

# **Preliminary investigation on sabre blade ruptures during fencing**

T. Coppola, C. Guarnaschelli, A. Mazzarano\*

Centro Sviluppo Materiali SpA (a RINA Company), via Castel Romano 100, 00128 Roma - Italia

\*a.mazzarano@c-s-m.it

## **Extended abstract**

Weapons used during fencing represent an application of steel particularly sophisticated, either for its basic function from the point of view of fencers' safety and from that of technical performance.

In particular sabre fencing, characterised by a dynamics sometimes also explosive during the bouts, is requiring very high standards in particular to the blade, which must present lightness, elastic and stiff behaviour, toughness, and finally a reasonable price in order to be changed also several time along a season. From the metallurgical point of view a good balance must be individuated among the chosen microstructure and an economic production route to guarantee the target functional properties and price.

Recently, some anomalous breaks of sabre blades with puncture of individual protections have pointed out the attention to athletes safety, while among the field experts is growing up a general feeling on a tendency to a reduced duration of the blades. The comprehension – starting from the examination of some sabre blades broken during the bouts – of the impact of the production route, in particular the thermal treatment, the kind of microstructure and the relevant mechanical properties on the behaviour of the blade during fencing, allows to put in evidence the chemical, physical and mechanical characteristics enabling to “ex-ante” designing an intrinsic safe sabre blade.

In this paper the results of a preliminary investigation carried out on a set of sabre blades broken during bouts are reported, together with some considerations of metallurgy and fracture mechanics applied to blades, useful to identify possible future activities.

The sabre blades analysed here were almost all realized with high carbon steel (spring steel), with the exception, in one case, of a low-Si steel, alloyed with Cr, Ni, Mo and V (see table 3).

The observed microstructures and the relative hardness (see figures 4 - 7), all different from each other, indicate that different heat treatments in the production cycle have been adopted. The steel with low content of Si has shown the highest hardness, in line with the FIE Regulation ( $\geq 500$  HV) (see table 4). This seems suggesting that the different blade producers have developed solutions compromising in different ways the blade characteristics such as weight, flexibility, toughness, duration etc..

It is shown that the fracture behaviour of the blades depends on a set of factors at the time difficult to quantify and not directly correlated to the mode of failure, among which one can indicate for example the geometry and the microstructure of the blade, the weight, the speed and style of the fencer.

A deeper investigation, starting from a statistical survey already under way, is considered necessary to better understand the specific mechanisms that lead to rupture of the blade and the boundary conditions to be complied with, and to establish the best microstructures and consequently the mechanical properties that allow to obtain a safe blade for the fencers, avoiding as much as possible “anomalous” rupture (see for example figure 1).

In parallel, in the light of the sophistication of current, “tolerated” by a far-sighting sport ruling, and foreseeable solutions in terms of materials and geometries of the sabre blades, it is considered

useful to suggest an analysis about the best methods for evaluating the properties of the blades and any specific pre-requirements, always with a view to ensure the highest safety level of the fencers.

## Introduction

Steel is the technological material which has much sustained the development of humanity, in particular after industrial revolution, with thousands of applications in all sectors, so to become so pervasive in our daily life that sometimes we do not aware of its presence.

There are many examples, and social activities are those where contribution of steel typically is under-evaluated. In sport, for example, we can find application of steel particularly excellent, such as in fencing, where all the three specialties, foil, epee and sabre, steel is the base, both for safety of athletes and for technical-functional characteristics.

Among the three, sabre, characterised by action with explosive dynamic, is that one always requiring to the weapon very high standard, in particular for the blade, including lightness, stiffness, flexibility, toughness, all for a reasonable cost.

From a strict metallurgical point of view a compromise between target microstructure and economic manufacturing cycle has to be arranged, in a way to guarantee mechanical properties required.

In the last years there were observed some anomalous rupture of blades with perforation of the individual protection and puncture of the fencer (1) again activating a strong and wide attention to the safety. As a medium level fencer can change 10-15 blades per year, while an elite one up to 40-50 (2), it is clear that anomalous ruptures must be kept at the lowest possible level.

Furthermore, it is recorded in the last recent years the feeling of a shorter life of the blades, independently of the supplier, sometimes linked to the temperature of the bouts in winter. In this frame CSM decided to start a preliminary investigation on this topic, metallurgically fascinating, in order to understand the impact on the service behaviour of chemical composition, microstructure, thermal treatments and relevant mechanical properties.

The final aim is to highlight more precisely those chemical, physical and mechanical characteristics allowing and "ex-ante" design of an intrinsic safe blade.

## Rules frame and activities

Sabre blades, as well as all the other material used during a fencing competition, as subject to the requirements set in a reference book "Rule for Material" (3), and in particular in Annex A, for our purpose, are indicated the mechanical properties requested (see table 1).

