Development of mixed (ferrito-ausferritic) structures for spheroidal graphite irons

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Abstract

For years in the automotive industry the objective is to reduce the weight of components for well known car performance and environmental reasons. One way is to use more resistant materials for instance in the area of suspension foundry castings. Austempered Ductile Iron (ADI) is one of the most unique materials due to its particular mechanical properties. Some tests have been made on chassis parts like front knuckles which have confirmed the good mechanical results obtained about the tensile strength and elongation. Nevertheless, the impact test results can be improved by some metallurgical structure evolution.
The combination of ferritization and ausferritization heat treatments for nodular SG irons should lead to a good compromise of characteristics between yield strength, elongation and impact test. The paper describes some of the works made according to this target acting on chemical and heat treatment parameters. Micrographic structures and mechanical properties obtained are shown. A comparison with existing ADI grades is established. Different structures and associated characteristics are described which allow to imagine a first orientation for chassis applications. Making use of a dilatometer several tests have been runned to define properly the quality of the structures.

Riassunto

È da anni che l'industria automobilistica si pone per ben noti motivi ambientali e di performance come obiettivo quello della riduzione del peso dei componenti dei suoi veicoli. L'impiego di materiali più resistenti, ad esempio per le fusioni di sospensioni in fonderia, costituisce un passo in questa direzione. La ghisa austemperata (ADI) è un materiale molto particolare grazie alle sue proprietà meccaniche peculiari. Le prove su fusi a snodo anteriori ed altre parti del telaio hanno confermato i risultati dei test meccanici di resistenza alla trazione e di allungamento. Lo sviluppo della sua struttura metallurgica, tuttavia, potrà portare al miglioramento dei risultati delle prove ad impatto.
Combinando la ferritizzazione con l'ausferritizzazione per il trattamento termico della ghisa grafitica sferoidale (SG) si dovrebbe raggiungere un buon compromesso fra il limite di snervamento e l'allungamento ed il comportamento nella prova ad impatto. I risultati di studi condotti in questo senso, agendo sui parametri dei trattamenti chimico e termico, vengono riportati con l'illustrazione delle strutture e delle proprietà meccaniche ottenute. Si fa pure il confronto con i gradi ADI già conosciuti. Vengono anche descritte delle diverse strutture e le relative caratteristiche delle quali si può prospettare un primo orientamento verso le applicazioni per la fabbricazione di telai. La giusta definizione della qualità delle stesse strutture è stata determinata in una serie di test dilatometrici.

INTRODUCTION

We often use heat treatments in foundry industry to optimise the irons characteristics. Among those treatments we find the ausferritic (previously called bainitic) treatment which allows to get a structure based on austenite between perlite and martensite. The metallurgical phase obtained is called ausferrite and is composed of acicular ferrite and residual austenite saturated by carbon atoms. This last metallurgical component gives to the iron excellent characteristics and in particular a good relationship between a high elastic limit and good elongation.
Ausferrite can be compared to steel bainite but this last one is composed of acicular ferrite and carbides. In case of irons the high silicon content avoids carbides precipitation and leads to a structure with acicular ferrite and residual austenite, called ausferrite.
This kind of structure gives to spheroidal graphite (SG) irons (called in that case ADI, Austempered Ductile Irons) a good compromise of mechanical characteristics and physical properties, which supplies a great advantage towards conventional SG irons.
During works target of which was to improve the impact test, we have seen that ADI irons did not have a deformation ability better than traditional ferritic SG irons. Nevertheless, this deformation ability is very useful when specified for car chassis castings for instance.
Those structures can be made by two ways :

- modifying the chemical analysis, increasing the silicon content,
- modifying the heat treatment with a previous ferritization.

The paper presents the works made according to the two ways and mains results obtained about mechanical characteristics, metallographic structures and dilatometric curves made to simulate the heat treatment.

