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# Macro and Micro mechanical in-situ characterization using synchrotron diffraction of Architected micro-composite Duplex Stainless Steels

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## Abstract

The mechanical behavior of micro-composites Duplex Stainless steels (DSS) produced by Accumulative re-Bundling and Drawing (ABD) has been investigated. We evidenced a systematic increase in the yield strength, as a function of the manufacturing step, independently from the phases' volume fraction. A simple rule of mixture (ROM) successfully predicted the first generation of composites presenting a simple microstructure. However, a modified ROM taking into account the contribution of each component and its grain size could not predict the mechanical response of the composites of higher generation. An in-depth analysis is conducted to investigate the microstructure-mechanical behavior relationship and to rationalize the resultant mechanical behavior from that of each constitutive phase. For this purpose, in-situ synchrotron High Energy X-ray Diffraction measurements during uniaxial tensile experiments have been carried out to calculate the strain partitioning within each phase of the composites.

Keywords: Duplex Stainless steel, Synchrotron X-Ray Diffraction, In-situ tensile tests, Micro-composites, Micromechanics

# 1. Introduction

The use of Duplex Stainless Steels (DSS) for structural applications is considered as one of the most significant advances impacting the construction sector [1]. These steels show a combination of properties that make them very competitive materials not only compared to carbon steels but also to austenitic stainless steels. The mechanical and functional properties of DSS can be summarized in the following points: i) very good strength/ductility compromise; ii) interesting functional properties in particular a low thermal conductivity coefficient ( $<15\text{W/mK}$ ); iii) capacity of weight saving due to their high strength compared to the austenitic stainless steels and iv) low Ni content (0-4%) making the price of DSS lower and more stable.

It has been proposed that the mechanical properties of DSS result from a complex interaction between ferrite and austenite leading to a mechanical behavior that cannot be predicted from the properties of the constituents alone [2]. Several authors [3][4] [5] have attempted to model the plastic deformation of duplex stainless steels starting from the mechanical properties of single-phase tie-line alloys.

The high strength/elongation and the deviation from the law of mixture were found to be the most important features of conventional DSS. These characteristics are usually attributed, in the literature, to several factors: i) differences in plastic behavior between the ferritic and austenitic phase [6][7]; ii) residual stress and texture effects [8]–[11]; iii) Transformation Induced Plasticity (TRIP) [12], [13]; iv) other microstructural effects such as the formation of precipitations, phases' grain size or the morphology [14]–[16].

On the other hand, the effect of the microstructure morphology on the mechanical properties has been observed not only in DSS but also in other two-phase alloys. For example, in [17] the behavior of 1080 steel with pearlitic and spheroidal microstructure was studied during low-cycle fatigue. The authors found that the micro-stresses are higher in the pearlitic condition than in the spheroidal condition, and attributed these differences to a morphology effect. Indeed, the pearlite lamellae transfer the load more effectively to the cementite phase. In more recent works, the effect of volume fraction, morphology and phase distribution in dual-phase steel has been extensively reported in [18]–[21].

Several authors used multi-scale modeling and in-situ and ex-situ experiments to analyze the different parameters cited above and in particular the load sharing and stress interaction between phases and consequently the micro stress-strain curves [6], [10], [12], [15], [22]. However, this approach seems to be insufficient to explain the complex plastic interaction between the ferrite and the austenite in conventional DSS microstructures [2], [12].

Thus, one can conclude that the key to the unique properties of duplex stainless steel lies in its structure and the interaction between the phases. The work of [23], for example, showed the possibility of enhancing the mechanical properties by playing with the structure of DSS. Indeed, they designed a new DSS alloy with 1 GPa of tensile strength and 60% of ductility by reducing the austenite stability and introducing Transformation Induced Plasticity (TRIP)

effect. Therefore, providing a good understanding and a full description of the mechanical behavior of DSS may provide a significant potential for breakthrough mechanical properties and particularly improving the compromise between strength and ductility.

In the present work, we investigate the mechanical behavior of DSS wires produced by Accumulative re-Bundling and Drawing (ABD), following our previous description of this material processing [24]. We evidenced in [24] a systematic increase in the yield strength, as a function of the manufacturing step, independently from the phases' volume fraction. An in-depth analysis has been conducted here to investigate the different hypotheses and to rationalize the resultant mechanical behavior from that of each constitutive phase. For this purpose, in-situ High Energy X-Ray Diffraction (HEXRD) measurements during uniaxial tensile experiments have been carried out. The advantage of this technique lies in the ability of monitor the stress-strain partitioning thanks to its selectivity based on the crystal lattices. Thus, the mechanical behavior of each phase can be observed during the tensile test. To predict and understand the flow behavior of these composites, a comparison with a micromechanical model has been then carried out. Several studies demonstrated the performance of such models to predict the stress-partitioning of various multiphase alloys and composite such as Cu-Mo [25], Duplex stainless steel [12], [26]–[28], Ferrite-Cementite [29].

## **2. Materials and Methods**

### **2.1 Materials**

The Architected Duplex Stainless Steels (ADSS) samples were prepared using the Accumulative re-Bundling and Drawing (ABD) process, described in detail in our previous work [24]. Commercial austenitic and ferritic stainless steels of grades respectively 316L AISI (UGIMA® -X 4404) and 430LNb AISI (UGIMA® 4511) provided by UGITECH, have been used in elaborating ADSS wires of diameter of 1.55 mm. Wires in both as-drawn and as-annealed (850°C for 1h) condition have been characterized. The microstructure of the examined samples is shown in Figure 1, where  $i$  represents in the  $n_i$  sample the number of re-bundling operations.

### **2.2 Macroscopic tensile tests**

A high capacity 3R-syntech testing machine from UGITECH Research Centre has been used for tensile testing at room temperature. An extensometer has been used for accurate strain measurement with a deformation rate fixed at  $2 \cdot 10^{-4} \text{ s}^{-1}$ . All tensile tests have been realized on wires of 1.55 mm of diameter and 300 mm of length.