*Table 1. Mechanical characteristics of steel after thermal treatment*

Rp 0.2 (MPa)	Rm (MPa)	A %	Z %	KCU (J/cm <sup>2</sup> )	K <sub>IC</sub> (MPa·m <sup>1/2</sup> )	HV
≥ 1900	≥ 2000	≥ 7	≥ 35	≥ 30	≥ 120	≥ 500

Four blades "post mortem" S2000 branded manufactured by three different suppliers are so analysed in order to individuate the chemical composition, microstructure and hardness.

## Chemical composition

In table 3 the chemical compositions identified for the 4 different blades are reported.

*Table 3. Chemical compositions (% weight)*

Blade	C	Si	Mn	Cr	Ni	Mo	V	S	P
1	0.62	1.72	0.68	0.18	0.27	0.034	< 0.01	0.002	na
2	0.61	1.69	0.80	0.22	0.10	0.042	< 0.01	0.001	na
3	0.58	1.68	0.79	0.22	0.20	0.027	< 0.01	0.012	0.016
4	0.52	0.30	0.65	0.92	1.37	0.22	0.13	0.003	0.013

The first three blades are similar in composition (which is typical of spring steel), while the fourth shows a significant difference for lower amount of carbon and silicon, and higher amount of chromium, nickel, molybdenum and vanadium.

### Microstructures and hardness

In table 4 are shown the results obtained in terms of microstructure and hardness, while in figures 4 – 7, are reported the micrographs of the four blades.

*Table 4. Summary of microstructure and hardness*

Blade	Microstructure	Hardness HV10
1	Retained Martensite	400
2	Bainite	260
3	Fine perlite	308
4	Retained Martensite	530

### Discussion

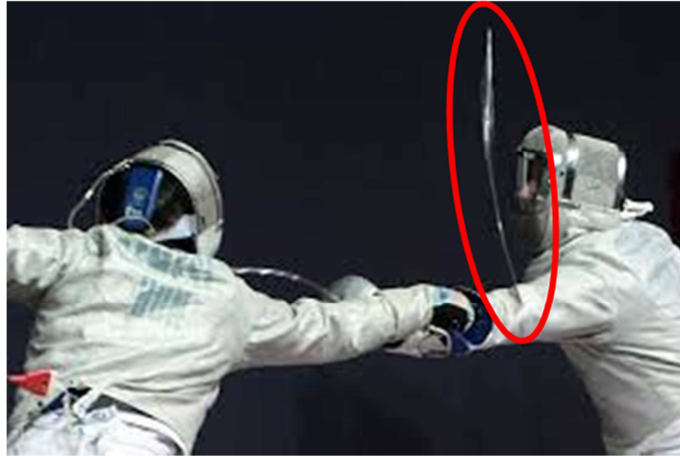
During the bouts the fencing blades are subject to a very high level of stress, in particular those for sabre, as very high quantity of energy is transferred to the weapon by the fencers who typically are heavier and quicker. As said, in such conditions the ruptures of the sabre blades are quite frequent, and they can become very dangerous when surface fracture is not fully orthogonal to the blade axis itself. In case of rupture such as that shown in figure 1, the broken blade behaves as an arrow.

*Figure 1 Sabre blade with "anomalous" rupture*



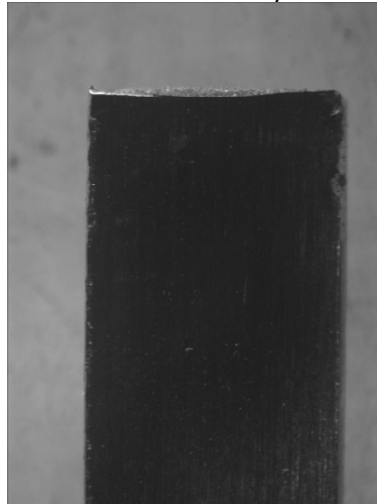
In particular conditions, such as the speed of the attack from a heavy athlete with a rigid arm (see for example figure 2), such point could pierce all the safety garments.

*Figure 2 Example of outstretched arm attack*



In the same conditions, a blade broken with a fracture surface mainly orthogonal is much less dangerous. It must be underlined that both the broken blades shown in figure 2 and figure 3 come from the same supplier.

*Figure 3 Sabre blade with "optimal" rupture*



It is clear that from the safety point of view the best blades are those able to guarantee, at the highest possible level, a fracture surface similar to that one shown in figure 3. Such fracture, with surface quite flat and without any significant variation of the section induced by the deformation can be obtained in a brittle type fracture.

However, the blade must also guarantee a high ultimate tensile strength, in order to withstand, also in dynamic regime, to the applied strains, explaining so the reason of the prescriptions set in table 1. Furthermore, such prescriptions are, in principle, to be measured on the blade, while the section available, only few  $\text{mm}^2$ , ask for specifically designed, if any, samples and test procedures, presently under investigation only.

