A Procedure for the Evaluation of Microalloyed Steel Applications in Case of Components Subjected to Repeated Impulsive Loads

A. BLARASIN and G. CAFFA - Centro Ricerche FIAT-Orbassano

Abstract

A lab methodology was developed to assess the possible use of microalloyed steels in bar for manufacturing of components undergoing impulsive-type stresses.

Such a methodology was verified in the case of a steering knuckle for commercial vehicles on the basis of a set of measurements performed on test tracks to simulate clashes against curb steps in a parking area, as well as impacts with roadbed discontinuities (such as holes, road bumps, etc.).

The specimen simulation of the stresses measured on actual components enabled to establish that also microalloyed steels, which ensure process savings in comparison to quenched and tempered steels, can be used to manufacture vehicle suspension components.

Riassunto

È stata messa a punto una metodologia di laboratorio per valutare la possibilità di adottare acciai microlegati per componenti sottoposti a sollecitazioni di carattere impulsivo.

Tale metodologia è stata verificata nel caso di un fuso a snodo per veicolo commerciale basandosi su una serie di rilievi effettuati su piste prova in concomitanza di urti contro gradini di marciapiedi in fase di parcheggio, e di impatti con discontinuità del manto stradale (buche, cunette).

La simulazione su provino delle sollecitazioni rilevate su componente ha permesso di verificare che anche acciai microlegati, i quali garantiscono economie di processo rispetto agli acciai bonificati, possono essere adottati per la costruzione di particolari della sospensione del veicolo.

Introduction

During the vehicle operation, front suspension components are often submitted to impulsive loads due to car manoeuvres (occasional bumps against curb steps in a parking area) or roadbed discontinuities (holes and road bumps).

Some of these components, such as wheel hubs and steering knuckles, are basically important to the vehicle safety. Therefore, when selecting materials for the construction of such hot forged components, one should request both adequate strength characteristics to ensure their fatigue behaviour and proper toughness levels, to avoid quasi-static failures in case of impulsive loadings.

Historically, the materials employed for such components were (and still are oftentimes) quenched and tempered steels, 39 NiCrMo3 type, with 880 to 1080 MPa strength levels, suited to guarantee for the component a good compromise between fatigue and toughness properties.

In the last few years, however, there was a tendency for these components to use either quenched and tempered (Q & T) steels with a reduction in alloy elements (42CrMo4, 41Cr4 types), or microalloyed steels [1] which allow to save the quenching and tempering treatment altogether.

In the case of Q & T steels, it was found out [2] that reducing alloy elements entails no noticeable loss of the mechanical and fatigue properties (even though a more accurate control of the heat treatment parameters is required).

Microalloyed steels, instead, just because of their typical metallurgical structure mostly consisting of pearlite, fail to attain toughness values comparable with the typical values of Q & T steels [3] and required by FIAT specifications.

As complying with current specifications would often prevent the use of such family of steels, special procedures have to be developed to assess beforehand the minimum toughness level to be requested for the material in terms of its application on a given component (fitness for purpose) whose operating conditions are known (or at least reasonably assumed to be).

In this paper a methodology is proposed to examine the fitness to use of these materials in the case of a vehicle front suspension component, on the basis of a set of acting impulsive-type loads as measured on a test track and correlated to the vehicle mission.

Analysis of stress cycles as measured on vehicle

For the analysis, a front suspension steering knuckle of a commercial vehicle was considered (Fig. 1) with an 18000 N load on the front axle.

The component was equipped with strain gauges arranged in the most stressed area, which is delimited by the fillet between the pin and the upright flange.

On the vehicle with the component so instrumented, a series of impulsive-nature events were simulated on the test track and their relevant induced stresses recorded.

In particular, the following events were taken into consideration:

a) bumps likely to occur during parking manoeuvres when driving the vehicle against a step (150 to 200 mm high), the motion direction being parallel with or perpendicular to the step itself, with standing start ($v_i = 0$) or at a 10 Km/h speed (Table 1).

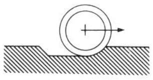
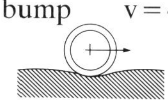
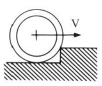
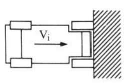
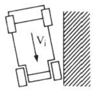
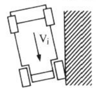
b) impacts caused by roadbed discontinuities. In this case, holes or road bumps (Table 1) were considered, with the vehicle at the impact running at 40 Km/h speed.

Fig. 2 indicates some examples of strain histories as measured on the component under investigation in connection with the different events examined.

In Table 1, instead, the related maximum stress values are σ_{max} reported.

During the vehicle's useful life equivalent to a distance of 500000 Km, the component will, in connection with the foreseen mission, subjected to a repeated set of events among the ones considered according to what reported in Table 1.

TABLE 1 - Stresses measured on front suspension steering knuckle in connection with impulsive load events

Event type		Frequency of occurrences	N° of event in the mission	σ_{max} (MPa)
"Chrysler" hole 	v = 40 Km/h	$\frac{1}{200 \text{ Km}}$	2500	460
"Argentine" road bump 	v = 40 Km/h	$\frac{1}{200 \text{ Km}}$	2500	225
Step 	vi = 0 Km/h 	$\frac{1}{150 \text{ Km}}$	3333	180
	vi = 0 Km/h 	$\frac{1}{150 \text{ Km}}$	3333	250
	vi = 10 Km/h 	$\frac{1}{150 \text{ Km}}$	3333	325

Materials

The experimental tests was carried out on the following steels:

– Q & T steel, 41Cr4 type, assumed as reference material, it being the one currently used for the manufacture of various hot forged vehicle suspension components.

– Microalloyed steels, S800 and S900 types, produced with continuous casting process by FALCK Company. It deals with steels belonging to the strength classes of 800 MPa and 900 MPa respectively, with the addition of sulphur (5900 steel) to improve tool machinability. Both material were hot forged ($T = 1200 \div 1250°C$) in bars 50 mm in diameter and subsequently cooled in still air with no further heat treatment.

The chemical composition and the main mechanical properties of the selected steels, are given in Table 2 and Table 3.