### **2.3 Microscopic in-situ tensile experiments using high energy synchrotron X-ray diffraction**

The in-situ HEXRD experiments aimed to determine the stress distribution in the different phases of our designed composites during in-situ uniaxial tensile tests at room temperature when applying increasing strain until failure. This technique also allows assessing a potential martensitic transformation induced by plastic deformation during the tensile test.

### 2.3.a Experimental setup

The experiment was performed at the ID15 beamline of the European Synchrotron Radiation Facility ESRF (High Energy X-ray Scattering) in Grenoble-France.

In the optical cabin, three Laue silicon monochromatic crystals are used to select three energy levels: 30, 60 and 90 keV. In the current study, the experiments were performed at an energy of 90 keV. A flat Pixium detector with 2480 x 1910 pixels of 154  $\mu\text{m}$  size was used to collect the Debye-Scherrer rings at 4 Hz acquisition rate.

The tensile machine (with load sensor of 4.4 kN) was positioned on a moving table that was translated in z direction, which allowed moving both tensile grips symmetrically with respect to the X-ray beam during the tensile tests, therefore ensuring that the illuminated volume of the sample remained at the center of the gauge length. The strain rate was fixed at  $2.10^{-4} \text{ s}^{-1}$  and wires of length 50 mm have been used in this experiment.

### 2.3.b Analysis of the diffraction data

#### i) Phase fraction evolution

After calibration, a circular integration was performed to obtain the conventional diffractograms showing the intensity (I) versus diffraction angle ( $2\theta$ ). These diffractograms were analyzed based on austenite and ferrite diffraction spectra using Rietveld analysis via the Fullprof software. Hence, any martensite formation during tensile tests would be observed by the change in austenite fraction.

#### ii) Elastic strain determination

The elastic strain for a given hkl plane ( $\varepsilon_{hkl}$ ) can be expressed by the following relation:

$$\varepsilon_{hkl} = \frac{d_{hkl} - d_{hkl}^0}{d_{hkl}^0} = \frac{\sin\theta_{hkl}^0}{\sin\theta_{hkl}} - 1 \quad \text{Equation 1}$$

Where  $d_{hkl}^0$  ( $\theta_{hkl}^0$ ) represents the interplanar distance (Bragg position) of the plane hkl before loading.

In the unstrained material, the diffraction rings are perfect concentric circles. In the deformed condition, these circles bend, forming ellipses with semi-axes oriented parallel and perpendicular to the tensile direction; the major axis (a) of the ellipse and the minor axis (b) are parallel and perpendicular to the tensile direction respectively as shown in Figure 2a. Indeed, as represented in the work of [30] the hkl planes parallel to the tensile direction correspond in fact to  $\eta=0^\circ/180^\circ$  (according to our configuration) and those perpendicular to the tensile direction correspond to  $90^\circ/270^\circ$ , see Figure 2b. In the current situation, the wavelength of the high energy X-rays is small and by consequence, the Bragg angles of the corresponding planes are small in the range of  $2\theta=3.9^\circ-14^\circ$ . This implies that the inclination of these planes versus the tensile direction can be neglected (which would not be the case for neutron diffraction). To measure the elastic deformation from the deformation of the diffraction rings, we discretized the diffraction rings into 8 portions of  $45^\circ$ , Figure 2c, and then made the azimuthal integration. The intensity of Bragg reflections  $I^{ph}$  for the phase ph was then fitted by a Lorentzian function:

$$I^{ph}(2\theta) = I_0 + \sum_{hkl} \frac{2A}{\pi} \frac{w^{hkl}}{4(2\theta - 2\theta_0^{hkl})^2 + (w^{hkl})^2} \quad \text{Equation 2}$$

Where:

- $I_0$  the baseline offset
- $A$  total area under the curve from the baseline
- $2\theta_0^{hkl}$  center of the peak hkl
- $w^{hkl}$  full width of the peak hkl at half height

Figure 3 shows the diffractograms of the composites in the loading direction after radial integration, initially before the tensile test with a preload of 10 MPa to set up the sample and to ensure its alignment. This acquisition was taken as the initial diffraction state. Six Bragg peaks are accessible for the  $\gamma$  phase, namely (111), (200), (311), (222) and (400). The most intense families of planes are (111) and (200). Regarding the  $\alpha$  phase, 5 Bragg peaks are accessible, namely (110), (200), (211), (220) and (310) of which the family of planes (110) and (211) are the most intense. Table 1 shows the respective average proportions of austenite and ferrite quantified by HEXRD measurements.

### 3. Results and discussion

The mechanical behavior of the ADSS composites is studied following two approaches: the first one is a macroscopic investigation relying on the comparison with the mechanical behavior of individual wires of both phases 316L and 430LNb and the resultant composites' microstructure. The second approach is microscopic, consisting in studying the composite's individual phases behavior using the HEXRD data.

#### 3.1 Macroscopic mechanical behavior

##### 3.1.a Composite n1 annealed at 1050°C

The stress-strain curve of the n1 composite is compared in Figure 4 with that of wires of the commercial grades 316L and 430LNb of diameter 1.55mm, identical to those used in the manufacturing of n1 composite and subjected to similar thermomechanical conditions. The austenitic and ferritic wires have been drawn from 2.2 mm and 1.8mm down to 1.55 mm of diameter, for ferrite and austenite respectively. Both wires have been then annealed at 1050°C for 10 minutes in a vacuum vertical furnace. In these annealing conditions, the 430LNb steel becomes significantly softer than the 316L steel.