Due to the specific impact of the shape and microstructure of the blade on its in service behaviour, such test procedures should also take into account the kind and local intensity of the applied stresses, typically a bending, and of the resistance of the steel in such stress state.

Geometry itself plays a significant role in terms of determining the intensity of the stress transferred to the final part of the blade itself, the region where typically the rupture is observed.

For what concerns the kind of stress, in case of a material without surface defect (ideal situation for new blades only), it has been demonstrated that the resistance to rupture is not an intrinsic characteristic of the material, but it also depends by the kind of stress applied (5). In the case of the sabre blade, the final section is rectangular, with a high ratio between width and thickness. As demonstrated in (6), such section, when bent, show a different level of resistance in respect to tensile, and in particular lower.

Furthermore during the bouts the blades are subject to hits, in particular on the edges, which behaves as local defect and possibly as fracture initiation points. In such case the behaviour of the blade should be considered in the frame of classical fracture mechanic, with toughness and resilience playing the major role. From this framework it is clear the need for the development of specific test procedures on samples taken directly from the blade.

Internal defect, such as oxide micro-inclusions, due the small section, can also induce the rupture. Finally, being sabre fencing executed very rapidly, the behaviour of the steel is influenced by the rate of the applied deformation, in some case also very high. The speed of application of the stress in presence of a defect (internal or on the surface) impacts not only the toughness (similar to the effect of lowering the temperature in the ductile-brittle transition curve), but can also modify the propagation way of the crack, from plane (figure 3) to the unsafe one (figure 1).

Finally, the continuous bending-unbending treatment of the blade applied by the fencers to maintain its straightness during the bouts, reduces systematically its mechanical characteristics, introducing work hardening and, as a consequence, reducing the life of the blade itself.

The above scenario highlights the difficulties in evaluating the real in service behaviour of the blades and the possibility to forecast it from the actual simple laboratory tests prescribed by the rules.

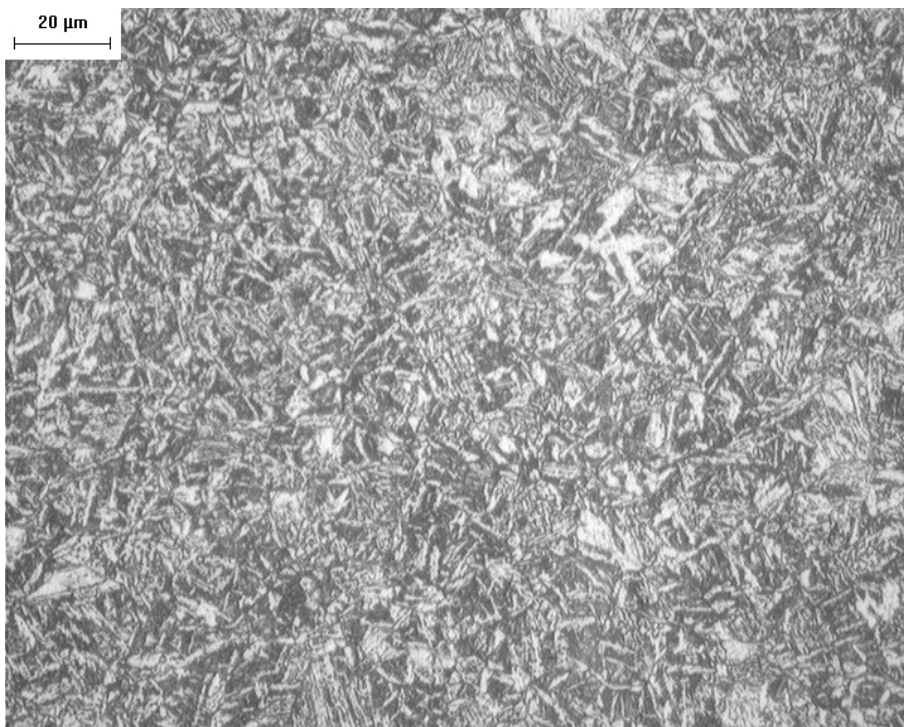
Due to the wide spread of chemical composition, microstructure and hardness measured on the four blades, it could be concluded that suppliers are experimenting, directly in field, different solutions to compromising fencer safety, blade life and price.

A statistical analyses, already started, taking into account the life of the blade, the kind of rupture, the characteristics of the fencer and the microstructures observed, should allow to put in evidence the specific mechanisms underpinning the design of a safe weapon for the athletes.

In parallel, possibly together with the suppliers of the blades and with the athletes, following the sophisticated solutions available and foreseeable in terms of steels and geometries, a specific project to individuate the most appropriate test procedures should start, again targeting the highest level of fencer safety.