Figs. 3 to 5, instead, illustrate their metallographic features: tempered martensite for the quenched and tempered steel, pearlite-ferrite for microalloyed steels.

TABLE 2 - Chemical composition of materials (weight %)

Steel	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Al	V	Nb	N
41Cr4	0.41	0.78	0.28	0.024	0.016	1.0	0.14	0.03	0.24	–	–	–	–
S800	0.21	1.54	0.46	0.012	0.005	0.08	0.11	0.02	0.19	0.025	0.18	0.030	0.0132
S900	0.38	1.48	0.34	0.016	0.030	0.2	0.12	0.03	0.23	0.015	0.10	0.037	0.0138

TABLE 3 - Mechanical characteristics of the steels

Steel	Tensile properties								Charpy impact test KCU (J/cm^2)	
	R_m (MPa)	R_s (MPa)	A_5 (%)	Z (%)	σ_f (MPa)	ε_f	n	K (MPa)	R.T.	$-40°C$
41Cr4	930	800	19	62	1390	0.967	0.112	1350	96	60
S800	800	590	21	67	–	1.108	0.130	1250	80	40
S900	940	620	19	54	1335	0.786	0.166	1575	35	10

Lab simulation methodology

To simulate in laboratory the impulsive-type stresses detected on the component, a repeated-shock test was performed through a WOLPERT PW 15-30 pendulum equipped with an instrumented ram (Fig. 6).

This, in relation to the drop angle, allows to detect the force applied to the specimen during the impact (Fig. 7), and thus to calculate the value of the applied stress.

The pendulum is equipped with an automatic system for ram release and return to initial position, so that tests can be performed automatically at a rate of about 25 impacts/min.

The geometry of the specimen was generally similar to an IZOD-type resilience specimen with modified notch (Fig. 8). Such a specimen, which during the test withstands bending loads, is characterized by a stress concentration factor $K_t = 2.2$, and thus close enough to the typical factor of car components.

Some tests, however, were also carried out on a modified BRUGGER specimen (Fig. 9), which is typically used to characterize case-hardened steels for gears [4]. In this case the value $K_t = 1.56$ [5] corresponds to the one of the component under investigation [6].

As mentioned in the previous item, different event types are envisaged in the vehicle mission, with a certain number of occurrences.

A conservative hypothesis was anyway assumed in this analysis. That is to say that the totality of impulsive events (about 15000) are to be ascribed to an impact at 40 Km/h speed with a CHRYSLER-type hole, since this discontinuity type has proved to be the most severe among the ones considered (Table 1).

During this event, the maximum local stress, as calculated from the strains measured on the component, is $\sigma_{lmax} = 460$ MP_a.

To meet the foreseen mission, the specimen of the material under investigation shall thus withstand at least 15000 cycles of this type without failure.

On the basis of the specimen geometry, the force requested to obtain the local stress foreseen, in the assumption of an elastic behaviour of the material, is given by:

a) Modified IZOD specimen

$$F = 2.2\ \sigma_{lmax} \tag{1}$$

b) Modified BRUGGER specimen

$$F = 12.987\ \sigma_{lmax} \tag{2}$$

The experimental analysis was normally carried out at room temperature. A few tests at −20°C and −40°C were also performed (especially in the case of microalloyed steels characterized by ductile/brittle transition temperatures higher than room temperatures) to check for a possible behaviour decay. During such tests, a jet of carbon dioxide properly oriented onto the specimen (modified IZOD) was used as a coolant. The specimen was equipped with thermocouples located at the notch, in order to ensure continuous temperature monitoring during the test.

Because of its complexity, this type of test was only used in the field of short duration tests (less than 1000 impacts).

The specimen endurance, as reported below, will generally be referred to the specimen fracture. In some cases, however, especially for tests with a high number of impacts, the life corresponding to crack initiation (as defined by a crack lenght of 0.2 to 0.5 mm) was also evaluated, periodically interrupting the test and submitting the specimen to non-destructive tests.

Discussion of results

Through the use of a proper instrumentation (x-t recorder interfaced to the instrumented ram of the pendulum by a storage oscilloscope) shown in Fig. 6a, the trend of the force applied to the specimen was recorded during the tests for different drop angles (Figs. 10 to 12).

The initial force value reported on Figs. 10 to 12 is the one measured at the second impact, in order to guarantee a stabilized response from the specimen.

In Figs. 10 to 12, one can see how, up to drop angles of 9°, the applied force remains practically constant over time, until fatigue crack initiations appearing.

Subsequently, one can see the specimen fracture with different propagation speeds which are typical of the different materials under survey (higher propagation speeds are observed in the case of microalloyed steels [3]). For higher drop angles (12° in the case of microalloyed steels and 15° for Q & T steels), the force will increase with the increasing number of the specimen impacts. This phenomenon is probably due to localized strain hardening, due to high local stresses and the consequent probable plastic deformation of the material near the notch.

A summary of the results so obtained, as shown in Figs. 13 and 14 for the two different geometries of specimen used, indicates how the Q & T steel, owing to its higher toughness (qualitatively resulting from a proper strength and ductility mix), offers better behaviour warranties with increasing applied forces (stresses).

Anyway, in the area of interest for the foreseen applications (15000 impacts), there are real safety margins (also in view of the most severe test conditions adopted) for the application of microalloyed steels even in the case of safety components undergoing impulsive-type stresses.

Such a behaviour, though not verified experimentally for the whole useful life range, was also confirmed by the results obtained during low temperature tests (−20°C and −40°C) as shown in Fig. 15.

Using the applied local stress σ_{lmax} (calculated by equations (1) and (2)) as normalising parameter, from Fig. 16 one can see that the two different specimen geometries offer almost equivalent indications in the case of the steel 41Cr4. However, when considering the data related to the microalloyed steels, one can see that under the same local stress condition (as calculated in the simplified assumption for an elastic behavioiur of the material at the geometric discontinuity where failure initiates) the BRUGGER specimen offers higher operation life.

Due to its higher construction simplicity, the modified IZOD specimen is more advisable when merit classifications are to be established among the different steels from the fatigue strength viewpoint under repeated impact loads.