To predict the mechanical behavior of n1 composite, a simple law of mixture can be applied. Indeed, if the flow stress  $\sigma$  is modeled according to an isostrain rule of mixtures (ROM), the flow stress of the composite  $\sigma_c$  can be written as a function of the flow stress of the two constituents and their volume fraction as following:

$$\sigma_c(\varepsilon) = V_{316L}\sigma_{316L}(\varepsilon) + V_{430LNb}\sigma_{430LNb}(\varepsilon) \quad \text{Equation 3}$$

Where  $\varepsilon$  is the strain,  $\sigma_c$ ,  $\sigma_{316L}$  and  $\sigma_{430LNb}$  are the flow stress of the composite and of the 316L and 430LNb wires, respectively.  $V_{316L}$  and  $V_{430LNb}$  are the volume fractions of the constituting phases (316L and 430LNb respectively) present in composite n1. The volume fraction of the austenite and the ferrite has been estimated by image analysis to be 45% and 55%, respectively.

As shown in Figure 4, a good approximation is obtained between experimental results and modeling with the simple law of mixture expressed in equation 3, despite the slight difference in the yield strength, namely 263 MPa in experiment against 230 MPa predicted by ROM. The applicability of the ROM is expected for this composite since no significant changes in terms of microstructure, have occurred between the individual wires and those of the n1 composite. Indeed, if we compare the average grain size of ferrite inside the n1 composite (measured from EBSD maps) and that of the individual wires (calculated by interception method on optical micrographs) we find a similar average grain size  $\approx 55\mu\text{m}$ . On the other hand, the average grain size of the individual wire of 316L is slightly larger ( $60\mu\text{m}$ ) than that inside the n1 composite ( $50\mu\text{m}$ ), which could explain the slightly larger yield strength in the composite.

### **3.1.b Composite $n(i>1)$ annealed 850°C**

Unlike the n1 composite, the tensile behavior of n2, n3 and n4 composites was examined after annealing at a lower temperature (i.e. 1h at 850°C with a heating rate of 70°C/h), to avoid excessive interdiffusion between the two constituents. The composites' tensile curves, shown in Figure 5, are thus compared with those of individual wires of 316L and 430LNb heat-treated in this case at 850°C for a duration of 1h with a heating rate of 70°C/h.

Although the volume fraction of each phase varies for each composite, one can notice the increase of the flow stress at each step. Indeed, the n2 and n4 composites have the same volume fraction of ferrite (76%vol), however, the flow stress of n4 composite is significantly higher than that of n2. A similar trend is observed in n3 and n5 composite (43% of austenite). The evolution of yield strength, tensile strength and uniform elongation are summarized in Figure 6. One can notice the strong increase of yield strength between n2 and n3. However, the increase in yield strength becomes relatively slow between n4 and n5. The tensile strength follows a similar trend as the yield strength, and the uniform elongation accordingly decreases with the number of generations of the composite.

Compared to the individual wires of 316L and 430LNb, it is interesting to notice that none of the composites' flow stress is situated between that of 316L and 430LNb wires. Indeed, the flow stress of n2 composite, with 77% of ferrite, fits perfectly with the flow stress curve of 430LNb wire up to 10% strain beyond which the work hardening of n2 composite starts to increase. On the other hand, the flow stress of n3 (43 % of  $\gamma$ ), n4 (24% of  $\gamma$ ) and n5 (43% of  $\gamma$ ) exceed that of 316L wire.

Figure 7 shows the stress-strain curves for composites (n2,n4) and (n1,n3), these pairs having respectively the same initial fraction of ferrite and austenite. The results evidence a systematic

increase in flow stress for composites  $n$  ( $i > 1$ ) for a given fraction of austenite phase as a function of the manufacturing step. Three hypotheses could explain this systematic increase: i) Strain-induced martensite transformation; ii) contribution of thermal martensite; iii) phase / grain size effect.

The first hypothesis can be ruled out since the austenite phase present inside the composites (316L) is stable with respect to plastic deformation at room temperature [31]. In Figure 7, a quantitative analysis of phase evolution during the tensile tests has been realized and shows indeed that the austenitic phase inside all composites is stable, *i.e.* no transformation to martensite has occurred. In addition, these results show that the stability of the austenitic phase is not significantly disrupted by the changes in the chemical composition of 316L due to interdiffusion of solute elements during the annealing steps [24].

The presence of the thermal martensite in ADSS has already been evidenced and discussed in our previous work [24] and its contribution to the mechanical behavior could be significant in composites  $n$  ( $i > 1$ ), since the fraction of martensite increases together with the interfacial area between ferrite and austenite, and with the extent of interdiffusion.

As shown in Figure 8 for the  $n_4$  composite, the presence of this martensite appears as a thin layer of very small grains at the boundaries of the ferritic regions. The estimation of the volume fraction of martensite formed within the vicinity of the interface  $\gamma/\alpha$  increases to reach 1.6%, 5.1, 5.6 and 6% in composites  $n_2$ ,  $n_3$ ,  $n_4$  and  $n_5$  respectively. These fractions are calculated by assuming that the martensite is formed within a constant layer within the vicinity of ferrite/austenite interface and inside 316L phase. The thickness of this layer was taken to be the maximum observed by EBSD and TEM [24], namely  $3\mu\text{m}$ .

The variation of grain size within the ferritic region of the composite could also partly explain the systematic increase of the mechanical properties. A sample processed by several steps of ADB possesses a spatially heterogeneous microstructure, because of the different history that the different generations of wires and tubes have been subjected to. For a given  $n_i$  sample (subjected to  $i$  steps of ADB), one can differentiate the regions corresponding to the different generations when the materials have been introduced in the process ( $j \leq i$ ). Using local and global EBSD maps, the grain size of each component in  $n_3$ ,  $n_4$  and  $n_5$  were measured, and are represented in Figure 9. One can notice two features:

- Within the same composite, the grain size for a given phase is smaller in the old generations than in the new ones. In other words, a decrease of grain size is noticed for a given phase moving from the external tube towards the core of the wire.
- For a given generation and phase, one can notice a systematic decrease of grain size when  $i$  (number of composite) increases.