EXPERIMENTAL PROCEDURE

In Inasmet prototype shop have been poured three batches of Y- bloc (ASTM – A 395) samples type 25 mm thickness cast in resin sand moulds. Different chemical analysis have been proposed to define the elements influence on material characteristics.
3 Silicon levels have been selected:
- pouring N°1 : Low Silicon,
- pouring N°2 : Medium Silicon,
- pouring N°3 : High Silicon.

Melting has been made with an electric induction furnace, medium frequency, 100 Kg capacity. Pouring temperature 1520°C.

Ausferritization heat treatment has been conducted in ADISA company at Irun / Spain, which owns equipment composed of austenitizating furnace under controlled atmosphere and a salt bath for the isothermal treatment. Previous ferritization treatment occurred in a traditional laboratory furnace in the technical centre of Inasmet at San Sebastian/Spain.
Mechanical characteristics have been measured using normalized samples 6mm diameter for tensile strength, 10x10 mm unnotched samples for impact test and hardness according to the Brinell standard specification 3000/10/15.
Micrographic structures have been observed from cuts made in the tensile sample head, polished and etched by Nital 4%.
Dilatometric curves have been traced with the help of a high speed DT1000 dilatometer.

RESULTS AND DISCUSSION

Austenitization temperature (Tγ) and time (tγ) influence according to chemical analysis.

Following heat treatment has been applied:
- Ferritization with a fully ferritic structure.
- Austenitization in the (α–γ) domain.
- Quenching and staying in the salt bath at the right upper bainite temperature (ausferrite).

Mechanical properties

Table 1 shows a synthesis of results got for tensile strength, hardness and impact test. Figures come from the all values population, according to different heat treatment parameters. Generally, tensile strength increases with austenitization temperature and time. This result is explained by a better level of structure transformation in the salt bath, as, the austenitization kinetic is higher and the carbon solubility in austenite is increased (1). Hardness levels are lower like the elastic limit. Elongation is acceptable in all cases, even with lower levels of transformation.
The impact test shows a certain dispersion of values. Results with lower Silicon content are better. We know that hardening the ferrite, the Silicon reduces the material toughness (2).

Micrographic structures

Samples microscopic observation allows to make the following comments: samples from pouring N°3 (medium Silicon) presents a ferritic structure with a little bit of residual austenite in grain boundaries and perlite in cells boundaries. Increasing austenitization temperature and time leads to more residual austenite and pearlite. If austenitization temperature is even higher, the ausferritic structure appears. We can see that kind of evolution on micrographic photos, below (Figure1).
Samples from pouring N°6 (High Silicon) present the same kind of evolution, but with a lower pro-eutectoid ferrite trans-

TABLE 1 - Mechanical characteristics. Range of values

Values	Tensile Strength MPa	Yield Strength MPa	Elongation %	Hardness (HB)	Impact (J)
Maxi	850	571	20.0	243	86
Mini	606	437	9.3	193	23

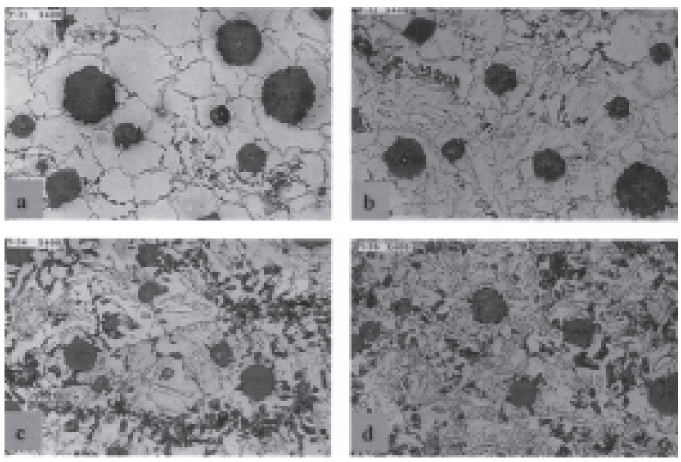

Fig. 1: Pouring 3 (medium Silicon) a) Tγ1,tγ1; b) Tγ1,tγ2; c) Tγ2,tγ2; d) Tγ3,tγ2. Tγ1<Tγ2<Tγ3 and tγ1<tγ2