From an analysis of the surface fractured area, carried out through the aid of a scanning electronic microscope (S.E.M.), an extended propagation area is to be seen (Figs. 17 to 19) even in the case of microalloyed steels when applying such forces as to cause failures around a life of 15000 cycles. In these steels, however, even at room temperature, the abrupt static fracture is prevailingly transgranular brittle type with limited microductility areas. In the case of the quenched and tempered steel 41Cr4, on the contrary, one can note a ductile type fracture in addition to a more extended propagation area of the fatigue crack.

Conclusions

A lab methodology was developed to assess a possible adoption of lower toughness microalloyed steels (as compared to quenched and tempered steels) to manufacture safety components subjected to impulsive loadings.

Such a methodology was applied in the case of a steering knuckle for a commercial vehicle, for which one could avail of some measurements taken on test track in connection with bumps against obstacles (curb steps), or impact with roadbed discontinuities (holes, road bumps).

From the experimental specimen simulation of the stresses measured on the real component, there came out that also microalloyed steels, which allow for process savings, can be used for the construction of the vehicle suspension components.

The results so far obtained, show that the requirements for levels of the mechanical characteristics (either in terms of strength or toughness) of the material cannot be designed independently on the application type (as often the case is), but must be correlated directly to the loading conditions that the component will undergoes during its operation life on the vehicle.

In case of application of this class of steels for manufacturing of safety critical components, the material screening criteria described in this paper must be obviously joined to a suitable series of tests, performed both at laboratory stage and on the vehicle, to verify the ability of the component to cope with unexpected overloads without catastrophic failures.

References

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[2] G. Ronchiato, M. Castagna, R. Colombo, *Fracture Mechanics and fatigue properties of lean constructional steels*, Metallurgical Science and Technology, Vol. 2, N° 3, Nov. 1984, pp. 93-101.

[3] P. Farsetti, A. Blarasin, *Fatigue behaviour of microalloyed steels for hot forged mechanical components*, Int. Journal of Fatigue N° 3, 1988, pp. 153/161.

[4] G. Ronchiato, *Sviluppo criteri per selezione acciai per ingranaggeria*, Rapporto int. C.R.F. MRC 76/80 Luglio 1980.

[5] S. Bertoglio, G. Martinelli, *Calcolo delle sollecitazioni e del fattore di concentrazione nel raccordo della provetta modello dente ingranaggio*, Rapporto int. C.R.F. SRM 35/79 - Novembre 1979.

[6] A. Blarasin, L. Bernard, *Sviluppo e applicazione di metodologie di calcolo per la previsione della durata a fatica di componenti*, Il Progettista Industriale, Anno VII, N° 1, 1987, pp. 56-64.

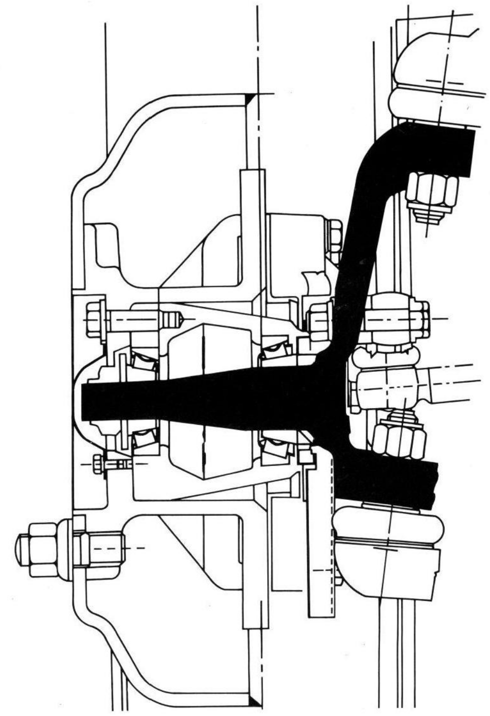


Fig. 1:
Front suspension steering knuckle for
a commercial vehicle.