In order to examine the possible influence of the grain size on the yield strength of the composites, Hall-Petch relation and rule of mixture can be used. The Hall-Petch relationship for both austenite and ferrite phases has been constructed using individual wires of 316L and

430LNb. These wires were subjected to different thermo-mechanical operations as shown in Table 2.

Figure 10 shows the relation between the yield strength measured by tensile testing as a function of the inverse of the square root of grain size for individual wires 316L and 430LNb.

The Hall-Petch [32], [33] relationship for both bulk wires was then expressed as following (in MPa):

$$\sigma_y^{316L} = 201.4 + \frac{351.3}{\sqrt{d}} \quad \text{Equation 4}$$

$$\sigma_y^{430LNb} = 181.5 + \frac{305}{\sqrt{d}} \quad \text{Equation 5}$$

Hence, one can calculate the yield strength of the composite n(i)  $\sigma_c$  taking into account the contribution of each generation. The ROM can then be written as following:

$$\sigma_c = \sum_{j=1} V_j^{316L} \sigma_j^{316L} + \sum_{j=1} V_j^{430LNb} \sigma_j^{430LNb} \quad \text{Equation 6}$$

Where  $V_j^{ph}$  and  $\sigma_j^{ph}$  are the volume fraction and the yield strength of the phase  $ph$  issued from generation  $j$  respectively. Table 3 compares these predictions to the experimental values. A significant difference between the calculated and the experimental yield strengths is observed.

This difference between the ROM and the experiments can be attributed to the fact that the Hall Petch relationship is derived from individual bulk wires, which are not representative for the austenitic and ferritic phase in the composites, especially at large ni numbers because of extensive inter-diffusion between the phases that cause changes in their mechanical properties. In order to understand further the micro-composites' mechanical behavior, we will now carry out a local analysis of the behavior of each phase during the tensile test.

## 3.2 In-situ tensile tests

### 3.2.a Peak selection

When performing in-situ measurements with X-ray diffraction, it has been established that the suitable  $\{hkl\}$  planes for measuring the stress within one phase are those whose elastic strain have a linear response with the applied macroscopic stress (in the elastic regime). Indeed, such linearity means that these  $\{hkl\}$  planes are less affected by intergranular interactions, allowing therefore properly converting a measured lattice strain into equivalent stress by Hooke's law [34].

Figure 11 shows the evolution of elastic strains for different  $\{hkl\}$  planes of the austenite phase in composites n2 and n3 with macroscopic applied stress. A strong anisotropic behavior and non-linear behavior of all  $\{hkl\}$  planes is revealed in the elastic part, meaning that none of the  $\{hkl\}$  reflections represent the macroscopic stress behavior [35], [36]. Therefore, it is necessary to take into account the contribution of each  $\{hkl\}$  plane reflection to produce a macroscopic equivalent strain  $\overline{\varepsilon_{ph}}$ . Daymond's model (METHOD B) [34] is used in this study

to calculate the equivalent strain by calculating the weighting of each measured peak with the following equations:

$$\bar{\varepsilon}_{ph} = \frac{\sum_{hkl} \alpha_{hkl}^{ph} \varepsilon_{hkl}^{ph}}{\sum_{hkl} \alpha_{hkl}^{ph}} \quad \text{Equation 7}$$

$$\alpha_{hkl}^{ph} = \frac{E_{hkl}^{ph}}{u_{hkl}^2 d_{hkl}^{ph} p A(\lambda) F_{hkl}^2 \sin^2 \theta} \quad \text{Equation 8}$$

Where  $\alpha_{hkl}^{ph}$  is the weighting function of the individual diffraction peak {hkl} of phase (ph),  $\varepsilon_{hkl}^{ph}$  is the strain obtained in analyzing the {hkl} reflection of the phase (ph),  $E_{hkl}^{ph}$  is the diffraction elastic constant for {hkl} diffraction peak of the phase (ph),  $u_{hkl}$  is the uncertainty of individual {hkl} reflection measurement, p is the polarization factor, A represents an absorption term, F is the structure factor.

This model is suitable for our study since we have shown in previous work [24] that the texture of an ADSS depends on the composite type and varies as a function of generation for a given phase.

The determination of the weighting factors in equation 8 requires the knowledge of the plane-specific Young's moduli for the two phases  $E_{hkl}^{ph}$ . To measure these elastic constants, we used samples of composites containing  $\approx 43\% \gamma$  (n3 and n5) and those containing  $\approx 76\% \alpha$  (n2 and n4) in the as-drawn state, which show very high yield strength and thus an extensive elastic regime. Figure 12 shows the relationships between applied stress and lattice strains for the as-drawn n3 composite, and Table 4 shows the measured  $E_{hkl}$  in this work compared with those measured in the work of [36] and [37] for FCC and BCC phase respectively. Due to its weak intensity in as-drawn state,  $(E_{220})_{\gamma}$  could not be measured. The measured values are in very good agreement with those from the literature.