formation level, due to higher level of Silicon. Figure 2 shows this evolution.
Talking about chemical elements influence on quenching TTT curves position, we can say that all elements move the curves on the right side, except Cobalt (3). This point is right for steels in which Silicon is under 0,5 %. In irons, with higher Silicon content, we have seen that when the Silicon content increases, the hardenability of other elements decreases (4). This fact, joined to other austenitisation temperature and time effects can explain the structures evolution (1).
Effectively, figure 3 shows the structure obtained with pouring N°1 (Low Silicon), treated in the same conditions as pouring 3 (medium Si) and 6 (high Si). We can see then an ausferritic structure with pro-eutectoid ferrite but without any pearlite.

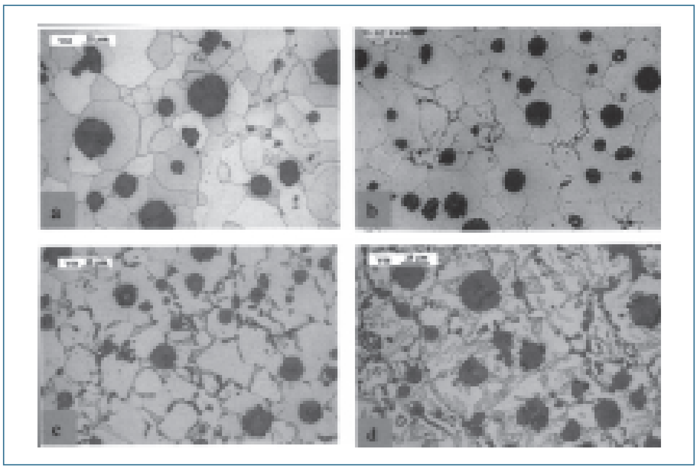

Fig. 2: Pouring N°6 (High Silicon) a) $T\gamma1,t\gamma1$; b) $T\gamma1,t\gamma2$; c) $T\gamma2,t\gamma2$; d) $T\gamma3,t\gamma2$. $T\gamma1<T\gamma2<T\gamma3$ and $t\gamma1<t\gamma2$

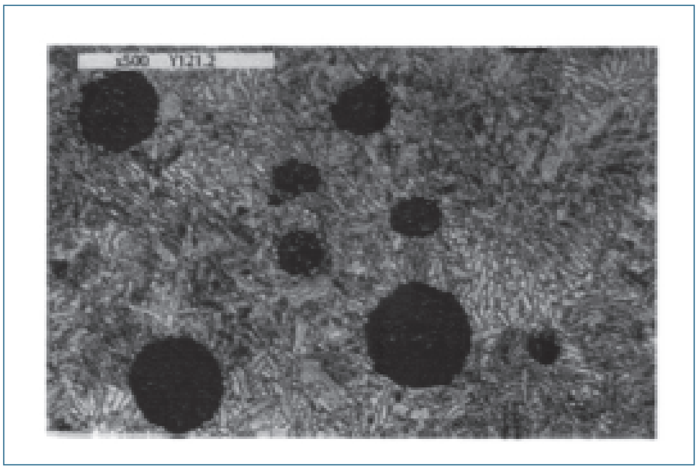

Fig. 3: Pouring N° 1 (low Silicon). $T\gamma1,t\gamma2$

Dilatometric curves

Dilatometric tests have been made on pouring 3 (medium Si) in order to know the structure evolution during heat treatment. It has been reproduced the process conditions corresponding to a 30 mm diameter cylinder.
Test result confirms the no ausferritic creation for the low austenitization temperatures (figure 4) and microscopic observations made on metallurgical structures (pro-eutectoide ferrite, austenite and pearlite). Ausferritic structure appears for a higher austenitization temperature (figure 5). This last situation is also meet with pouring 1 (low Silicon level) whatever the austenitization temperatures.