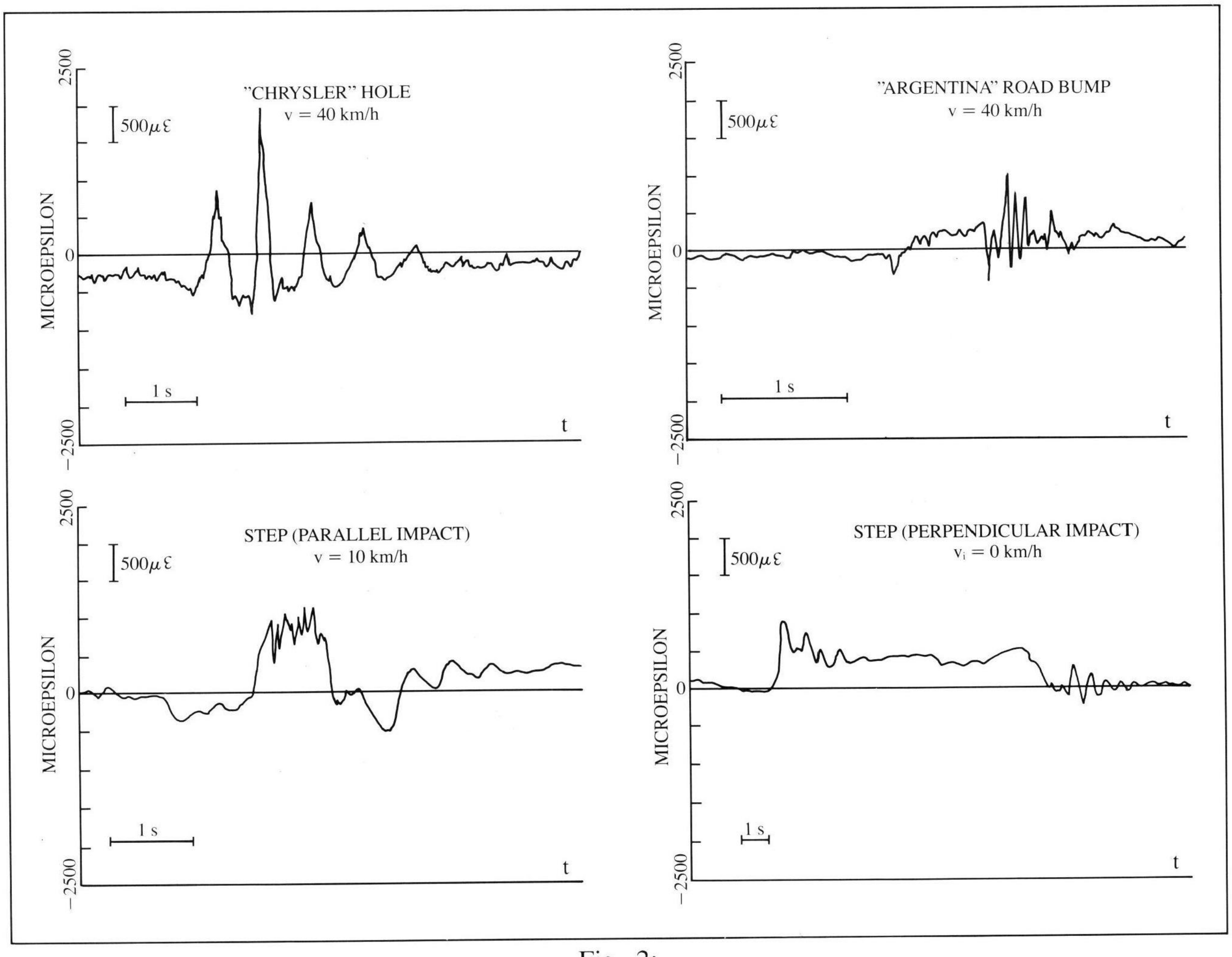


Fig. 2:
Exemples of time histories recorded on vehicle.

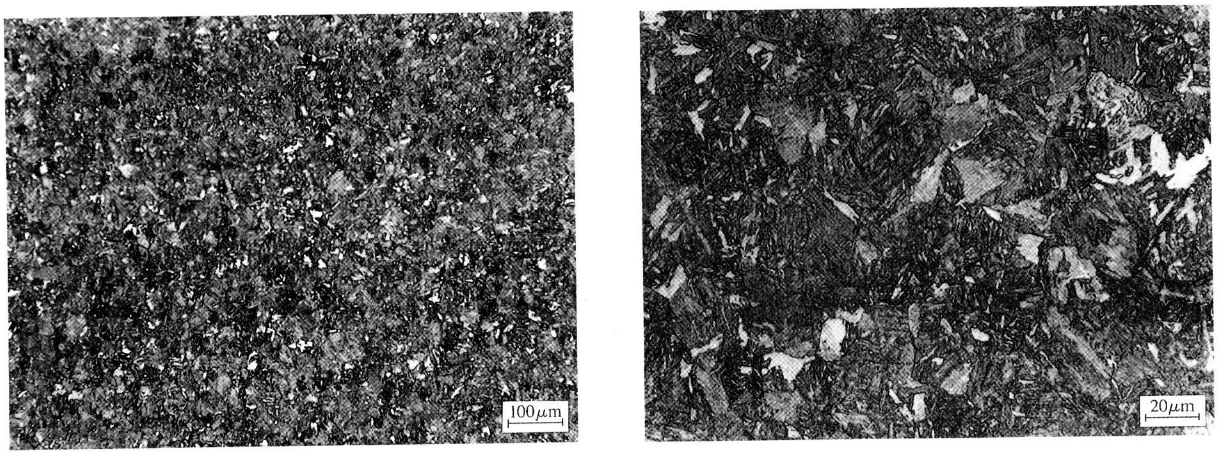


Fig. 3:
Microstructure of quenched and tempered steel 41Cr4.

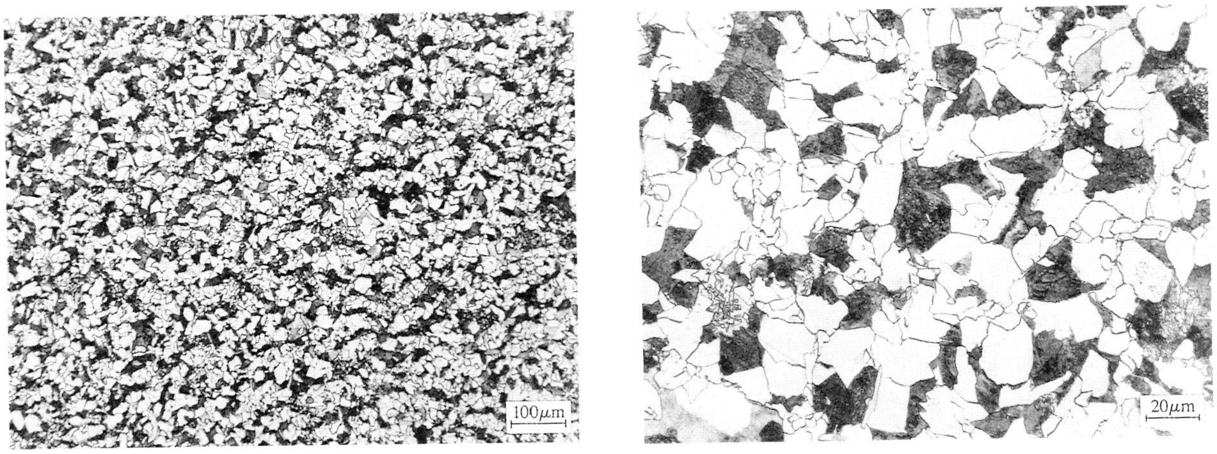


Fig. 4:
Microstructure of microalloyed steel S800 after forging and cooling in still air.

