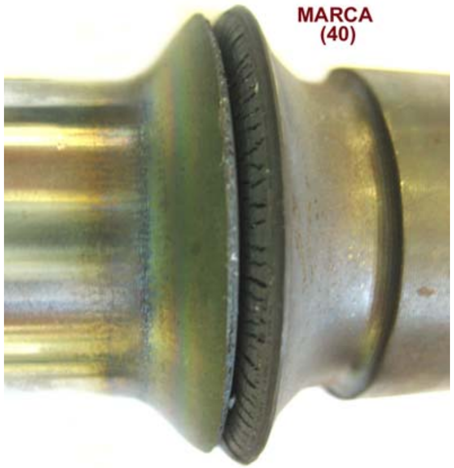


PROHIPP: INFLUENCE DIFFERENT INOCULANTS IN COOLING CURVES AND FINAL MICROSTRUCTURE

ACHIEVEMENTS OF THE RESEARCH

E. ACHIEVE A WELDING CASTING

STATE OF ART: CAST IRON IS VERY DIFFICULT FOR WELDED ESPECIALLY FRICTION WELDING

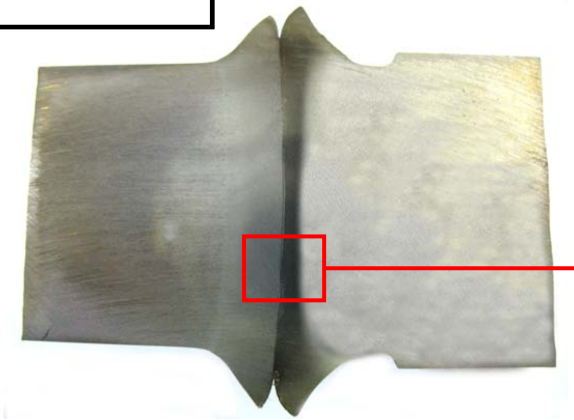


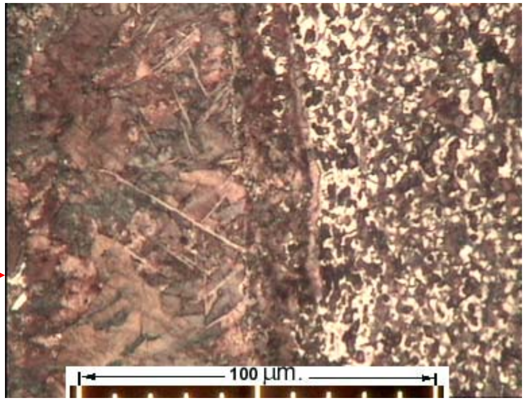
LITERATURE:

(KUKA-MANUFACTURING MACHINING FOR FRICTION WELDING)

DUCTIL CAST IRON IS POSSIBLE WELDING

PROHIPP: SCAGLIA TRY TO WELD CAST IRON WITH PARAMETERS OF KUKA AND THE RESULTS ARE NO OK





THE JOINT OF TWO PARTS IN NOT OK

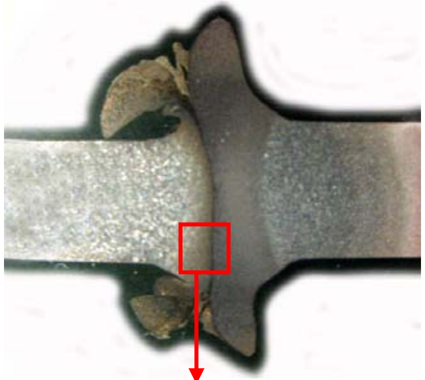
E. ACHIEVE A WELDING CASTING

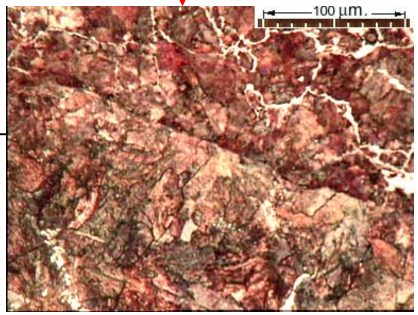
LITERATURE:

(EU PATENTS)