## **Thanks**

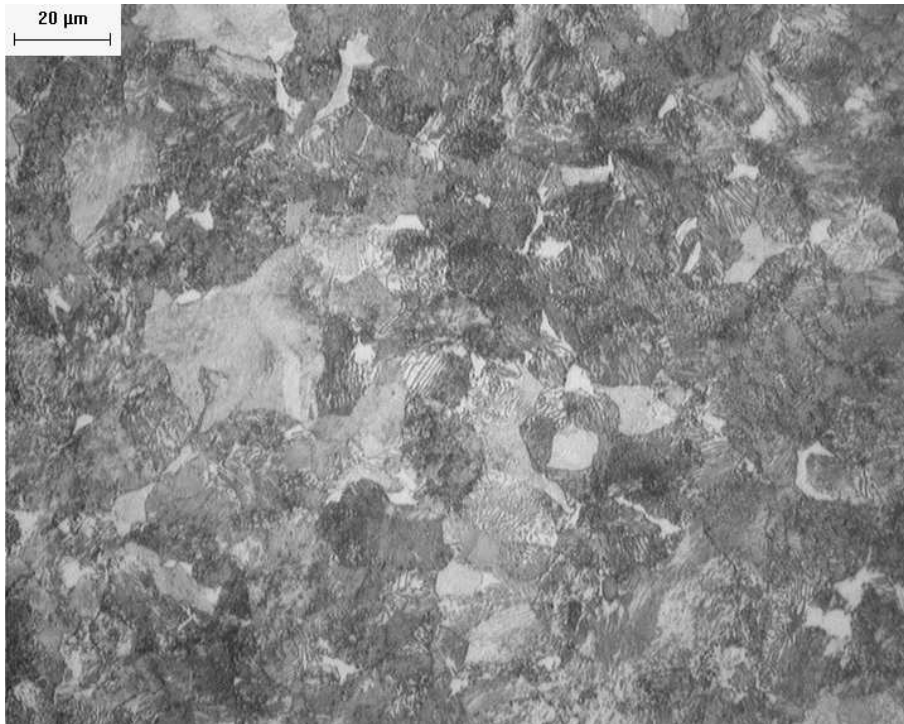
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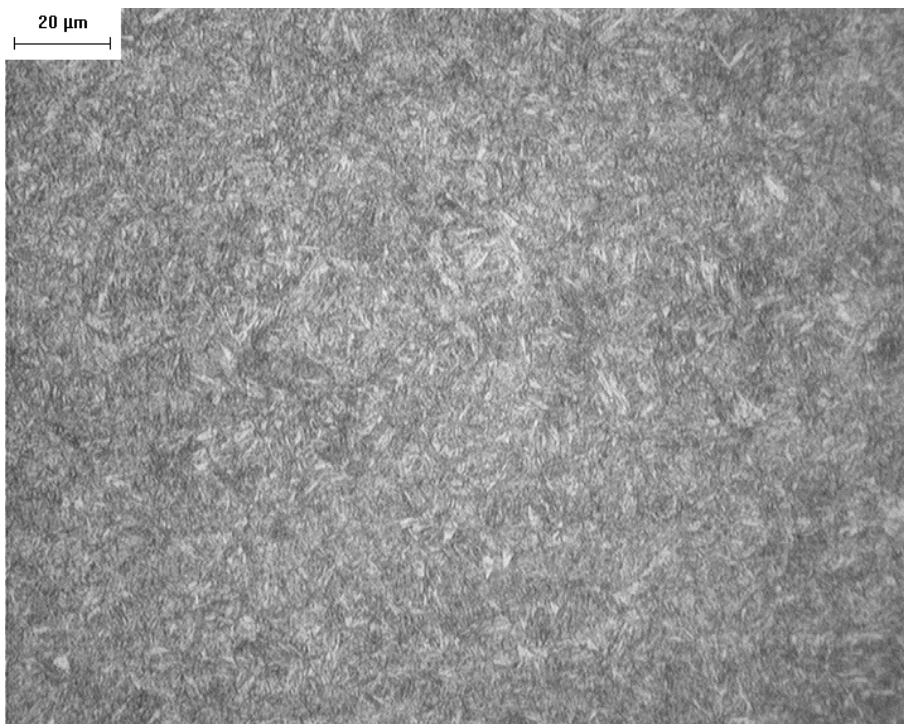
*Figure 4. Microstructure of sample 1. Martensite and bainite. Hardness 400HV*



*Figure 5. Microstructure of sample 2. Bainite. Hardness 260 HV*



*Figure 6. Microstructure of sample 3. Fine pearlite + ferrite. Hardness 308 HV*



*Figure 7. Microstructure of sample 4. Martensite. Hardness 530 HV*

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