### 3.2.b Averaged stress calculation

In order to assess the load sharing between both phases, average phase stresses rather than average lattice strains are required. The composite's stress can then be calculated using mixture and Hooke's law as follows [38-39]:

$$\sigma_c = V_{\gamma} \sigma_{\gamma} + V_{\alpha} \sigma_{\alpha} = V_{\gamma} E_{\gamma} \bar{\varepsilon}_{\gamma} + V_{\alpha} E_{\alpha} \bar{\varepsilon}_{\alpha} \quad \text{Equation 9}$$

Where  $V_{\gamma}$  and  $V_{\alpha}$ ; are the phase volume fractions. The bulk Young moduli,  $E_{\gamma}$  and  $E_{\alpha}$ , of the commercial 316L AISI (UGIMA® -X 4404) and 430LNb AISI (UGIMA® 4511) are 196 GPa and 220 GPa, respectively. Combining Equation 5 with 7, the composite stress can be rewritten:

$$\sigma_c = V_{\gamma} E_{\gamma} \left( \frac{\sum_{hkl} \alpha_{hkl}^{\gamma} \varepsilon_{hkl}^{\gamma}}{\sum_{hkl} \alpha_{hkl}^{\gamma}} \right) + V_{\alpha} E_{\alpha} \left( \frac{\sum_{hkl} \alpha_{hkl}^{\alpha} \varepsilon_{hkl}^{\alpha}}{\sum_{hkl} \alpha_{hkl}^{\alpha}} \right) \quad \text{Equation 10}$$

Figure 13 compares the calculated stress strain curves with the experimental macroscopic tensile tests of the investigated composites n2, n3, n4 and n5 after annealing. Interesting features can be observed in this figure:

- Very good agreement between the averaged calculated stress using Equation 4 and the macroscopic tensile curve is obtained for composites n2, n3 and n4.
- The calculated stress curve of composite n5 (43%vol of austenite) shows a significant decrease of its slope starting from 7% of true strain.

Several parameters can explain these features. First, one possible explanation of the slope change of n5 composite could be the contribution of a third phase in the strengthening process. As demonstrated previously, no martensitic transformation occurred during the tensile test. Nevertheless, all composites contain already a martensitic phase inherited from the previous steps. Therefore, the presence of this martensite may partly explain the change in slope in the n5 composites. Under this hypothesis, the larger slope change in the n5 composite could originate from its containing more accumulated martensite than other composites. Moreover, the architecture perturbation in composite n5 originated from extensive interdiffusion, as evidenced in [24], causes microstructural changes in terms of grain size and chemical composition of the austenitic phase issued from older generation.

Secondly, in this kind of experiment, the diffraction spectra of each phase are representative of the average response. However, the mechanical behavior of an individual phase in the composite is also dependent of the behavior of the phases issued from each generation of the composite, as it was discussed previously and demonstrated in our previous work [24]. Indeed, a variation of the grain size and the texture as a function of the generation within the same phase has been revealed. This was attributed to the thermomechanical history undergone by each component.

Figure 14 summarizes the calculated separate stress evolution of the austenite and ferrite phase of all composites as a function of the macroscopic true strain. It shows the systematic increase of the calculated stresses for both phases as a function of the composite n, which is consistent with our discussion on the influence of the grain size within the phases. This data also evidences the stronger strain hardening rate in the austenite phase within the composites, and conversely the higher yield strength in the ferrite phase.

Thus, Daymond's model used in this work to describe the macroscopic mechanical behavior starting from local mechanical response gives a very good approximation. Thanks to this model, we can conclude that for a filamentary duplex stainless steel, the increase of the mechanical properties results, indeed, from the microstructure of each phase and generation within the same phase rather than a complex interaction between the two phases and their distribution.

## 4. Conclusion

- A systematic increase in composites' flow stress as a function of the manufacturing step independently from the phase volume fraction has been observed.
- A simple rule of mixture (ROM) from the constituent's materials stress-strain curves successfully predicts the n1 composite's flow stress.
- The flow stress of composites n>1 shows a high deviation from the simple ROM. A modified ROM taking into account the contribution of each component and its grain size failed in the prediction of the mechanical behavior. Thus, the limit of the macroscopic approach has been drawn.
- Lattice strains of both phases BCC and FCC were successfully measured by synchrotron X-ray diffraction for ADSS composites n>1 during tensile tests carried out on the as-drawn and as-annealed state.
- The strain partition of each phase has been calculated by taking into account the contribution of each hkl plane
- The calculated macroscopic stress-strain starting from local mechanical response gave a very good approximation for composite n2, n3 and n4. On the other hand, the model evidenced the possible influence of the martensite induced upon cooling and the microstructure perturbation due to the extensive interdiffusion on the mechanical behavior of composites n5.

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# A PROPOSAL FOR THEORETICAL AND EMPIRICAL EXTENSION OF THE SOCIOLOGY OF ANTI-DOPING

**DECLARATION OF INTERESTS:** None

## ABSTRACT

The purpose of the paper is to highlight the interest of using diverse sociological approaches and models for studying anti-doping (developed outside the epistemic community of researchers working on doping) and to point out the sociological interest of the doping issue for social sciences.

First, we will present a model developed by pragmatic sociologists for describing social issues in society that could assist researchers in describing the complex reality of the anti-doping issue. The model proposes to examine the ways in which axiology, devices and realities are articulated in anti-doping related criticism and the existing circulation between the six social logics described in it. Its use could allow researchers to apprehend local and global transformations in the system and the articulations between these two levels. Second, we will resume the most relevant results of a research that analysed the prevention activity using an approach of work sociologists. A part of this research sought to identify the meaning that people working in prevention gave to their activity. The received answers were manifold; five ways of “doing prevention” were identified, to which institutions were committed differently. The described panorama showed a dispute where the debate as such was not tabled and nobody seemed able to definitively close the dispute, not even the World Anti-Doping Agency (WADA). Finally, an ongoing research will be presented. It focuses on the procedures-based management implemented by WADA and aims to compare its development with the implementation of similar management systems by other institutions. The research could allow us identifying possible related risks, for example, the loss of the pleasure of working, the emergence of fear or the increasing work pressure. We hope the paper will encourage other social researchers to renew the usual theoretical approaches.

## KEY WORDS

Anti-Doping; Pragmatic Sociology; Sociology of Risks; Sociology of Work; Prevention; Quality Procedures; Procedure-Based Management

## Introduction

The title is likely to surprise sociologists not familiar with research in anti-doping. Some colleagues may consider themselves social philosophers; others prioritise empirical research. Despite these differences, at least in France, social scientists test and discuss social theories and apply them to studies on the field in order to produce knowledge transferable to other objects. These sociological models are often used to analyse other objects than the objects they were primarily created to study. The scientific relevance of these models is related in that way to their “scope” (Chateauraynaud, 2011), to their capacity to elucidate other objects.

