Tests and Examinations of the Old Hône-Bard Railway Bridge

W. NICODEMI, M. BONIARDI - Istituto di Chimica Fisica Applicata - Politecnico di Milano

Abstract
Mechanical and metallographic tests were run on surviving fragments of the late-19th-century Hône-Bard railway bridge demolished in the Sixties to assess the characteristics of the « agglomerated » (similar to « wrought ») iron used in their construction. An explanation is also offered of the suprising discrepancy between the lab data for this iron and its brilliant service record.

Riassunto
Avendo a disposizione del materiale con cui erano costruite le travate portanti del ponte ferroviario di Hône-Bard (posto in opera alla fine del secolo scorso e demolito soltanto negli anni sessanta) è stata predisposta una serie di prove meccaniche e metallografiche atte a valutare le caratteristiche del « ferro agglomerato » con cui queste strutture erano realizzate.
A fronte del curioso contrasto tra i dati sperimentali ricavati in laboratorio ed il brillante comportamento in opera del materiale, si è tentato di spiegare il suddetto differente comportamento sulla base dei risultati ottenuti.

Introduction

Severe damage was caused during the last war to several bridges along the Chivasso-Ivrea-Aosta branch railway line. They had been erected aroud the year 1896, when the line was extended to Aosta.

On the cessation of hostilities, the State Railways set about a complete reinstatement of all the bridges on this line.

Initially, attention was directed to those that had been destroyed or severely damaged. Eventually, following the poor outcome of structural tests, it was decided to replace them all. This was done during the Sixties.

Many of these tests were carried out at the Railway's Experimental Institute and cross-checked in the labs of the Milan Polytechnic's Metallurgy Institute.

Two reasons lie behind the preparation of the present paper.

In the first place, it enables the authors to look back with nostalgic pleasure to an experiment conducted under the direction of their teacher and friend, Prof. R. Zoja, when they were some twenty-five years younger. In the second place, since much of the old bridge is still available for study, the opportunity has been taken to compare the results of this original investigation of its characteristics with some data provided by more modern techniques, namely scanning electron microscopy (SEM) and fractography.

The material examined

The origin of the steel used to build the Hône-Bard bridge (fig. 1) has not been recorded. We feel, however, it was made of what the Italian State Railways then called «agglomerated iron» (i.e. not cast). Evidence in favour of this view is provided in fig. 2 showing the macroscopic appearance of an angle piece and a plate after etching with 2% Nital.

Agglomerated iron is in many ways similar to bloom iron, since it contains large amounts of slag. It was produced by rolling bushels of old iron from all kinds of working operations into sections an sheets of the sizes required.

It was widely used for the construction of railway bridges until 1916, when a much more severe design calculation method was introducted and more technologically advanced materials were in ready supply on the Italian market.

A good idea of its soundness can be gleaned from the fact that even in 1981 the railway authorities allocated the tidy sum of Lire 470 bn for the reinforcement and rehabilitation of foundations and superstructures, and the replacement of aged bridges still in service.

A passage from the specifications approved by the Board of Directors on 2 October 1908 and adopted without change in the administration's 1916 Technical Standars can be usefully quoted: «Agglomerated iron must be mild, fibred, readily weldable, malleable and hot and cold worked according to the forms prescribed without internal or external splitting or alterations. On fracture, it must display a grey, uniform, fibrous texture».

With reference to sections and sheets, it is laid down that: «Pieces made of either agglomerated iron or cast steel must be surface-rolled with sharp, continuous edges, free from seams, roaks, splits, welding defects, burns metal losses or other defects and with no traces of oxide and slag».

The mechanical requirements for agglomerate iron and cast steel set out in the 1908 specifications are shown in Table 1.

TABLE 1 - Mechanical specifications laid down by the Italian Railways in 1908

Indications	Agglomerated iron (common)	Cast steel (homogeneous)
Sections	Min. quality coefficient	
Bolts		

Chemical analysis

The results of the chemical analysis of the agglomerated iron used for the Hône-Bard bridge are compared with those from two other bridges on the same line (at San Marcel and Ivrea) in Table 2.

It will be seen that agglomerated iron with its high P and low C percentages was generally employed for plates and angle pieces, whereas a *cast* steel (more C, less P), with undoubtedly better properties and greater strength, was preferred for the bolts.