Need analysis for salt bath treatment

As there is no ausferrite in some of the structures studied in § 3.1, we have thought to suppress the isothermal treatment in the salt bath in order to simplify the heat treatment. A test has been made with pouring 3 (medium Silicon) in which a previous heat treatment cycle has been reproduced. Quenching in salt bath has been replaced by a direct quenching in oil at room temperature. Results are shown here after.

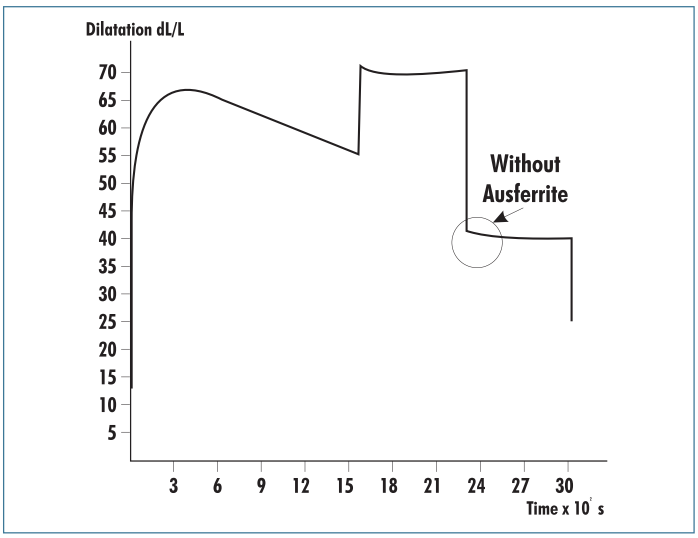

Fig. 4: Pouring N°4 $T\gamma1$. Dilatation in fonction of time. No dilatation (without any ausferrite) during staying in salt bath.

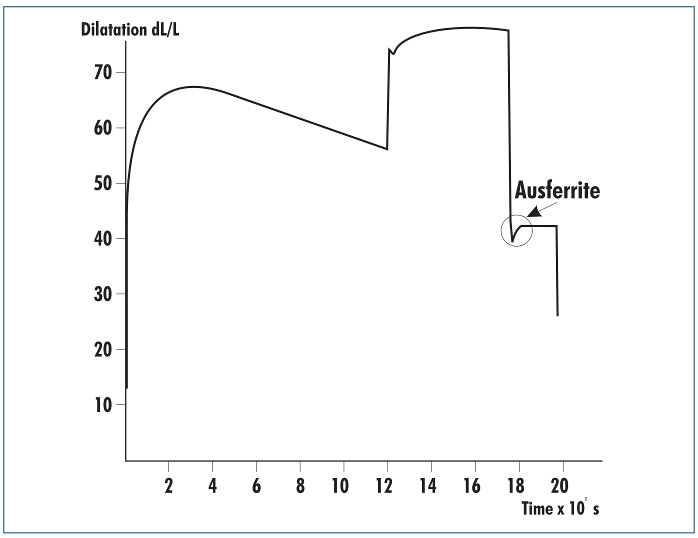

Fig. 5: Pouring N°3 $T\gamma3$. Dilatation in fonction of time. Dilatation (ausferritique reaction) during staying in salt bath.

Mechanical properties

Table 2 shows tensile strength, hardness and impact test results.

TABLE 2 - Pouring N°3. Mechanical characteristics

Ref.	Tensile Strength			Hardness	Impact test			
	Tensile (MPa)	Elastic Limit (MPa)	Elongation (%)	HB	Individual values (J)			Average value (J)
Salt bath	668	461	16	197	113	71	76	86
Oil bath	798	510	5.3	306	27	32	31	30

Generally, quenching in oil bath gives more tensile resistance and hardness but less ductility and less toughness than with quenching in salt bath for the same level of ferritization and austenitization.

Micrographic structure

With oil quenching, micrographies show the presence of martensite in the metallographic structure (figure 6).

Dilatometric curves

One dilatometric test has been made to confirm martensite creation during the oil quenching.
On figure 7 we can clearly observe expansion due to martensite precipitation. Ms temperature can be situated around 100 °C.