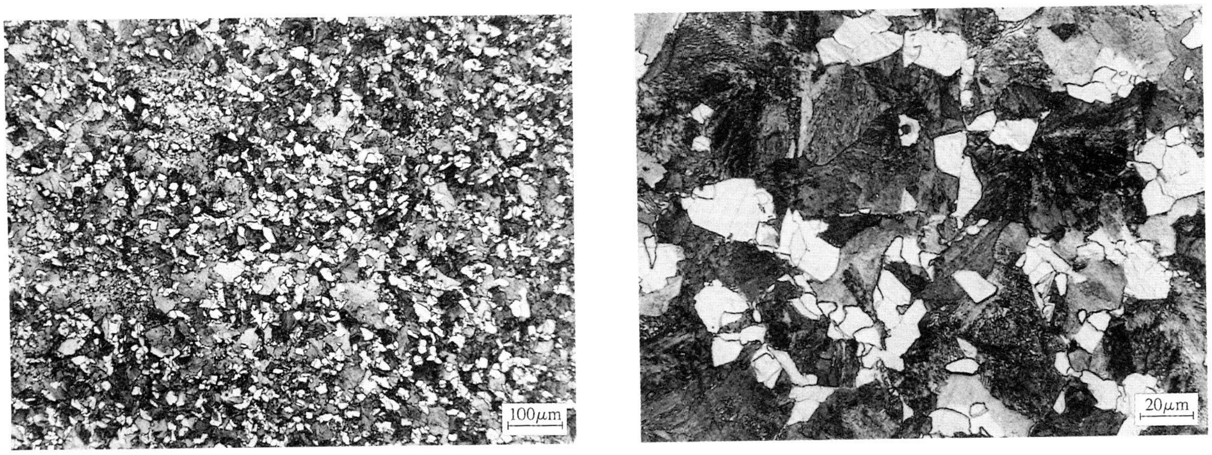
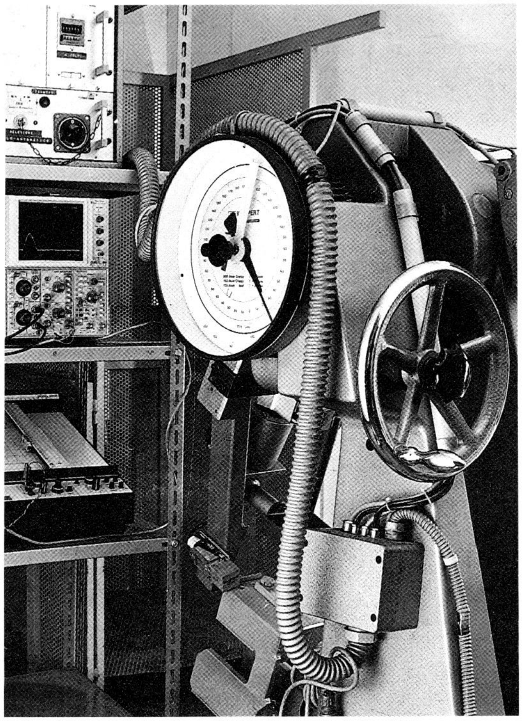
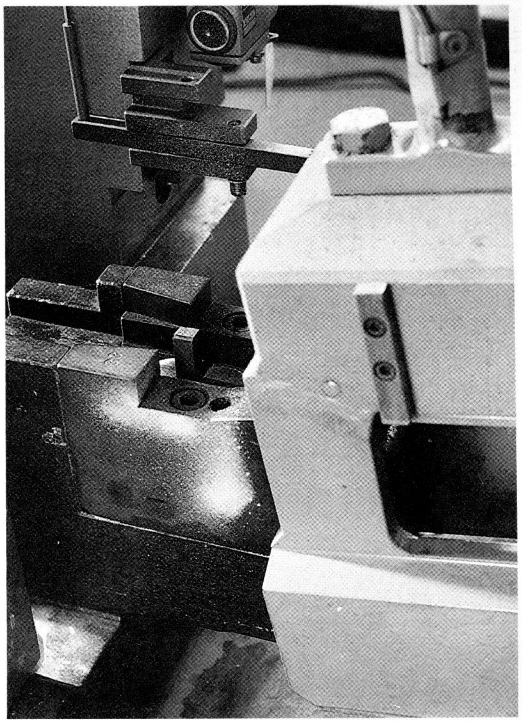


Fig. 5:
Microstructure of microalloyed steel S900 after forging and cooling in still air.



a) Overall view of the equipment.



b) Specimen assembly.

Fig. 6:
Equipment used for fatigue impact tests.

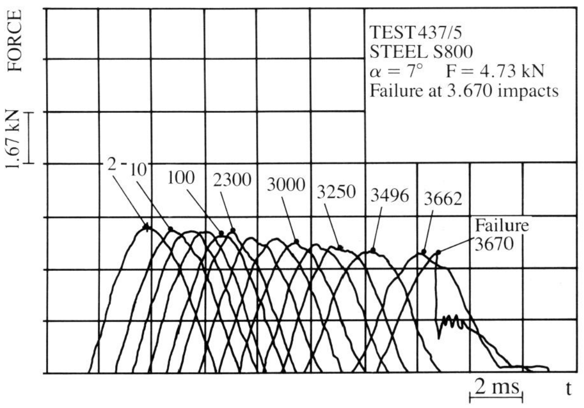


Fig. 7:
F-t plots as a function of the number of impacts, recorded during a test.

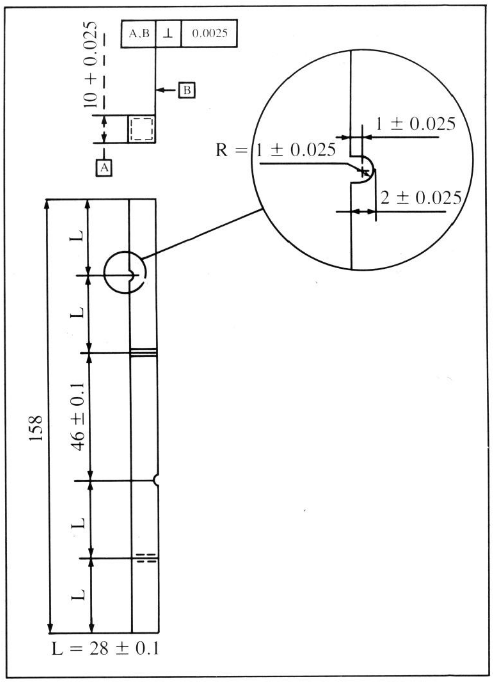


Fig. 8:
Modified IZOD specimen (Kt = 2.2).