When we examine sociological literature on anti-doping, it is surprising to note that theoretical resources are rare and varied. Some colleagues mobilize Weber (Christiansen et al., 2016), Foucault (Wagner, 2010; Pappa & Kennedy, 2015; Ryan, 2015) or Elias (Connolly, 2015; Hanstad et al., 2008; Hanstad & Skille, 2008; Hanstad, 2009; Waddington, 2010). The use of figurational sociology developed by the latter seems to be the most common theoretical framework, along with New Institutionalism (Hanstad & Wagner, 2011; Wagner & Møller Pedersen, 2014; Hanstad & Houlihan, 2015). Other frameworks have also been used by researcher (e.g., the Critical Discursive Analysis: Jedlicka, 2014; Wagner & Møller Pedersen, 2014), but they are not many, and this short list is almost exhaustive. It is astonishing to notice that other recent models that are being currently discussed in the community of sociologists have never been used in anti-doping.

Without wishing to play down the interest of the studies mentioned above, we aim to highlight in this article the interest of summoning different sociological models, elaborated outside the “epistemic community of researchers” working on doping (term used by sociologists of science and epistemologists to designate all the researchers that share objects, theories or methods).

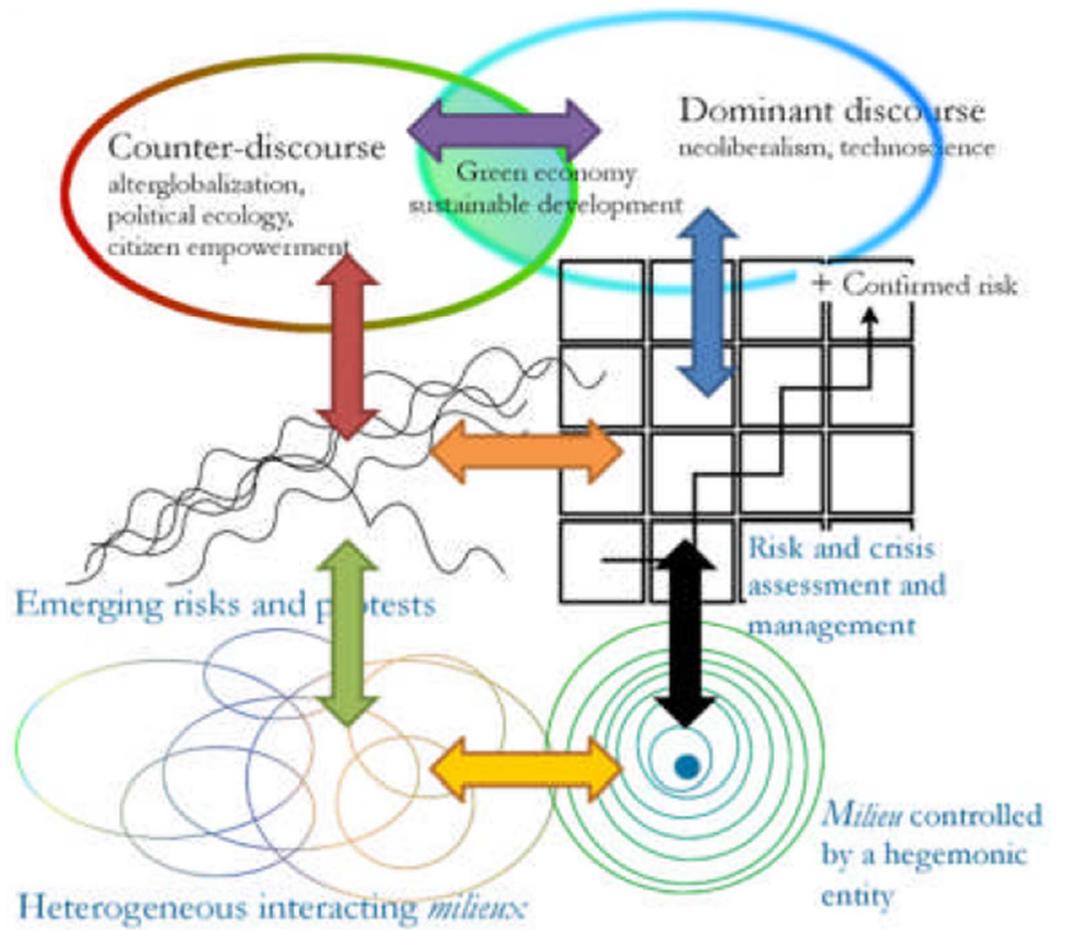
Our research group tends to focus primarily on the study of anti-doping “devices”. Devices are understood to be placed between the representations (axiology) and the ontologies or realities on the field, in the *milieu* using Deleuze’s terms (Deleuze & Guattari, 1994). When we use the term “device” we refer to statistics, regulatory devices (e.g. WADC or International Standards), institutions and other tools and documents developed by WADA. This concept was developed by political scientists but has irradiated pragmatic sociology for nearly 40 years now. Pragmatic sociology is a sociological current nourished by American philosophers from the beginning of the 20th century (James, Dewey, Peirce). As Susen and Turner (2014) point out, in the early 1980s, Boltanski overturned Bourdieu's tradition by moving from "a critical sociology to a sociology of criticism". Pragmatic sociology is widely discussed by the sociological community, in North America (e.g., Silber, 2003) and in European countries (Atkinson, 2019; Frere & Jaster, 2018). Centring the analysis on these devices makes it possible for the researcher to observe how actors link their principles to the realities in the field, and vice versa. This allows the researcher to examine how actors construct their judgments in different situations. Actors link the realities in the field to their representations in order to give them a meaning and to be able to act accordingly.