TABLE 2 - Chemical composition of agglomerated iron from the agglomerated iron used for the weight-bearing longitudinal members of the Chivasso-Ivrea-Aosta line railways bridges

	Chemical composition
Location	Type of section
	large plate
	small plate
	angle piece
	bolt
	trentle plate
	....

Mechanical tests

The strength of the material was then assessed by tensile tests on specimens taken both along and at right angles to the rolling direction (Table 3).

A series of impact tests was also performed to evaluate the toughness of the material. This procedure, of course, was not contemplated in the 1908 specifications, as it had not yet been introduced. The transition curves for both longitudinal and transverse test specimens from one of the plates are shown in fig. 3.

Examination of the results as a whole makes it clear that even the 1908 specifications had not been fully complied with. The tensile tests indicate that the behaviour of the longitudinal specimens is fully comparable with that of a modern Fe 360.

The transverse specimens, on the other hand, are marked by frequent premature failure with low ultimate elongation and area reduction percentages. The transition interval in the impact test is around −10°C. This, however, is associated with particularly low energy absorption values.

TABLE 3 - Mechanical characteristics of agglomerated iron from three bridges on the Chivasso-Ivrea-Aosta railways line

Location

Metallographic analysis

Metallographic examination of a series of specimens from both flat and angular sections showed that their microstructure consisted of ferrite with a normal crystalline grain not oriented in the rolling direction (fig. 4).

A microanalysis was then made of the basic metal and its slag content. It was found that the agglomerated iron was was a Fe alpha (0,01÷0,02% C) with appreciably higher than usual O and P contents (fig. 5). Three types of inclusion were observed:

— nodular inclusions measuring 5-10 μm, consisting of iron oxides rich in Ca, S and P;

— compact, elongated inclusions measuring up to 400 μm composed of Fe and Mg phosphates, silicates, together with Fe sulphide, Ba sulphate and Fe carbide microinclusions;

— elongated, fragmented inclusions measuring up to 1-2 mm composed of Fe, Mg and Al oxides, phosphates and silicates.

One particularly large inclusion in an impact test bar was chemically analysed. The results showed that it was composed of a large number of oxides (Table 4).

TABLE 4 - Chemical composition of a large inclusion from an impacts test specimen (A) and the electrolytic dissolution residue of a specimen taken from a flat plate (B)

Specimen

Fractographic analysis

An SEM study was then made of the fracture surfaces of impact test specimens. Macrographic inspection revealed a distinctly «woody» appearance with apparently fragile crack tip propagation unaccompanied by plastic creep or area reduction (fig. 6). This is referable to the marked anisotropy of the matrix brought about by both the many inclusions oriented in the rolling direction and the large amounts of nodular oxides observed earlier. Microscopic examination, on the other hand, showed ductile yielding over nearly the whole surface in the form of extensive «dimples» that had formed around the inclusions (fig. 7). Elsewhere, a typical brittle fracture behaviour (cleavage) was noted, with separation along crystallographic planes and formation of the so called «river patterns».

Conclusions

When the realises that some fifty years had already gone by since the revolutionary discoveries of Bessemer, Martin and Siemens by the time these bridges were installed at the turn of the century, one cannot help but be amazed at the slowness with which these new manufacturing technologies were adopted in Italy.

This situation, indeed, reflects a state of affairs that can still be discerned in Italian industry, namely expert metallurgists and technical designers/users operating on opposing fronts.

In any event, there can be no doubt that the agglomerated iron produced by the iron and steel industry almost a century ago was greatly inferior to today's steels, both in terms of plain strength (yield strength, ultimate tensile strength, toughness, etc.) and from the purely metallurgical standpoint (chemical analysis, structural homogeneity, inclusions, etc.).

In view of the poor quality of the metal used in the Hône-Bard, San Marcel and Ivrea bridges, an increasing frequency of increasingly heavy traffic with reference to the conditions envisaged in the original design, and the cold weather, especially in the Aosta Valley, one may well be surprised at their lasting so well without failure for over 60 years. An explanation for this strikingly brilliant performance can perhaps be found in the fractographic data collected in this study.