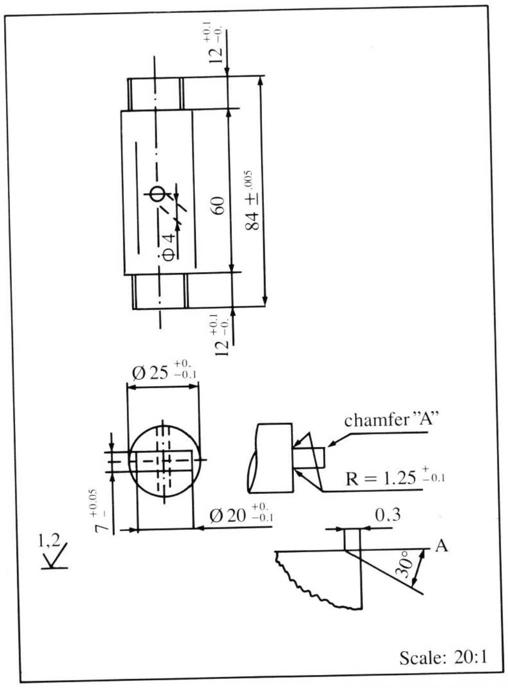


Fig. 9:
Modified BRUGGER specimen (Kt = 1.56).

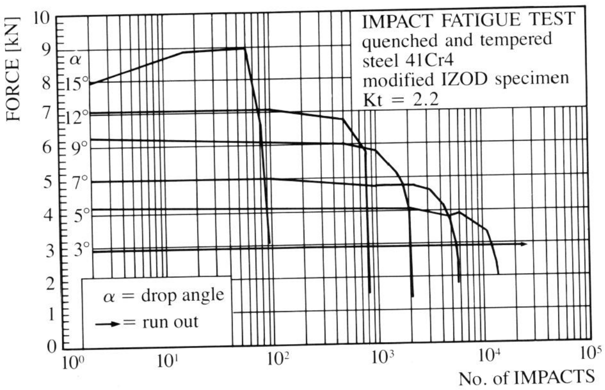


Fig. 10:
Quenched and tempered steel 41Cr4; F-N plot as a function of drop angle during the impact fatigue test.

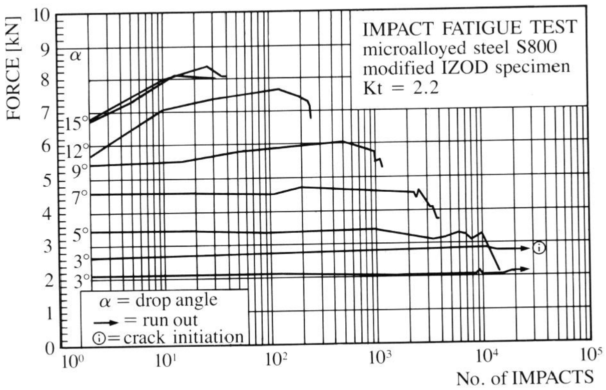


Fig. 11:
Microalloyed steel S800; F-N plot as a function of drop angle during the impact fatigue test.

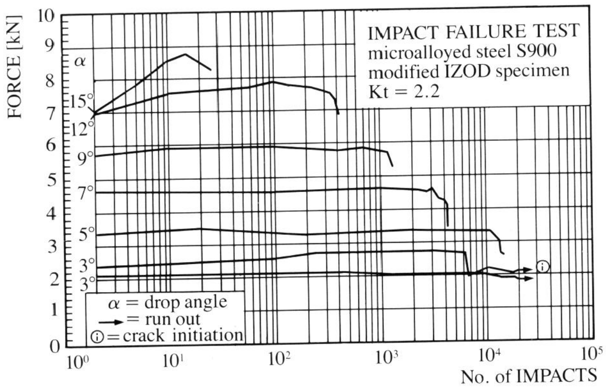


Fig. 12:
Microalloyed steel S900; F-N plot as a function of drop angle during impact fatigue test.

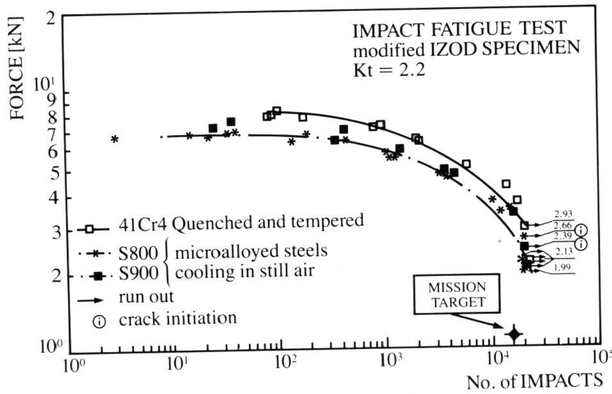


Fig. 13:
Impact fatigue test with modified IZOD specimen -summary of results.

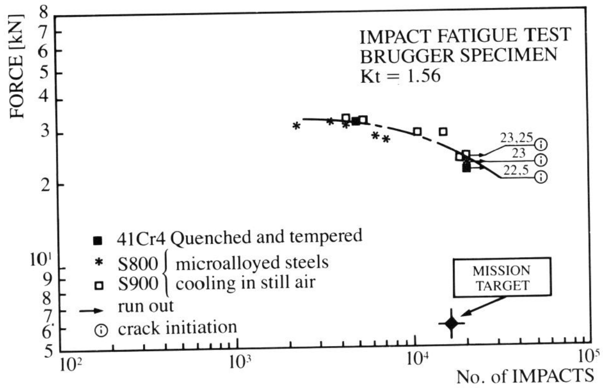


Fig. 14:
Impact fatigue test with BRUGGER specimen -summary of results.

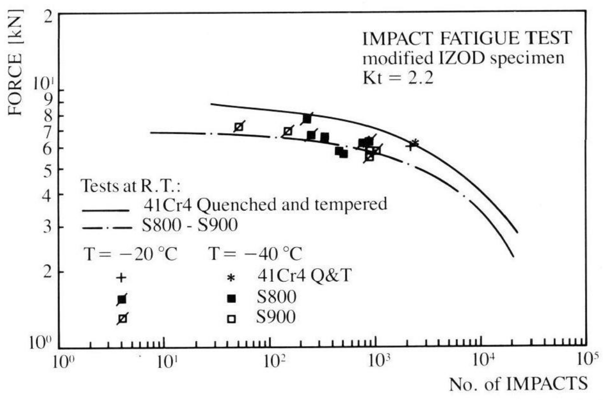


Fig. 15:
Effect of test temperature on impact fatigue behaviour; summary of results.