The purpose of this article is not to discuss classical authors' writing on doping, but to show that recent sociological models could allow us to understand some aspects of the fight against doping. From a sociological point of view, in order for scientific debates on anti-doping to be better organized, we believe that it is necessary to identify the theoretical models that enable clarifying the social practices that we wish to describe and analyse. Empirical research works suggested by these approaches differ from those generally carried out by our colleagues working in anti-doping. It also needs to be pointed out that many papers do not mention any empirical work in the sense that it is understood in sociological analysis. Even if several researchers in anti-doping define their research method by delimiting it and by submitting to analysis tools, other works are closer to “*essayism*”, an interesting literary form which consists in freely commenting some elements of the anti-doping fight that are certainly heuristic (because they provide information on possible interpretations), but are nevertheless far from sociological requirements.

This may seem paradoxical to the reader, but unlike in most of our papers, in this article, we will not use original empirical data. We will instead mention other research works, some of which have been conducted by us. What is important here is to show that recent models in sociology can be used to better understand the fight against doping. We will present three of them, we will attempt to describe them, to show their contribution to the fight against doping and to identify some lines of research to which they could lead.

## 1. Mobilizing the sociology of risks

The first model that will be presented has its origins on the pragmatic sociology of risks (Chateauraynaud & Debaz, 2017). It aims to model the society based on the sets of actors and institutions involved in or concerned by problematic issues. It allows us to better describe problematic issues in society (health risks, doping, etc.) by first dividing the reality in six logics that co-exist, in order to make analysis more precise and accurate. The reality is thus organised in three levels (axiology, devices and the *milieu* or the field, in descending order) and in two columns: the right one for the dominant discourses, devices in place and controlled *milieu*, the left one for the counter-discourses, alternative devices and heterogeneous *milieu*. A multilevel and complex reality is presented in the model; the doping issue is characterised by such complexity. We propose to examine its heuristic value for doping issues, by focusing on the ways in which axiology, devices and realities are articulated in anti-doping related criticism.



The model of the Six Logics of Action in critical processes  
 In french: “*Six logiques d'action au cœur des processus critiques*”  
 Retrieved from Chateauraynaud & Debaz (2017, p.501)

At the top, in the right, the dominant discourse is represented. The dominant discourse makes it possible to create and develop devices in consistency with representations on the issue, values and concepts of the institutions in charge. This discourse can define, for example, what collective goods or universal values are, and how they can be achieved. The discourse of the institutions in charge of anti-doping like WADA, UNESCO or the International Olympic Committee (IOC) are included in this first logic. These institutions promote their conception of fairness and clean sport, defend sports ethics and encourage public authorities to commit themselves to the fight against doping. Some academic works that study Olympic Games or the listed institutions also carry these ideals (Boniface, 2012).

The second social logic, at the top in the left, comprises the counter-discourse. This critical perspective is present in many works in social sciences literature that have treated sport and doping. In France, for several decades, a critical approach to sport has existed which, relying on the Frankfurt School and the theses of Marcuse (1964) and Habermas (1968), perceived the study of performance as a problematic ideology. If we applied their thesis, doping would not be the practice of several deviants perverting the sports ideal, but the natural fruit of an activity that decidedly exploits the body to turn it towards competition and excess. From a

different perspective, criticism also exists against these institutions concerning the fight against doping (Miah, 2004).

In the middle level in the right, the dominant devices are represented: norms, mechanisms, procedures. The study of these devices is fundamental; otherwise, the analysis of the discourses and counter-discourses could hardly be connected to the implementation of policies on the *milieu*. Historically, well known sociologists as Max Weber and Michel Foucault or ethno-methodologists (Clayman, 2015) have sought to study rational action, bureaucracy, control mechanisms and interpretation processes that produce reports, hearings, deliberations, working papers, evaluations or consultations. Regarding anti-doping, this logic includes the Code and the set of other international and national devices (IS, toolkits, Technical Documents, reports). Many researchers, ourselves included, have contributed to it by writing reports or evaluating some of these devices.

Mobilization of actors having a counter-discourse or defending alternative devices is a necessary condition for the existence of the fourth logic, in the middle in the left. Even if some athletes can be critical with some principles of the Code or other devices, group criticism is rare. This can be the consequence of the rather weak mobilization among athletes and a weak capacity to constitute collectives to speak out against the dominant devices and discourse, despite the fact that independent initiatives of athletes in relation to doping seem to become more common (e.g. Athletes V Alliance, Athletes for Transparency). This fourth logic is the least studied one by social scientists.

The fifth logic, down in the right, refers to the reality of the field, of the *milieu*, controlled by a hegemonic power. It represents a social environment where devices are implemented by a centralized power with a hierarchical organization and a hegemonic position and includes every people respecting the rules, standards and other devices in place. In the case of doping, these can be athletes that fill their localization information in ADAMS (Anti-Doping Administration & Management System), pass doping controls and do not take prohibited substances; doctors that treat their athletes respecting the legislation in place; coaches that act with respect of the Code. The hegemonic figures that concentrate power are not only the mentioned doctors and coaches, but also other athlete support personnel and national federations. It is difficult for an athlete to avoid these actors (they are part of their national technical direction, club or federation), they all have certain level of knowledge about doping and anti-doping and are connected to the regulations and practices in the field.

The sixth and last social logic concerns the heterogeneous interacting social environments. The control of a hegemonic power or authority is less important and leaves the place to margins of freedom. These interacting social environments can lead to the transformation of behaviours, for example, when an athlete gets injured or when he enrolls in a gym to enhance his performance, in parallel of his competing sport activity. Doping practices are also part of this logic as well as whistleblowers, because they alert over covered practices that would demand action from institutions' side. Sociologists and anthropologists with expertise in ethnography can apprehend these micro-worlds and examine the continuous re-adaptation of attitudes and habits, the capacity of actors to resist micro-transformations of the systems and their adaptation strategies. Within this sixth logic, doping practices have received an

important interest from social scientists, some based on questionnaires or interviews, others on observation or evidence analysis.