The low tensile stress values and particularly the low toughness of the agglomerated iron employed can be referred to:

— a large number of inclusions giving rise to pronounced discontinuity within the matrix, and at the same time creating a marked decrease in the resisting section;

— the fact that these inclusions formed the initiation zones for the fracture cracks that formed during the mechanical tests.

The excellent service behaviour of this iron, therefore, can be related to another phenomenon, namely the high degree of microductility of the ferrite structure as shown by the SEM findings. An intrinsic resitance to fracture thus enabled this metal to survive without disastrous yielding under arduous conditions and for many years, even though its tensile characteristics were not sufficient to ensure it a proper degree of reliability.

References

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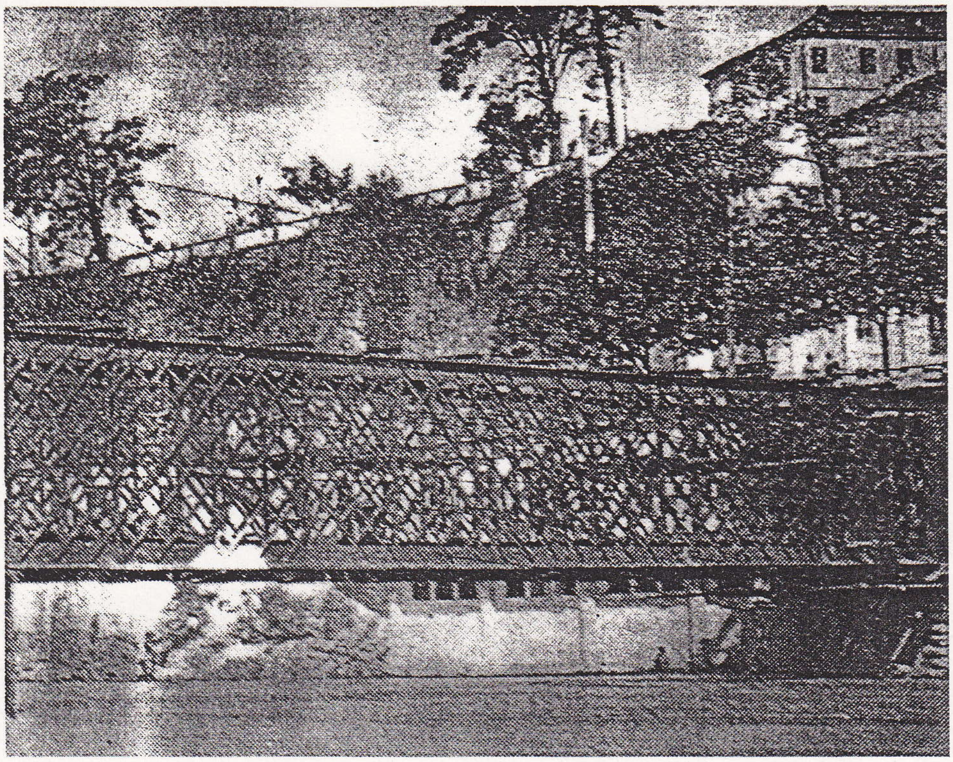


Fig. 1 (a): The old Hône-Bard railway bridge.