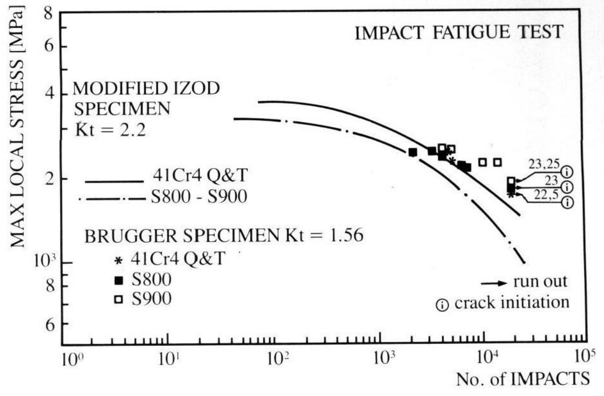


Fig. 16:
Comparative results of impact fatigue tests with different specimen geometry.

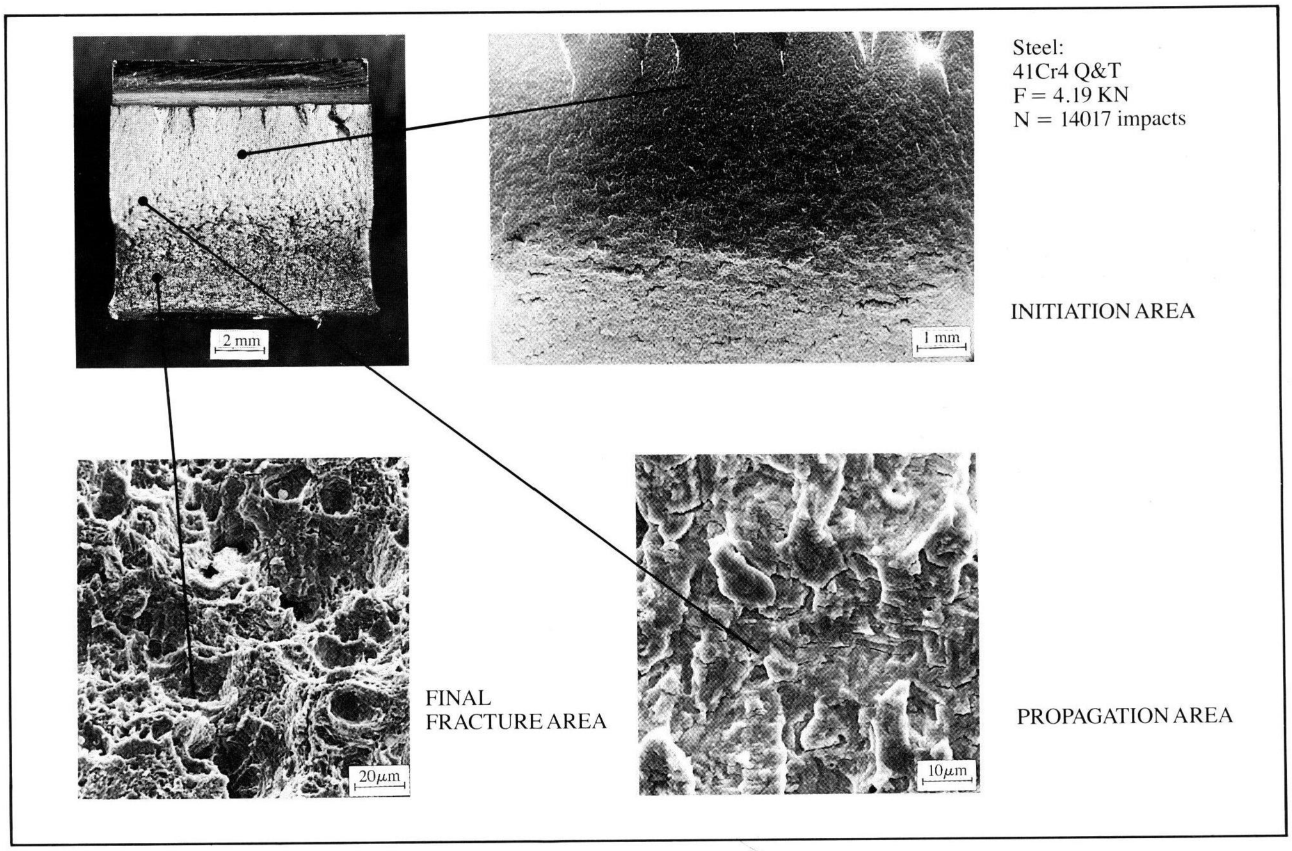


Fig. 17:
S.E.M. analysis of a modified IZOD specimen submitted to impact fatigue.