Mechanical characteristics comparison

Following the results analysis, mixed structures can be arranged in two classes, in function of metallurgical phases observed. Characteristic description and comparison with other traditional SG irons is made here after.

Mixed structure 1 (pro-eutectoide ferrite, pearlite and austenite – fig 1b)

Structure from pouring N°3 (medium Silicon) is well representative of this group.
That kind of structure allows to get a tensile strength and elastic limit corresponding to a pearlitic structure and a ductility like ferritic structure (elongation). Hardness is situated in the middle.
In comparison to ADI ausferritic structures we can notice that tensile and elastic limits are lower but that ductility is higher with a mixed structure.

Fig. 6: Pouring3 (medium silicon). Oil quenching

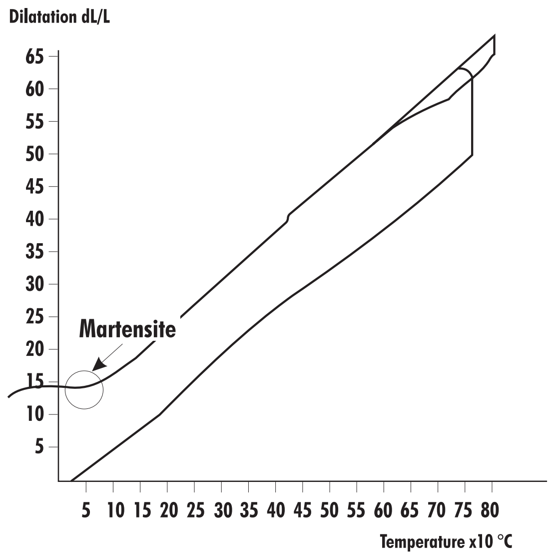

Fig. 7: Dilatation-température curve. Dilatation (martensite formation) during cooling at room temperature

Lastly, impact test values are close to ferritic or ausferritic ones.

Mixed structure 2 (proeutectoid ferrite and ausferrite (acicular ferrite and residual austenite), fig 3

Pouring 1 structure (low Silicon) is representative of this group.

Tensile strength, elastic limit and hardness are higher than mixed structure 1. Values are very similar to pearlitic values but elongation is much higher near ferritic structure. Impact test result is close to mixed structure 1.

TABLE 3

Irons	Tensile strenght (MPa)	Tranction Elastic imit (MPa)	Elongation (%)	Hardness (HB)
EN-GJS-400-15	400	250	15	155
EN-GJS-700-2	700	420	2	265
EN-GJS-800-8	800	500	8	290
Mixed N°1	690	490	17.5	205
Mixed N°2	785	535	13.5	241

Table 3 shows mechanical characteristics comparison of mixed structures 1 and 2 with other irons grades EN-GJS-700-2 (pearlitic) et EN-GJS-400-15 (ferritic) issued from standard EN1563 :1997 and grade EN-GJS-800-8 (ausferritic) issued from standard EN1564 :1997.

To summarise, we can say that mixed SG structures bring :

- In regards to pearlitic irons, a better ductility trough elongation and better impact test resistance.
- In regards to ferritic irons a better tensile resistance, higher hardness and same level of toughness.
- In regards to ADI ausferritic irons a lower tensile resistance, same toughness but better hardness (machinability) and ductility.