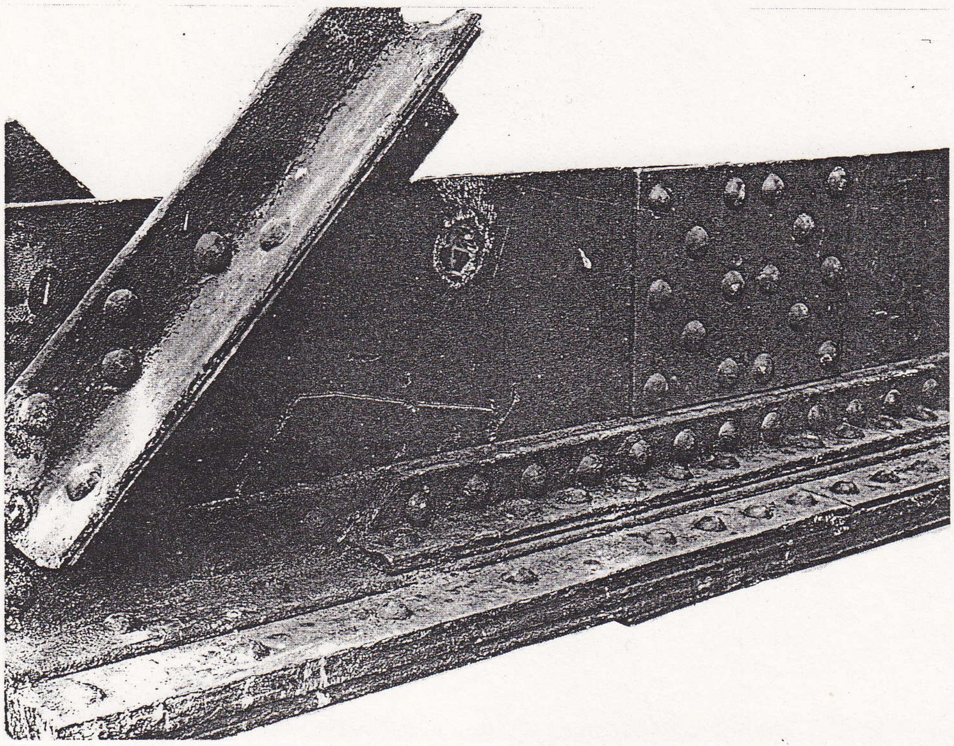
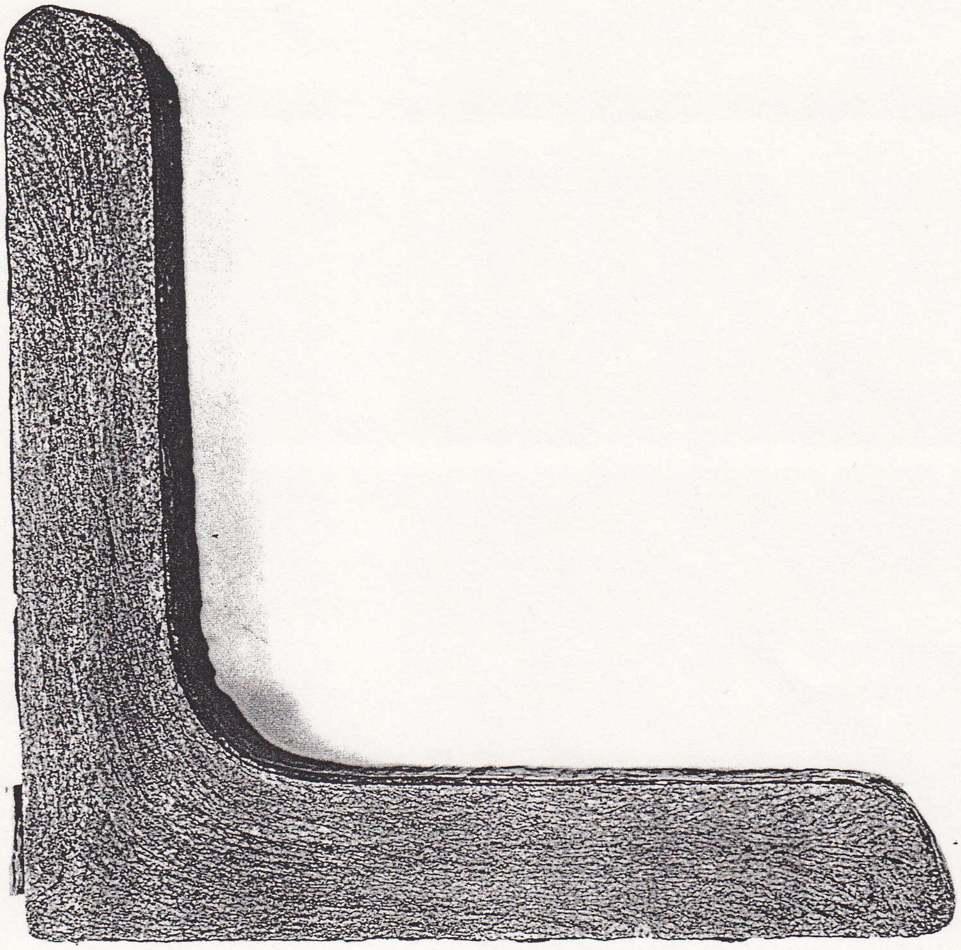
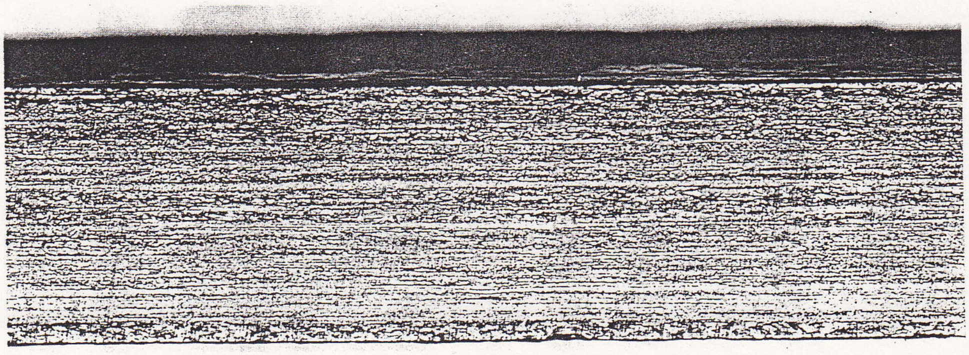