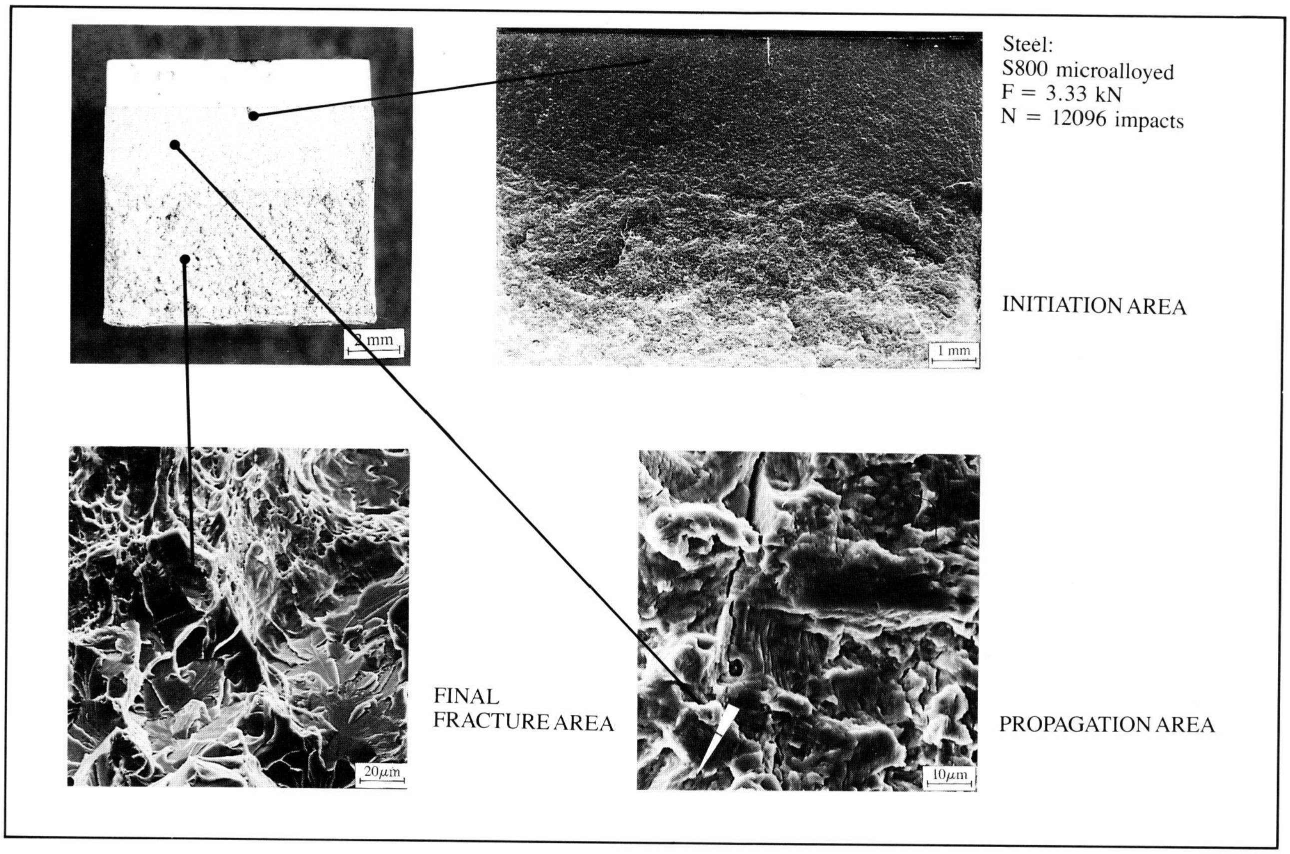


Fig. 18:
S.E.M. analysis of a modified IZOD specimen submitted to impact fatigue.

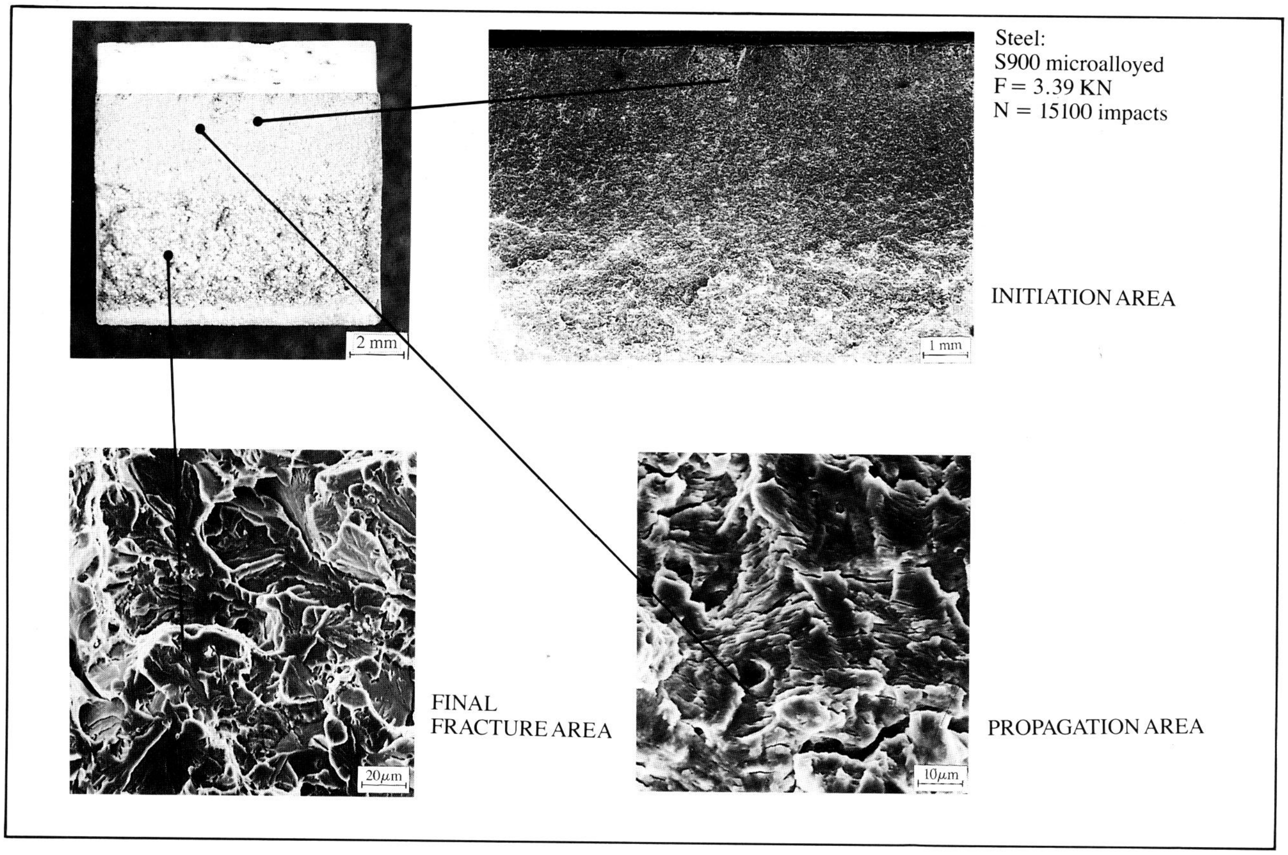


Fig. 19:
S.E.M. analysis of a modified IZOD specimen submitted to impact fatigue.