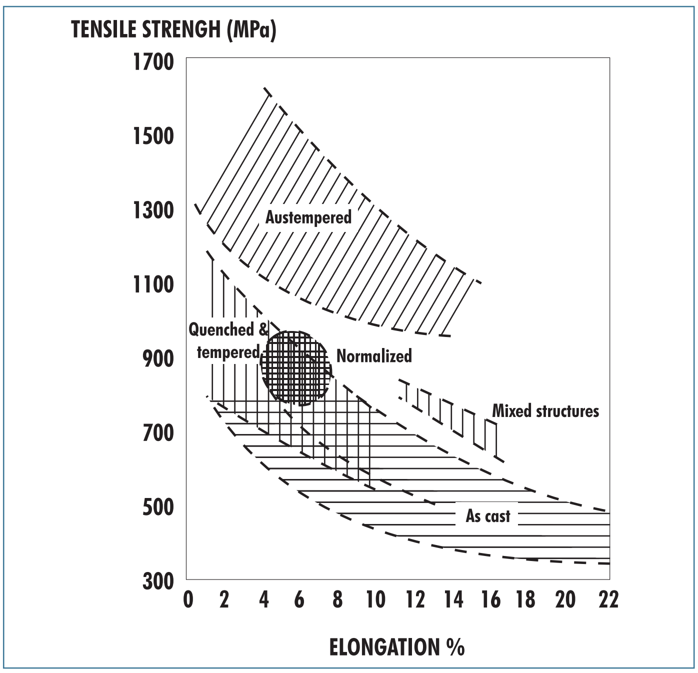

Fig. 8: Tensile strength versus elongation for different types of SG Irons.

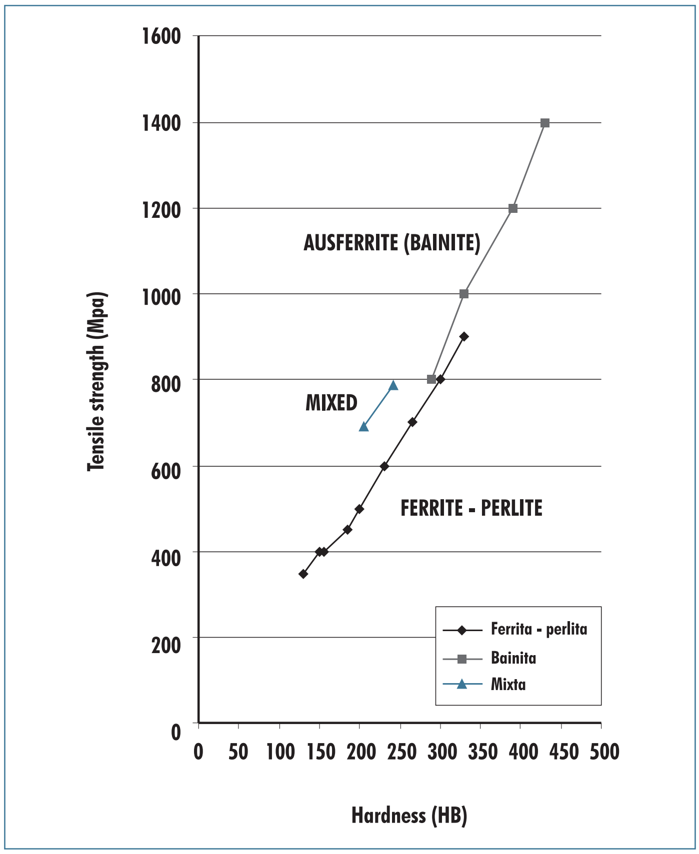

Fig. 9: Tensile strength versus Brinell hardness for different types of SG Irons

In figure 8, is represented tensile strength versus elongation for different kinds of SG irons. Mixed structure area is separated from traditional areas occupied by ferritic and pearlitic irons.

On the same way, on figure 9 is represented tensile strength versus Brinell hardness. In that configuration, mixed structures are revealed as a prolongation of ausferritic structures.

CONCLUSIONS

The heat treatment process which consists in making a ferritization treatment followed by an austenitization treatment in the domain (α–γ) and then a salt bath isothermal quenching, leads to a mixed ferritic-ausferritic structure in SG irons.

Depending on Silicon contents, mixed structures are made of pro-eutectoid ferrite, perlite and austenite with medium Silicon levels, or made of pro-eutectoid ferrite and ausferrite (acicular ferrite + residual austenite) with a high level of Silicon.

Mixed structures lead to a good mechanical characteristics compromise, with a tensile resistance and hardness close to pearlitic structures and ductility and toughness close to the ferritic structures.

According to those results, mixed structures can allow the foundryman to enlarge the application field of SG irons in particular when Austempered Ductile Irons cannot bring the ductility or deformation values needed. Moreover, mixed structures allow to get a better machinability than ADI castings.

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