Fig. 1 (b): Part of the lower longitudinal member on which the metallographic analyses and strength test were parformed.

Fig. 2: Macrographic appearance of the agglomerated iron.



(a) angle peice 62 × 62 × 10 cm - cross-section (2% Nital etching)



(b) part of plate 300 × 20 cm - longitudinal section (2% Nital etching)

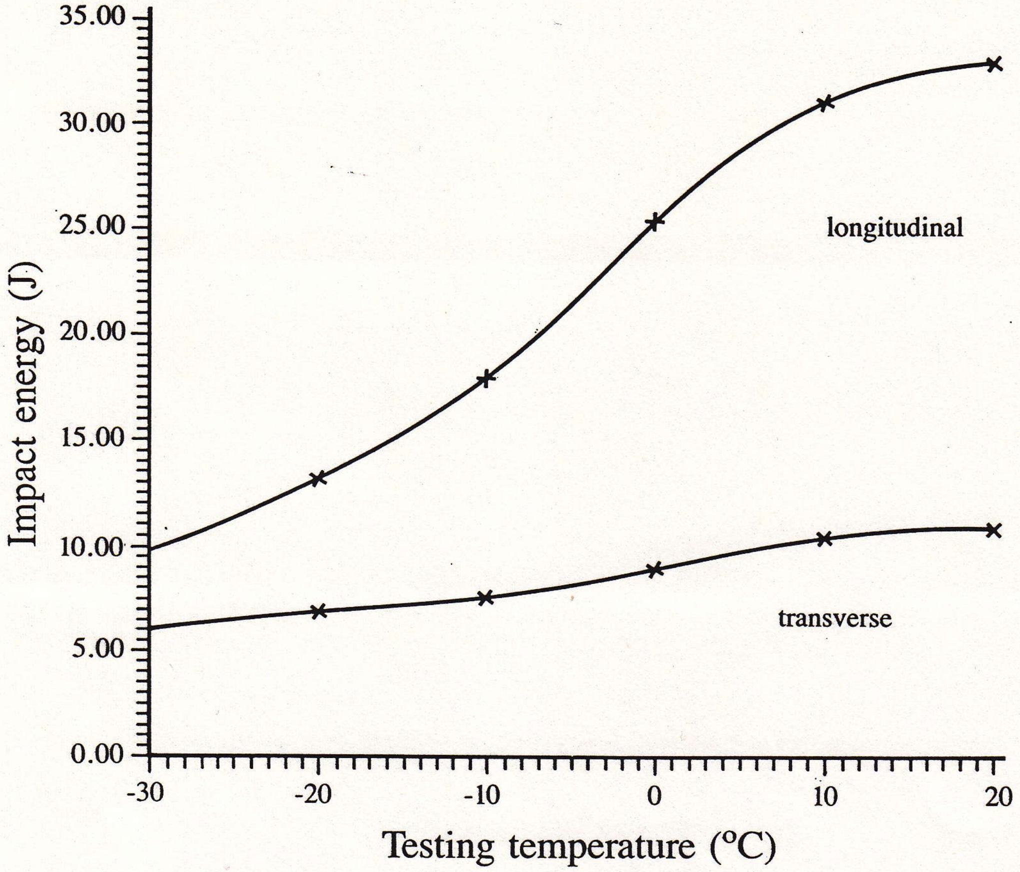


Fig. 3: Transition curves for longitudinal and transverse test specimens from plate 250 × 18 cm.