MINIMUM Nº NODULUS AND CHEMICAL COMPOSITION

PROHIPP: Nº NODULUS SIMILAR BUT WITH DIFFERENTS CHEMICAL COMPOSITION AND PROCESS OF MELTING





THE JOINT OF TWO PARTS IS OK

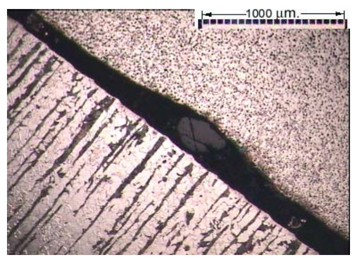
ACHIEVEMENTS OF THE RESEARCH

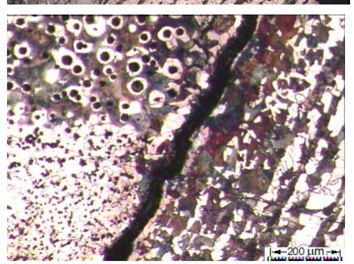
E. ACHIEVE A WELDING CASTING

OBJECTIVE: CAST IRON PIECE FOR WELDING

CAST IRON BAR WITH STEEL INSERTS

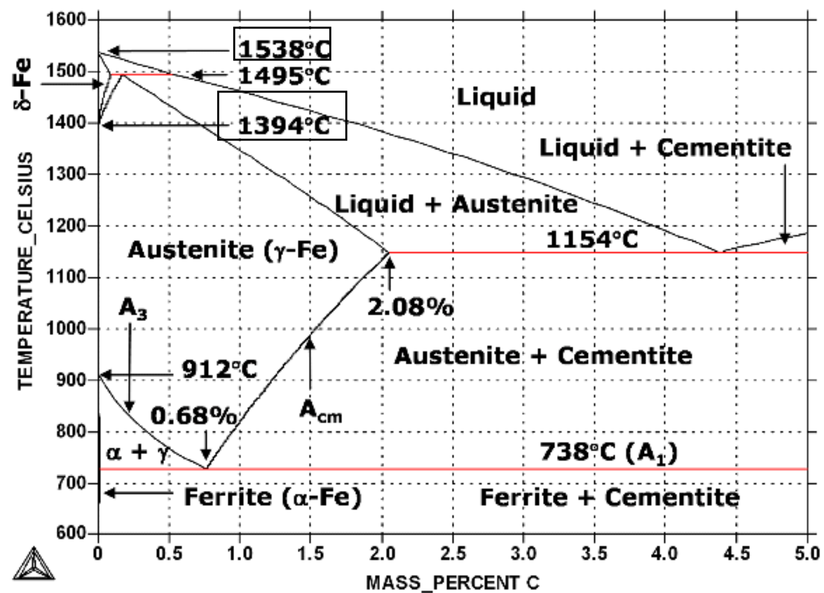
FIRST RESULTS **NO OK**





PROBLEM: TªMELT STEEL > TªMELT CAST IRON

IN CONSEQUENCE STEEL DOES NOT MELT WITH CAST IRON PIECE (theorical)



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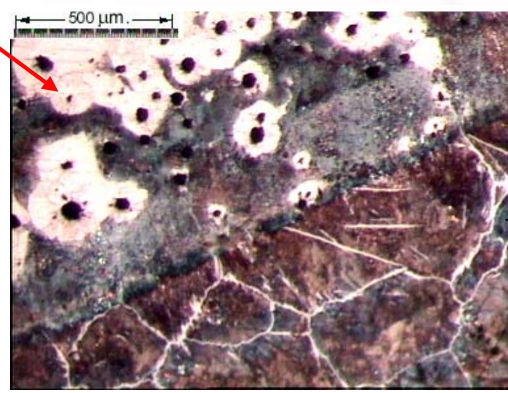
ACHIEVEMENTS OF THE RESEARCH

E. ACHIEVE A WELDING CASTING

OBJECTIVE: CAST IRON PIECE FOR WELDING

CAST IRON BAR WITH STEEL INSERTS

<u>STELL INSERTS WITH UP CONTENT OF %C IN ESPECIFIC AREA IN ORDER TO DOWN Tª MELT</u>



THE JOINT OF TWO PARTS IS OK