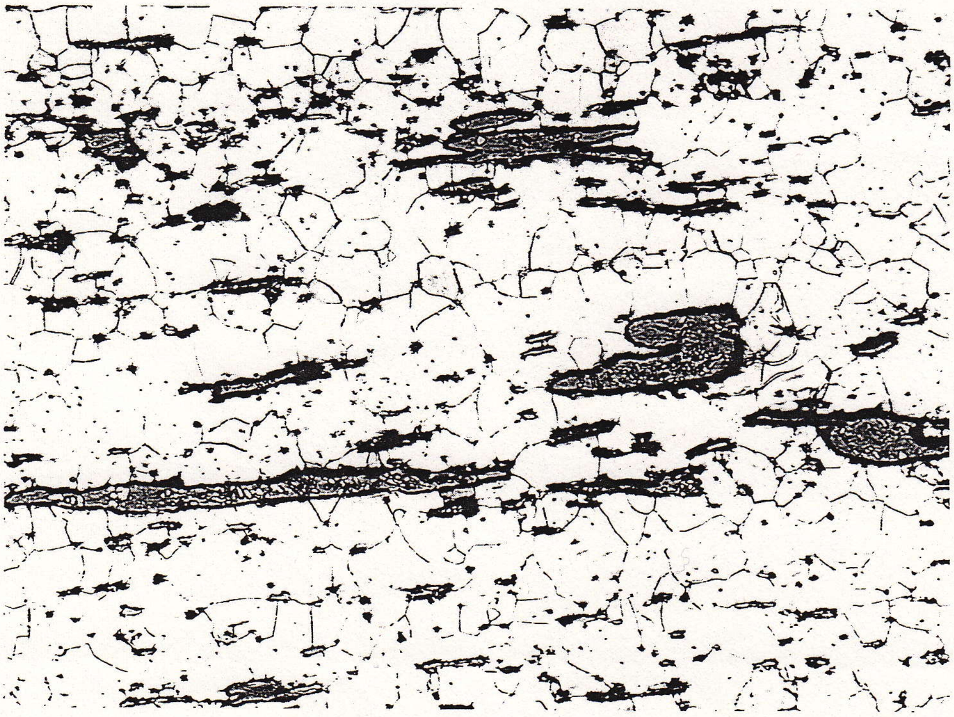
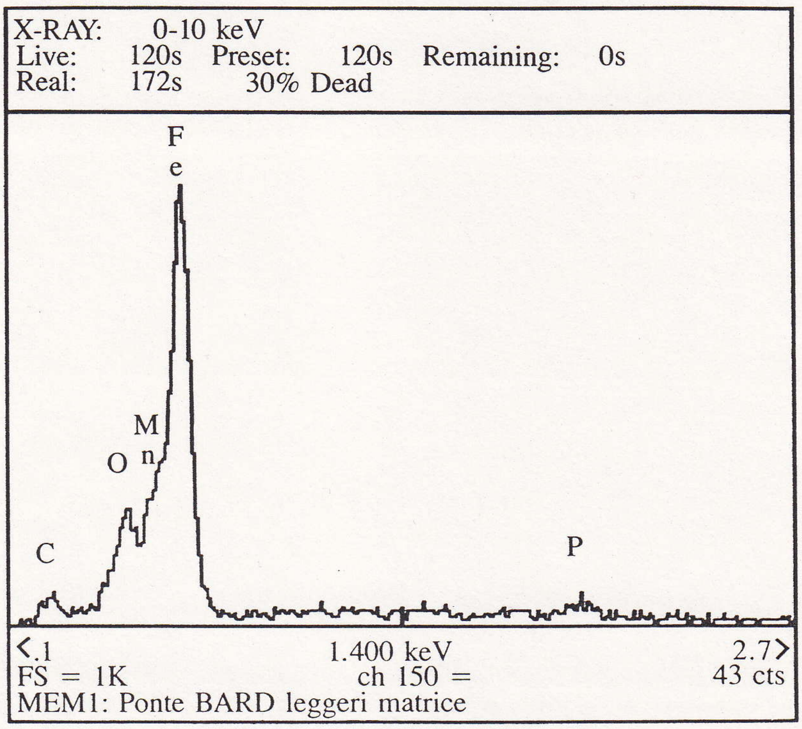


Fig. 4: Microstructure of plate 300 × 20 cm after 2% Nital etching (cross-section × 100)

Fig. 5 (a): a) Microstructure of nonmetallic inclusions (× 100)



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X-RAY:     0-10 keV
Live:      120s   Preset:     120s   Remaining:    0s
Real:      172s        30% Dead
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<.1                          1.400 keV                    2.7>
FS = 1K                        ch 150 =                  43 cts
MEM1: Ponte BARD leggeri matrice
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Fig. 5 (b): Microanalysis of the light elements of the basic metal

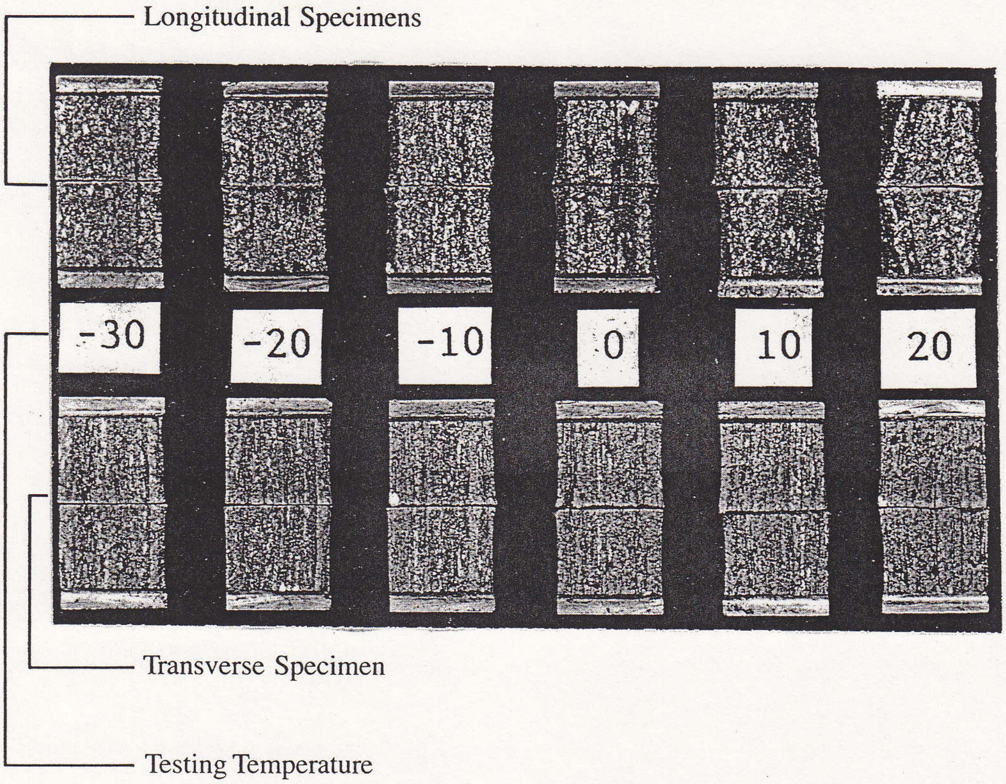
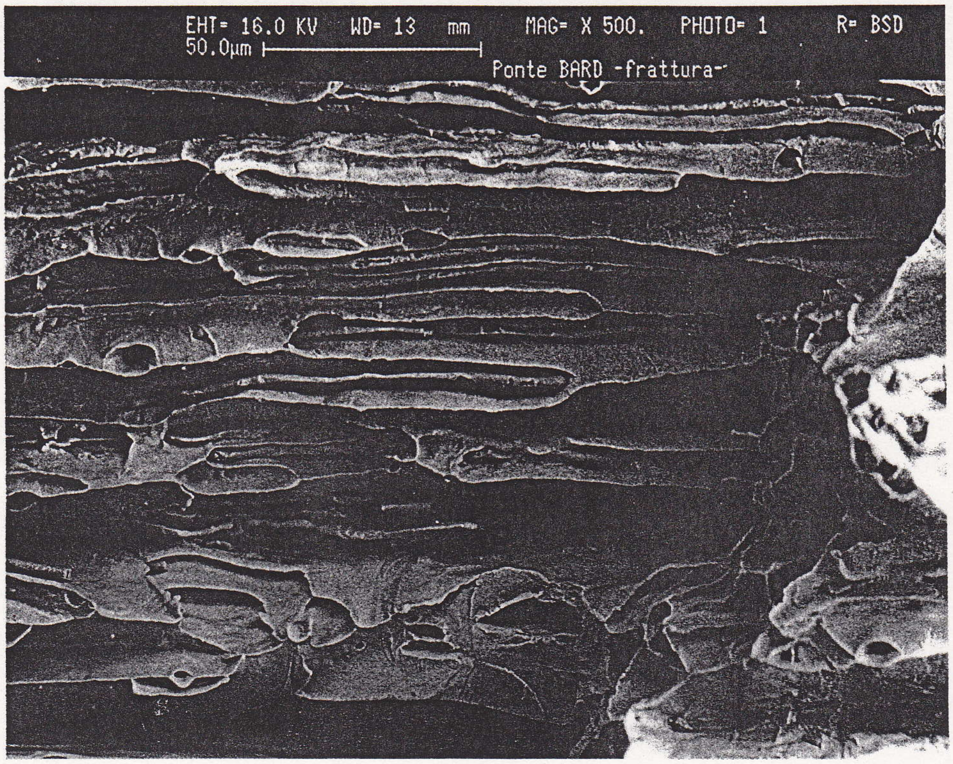
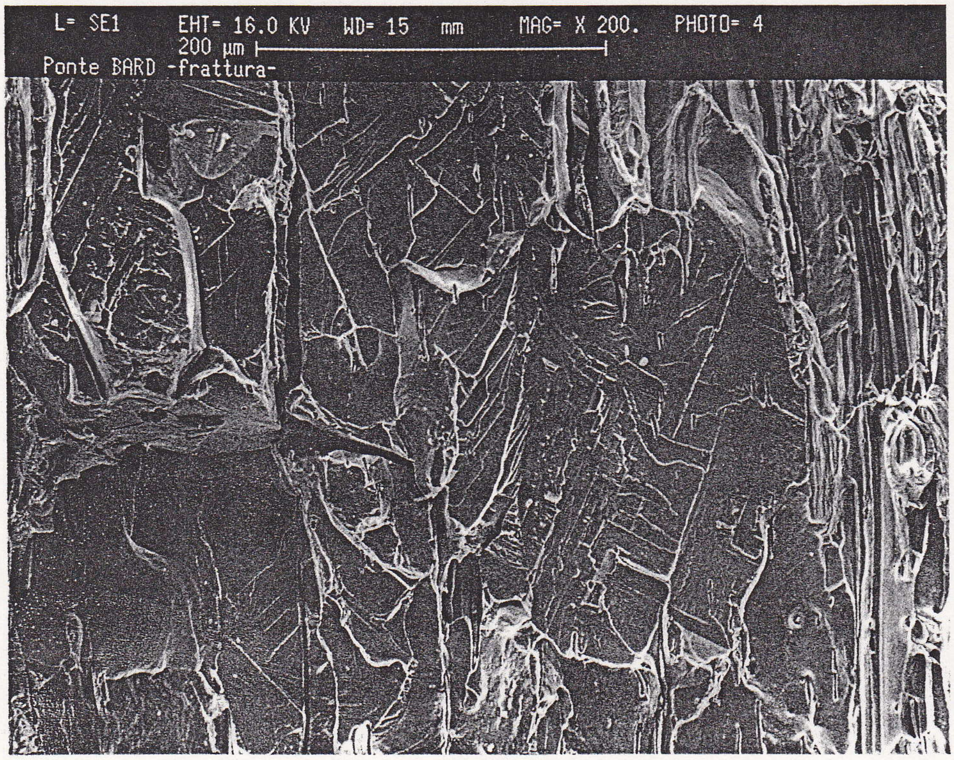


Fig. 6: Fracture surfaces of some of the impact test specimens used to determine the transition curves.

Fig. 7: Detail of the fracture surface of an impact test specimen.



(a) ductile fracture (dimples)



(b) brittle fracture (cleavage)