Describing these logics of action does not aim to prioritise the study of any of them, but to assert that they are all relevant and to identify the ways in which actors and arguments can circulate from one to the other. The general hypothesis that the authors of the model defend is that all the crossing points are important for a democratic system to survive. We need all these logics of action: the authority creating, developing and implementing norms, but taking into consideration existing criticism and thus making possible for devices to evolve; actors on the field implementing policy; different actors expressing their demands and needs, demands and needs that can also be at the origin of global evolutions of the public anti-doping action. It is particularly interesting for social scientists to take into account the world in its disorganization and turmoil, preferably without overlooking any of the six logics.

Examining the circulation between these social logics is an even more ambitious sociological program that would allow us capturing local and global transformations in the system and the relationship between these two levels. In anti-doping, the circulation between the logics is uneven. There is a clear circulation between representations, values and principles, the production of policies, International Standards and other devices that ensure compliance and their implementation on the field by doctors, coaches, other athlete support personnel or national federations. On the contrary, discussions with counter-discourse producers are almost non-existing and asymmetrical. Mobilization and protests are rare and do not challenge the instruments in place. Concerning the sixth logic, it needs to be said that it is often present in speeches, statements or explanatory memorandums because actors tend to point out the practices contrary to the hegemonic discourse or that scape to the control of devices and push them to act.

The presented model has not yet been used for studying doping, but some preliminary reflections have brought us to identify two interesting facts. On the one hand, major differences exist between the doping issue and the other health issues. In the fight against doping, main decision-makers and actors in charge are committed to conciliating axiological principles and policy instruments, but neglect the rest. On the other hand, the absence of academic research on certain social logics is relevant. We have the impression that everything is still to be done in the social sciences, in a similar way as in social psychology (Backhouse, Whitaker, Patterson, Erickson, & McKenna, 2016). We do not have an answer to explain that; nevertheless, we believe that as social scientists we should question and try to explain these differences.

## 2. Mobilizing the sociology of work

The study of prevention, to which WADA usually seems to limit the role of social sciences, also deserves to be developed. The lack of precision about the term prevention and the plurality of the lexicon invites us to it: WADA, as well as NADOs (National Anti-Doping Organisation), talks about prevention, information, education or raising awareness. As defended by many sociologists of work, focusing on the real work of prevention workers or

“*preventologists*” can be a way to study prevention. Making them talk about the sense they give to their job it is heuristic means to overcome the tension between prescribed work and real work. Using this approach, Yves Clot (2014) could show that even metro drivers, that have a quite repetitive job, could have different strategies and would give a different sense to what they understand to be “making the work properly or right”. Some could go fast and brake firmly in order to be in time, while others would prioritize passengers comfort, for example. These conflicting criteria must be admitted into the analysis by expressing the meaning that the agents give to their work (Clot, 2009: 300-302).

Focusing back on prevention, it needs to be said that in a research program financed by the French Sports Ministry (Trabal et al., 2008) we have conducted several observations and carried out interviews with *preventologists* from the French NADO and from the regional doping institutions seeking to identify the sense they give to prevention activities: prevent from what, in the name of what, why? The received answers were manifold. The following table illustrates five different types of prevention actions, divided according to the qualification of the status of the targeted person, the risks that need to be prevent, the identification of these risks, the logic of action chosen and the normative support for these logics of action:

<b>Qualification of the target</b>	<b>Risk that needs to be prevented</b>	<b>Identification of the risk</b>	<b>Logic of the action</b>	<b>Normative support</b>
HIGH-LEVEL ATHLETES	Positive control	Anti-doping control	Information on law system	The Code
SPORTSMEN	Not level-playing competition	Cheating	Values-based education	Ethics Fair play
AMATEURS	Pathology Illness	Symptom	Care	Medicine
PATIENTS	Doping behaviour	Addiction Consumption	Sanitary alert	Study of addictions Physiology Behaviourism
CITIZENS	Not necessary medical consumption	Social epidemiology	Health education	Ottawa chart

Table 1: Types of prevention actions

As the table shows, in prevention actions, the status of the group of athletes that form the public can be homogenous, but can also be diverse. Participants can be seen as high-level athletes, sportsmen and sportswomen, amateurs, patients, citizens or even as having more than one of these statuses at the same time. *Preventologists* can then give a particular sense to their action, depending on their formation, their professional career (e.g. coming from sports competition, from sports medicine, from health institutions), experiences with illnesses or positive controls or institutional attachments.

Precisely, what type of prevention actions do these institutions undertake? We noticed that in the recent past, institutions in charge of anti-doping have rarely commented on this issue. Prevention was an answer, symmetrical to the activity of control and sanctioning, but its object was of little interest for anyone beyond the actors charged with "doing prevention". It was a political display to show that the public authorities were acting, but "doing" prevention can have as many meanings as the verb "to do" can bear. Whether the issue is hooliganism, drug addiction, sexually transmitted diseases or road safety, it is surprising that even if

literature in sociology is studying prevention as a "watchword", it has much less worked on the activity of prevention in itself. In doping, the imprecision and vagueness of the term has certainly led to a leeway or a margin permitting each actor to prioritize their understanding of prevention and work accordingly, partly also because the activity has been associated for a long time to a form of activism or volunteering.

However, little by little, institutions in charge of anti-doping started positioning themselves. WADA has adopted epidemiological concepts to distinguish between prevention, information, education and raising awareness and has identified targets for each of them. Japan, to mention a governmental example, successfully proposed to the Conference of the Parties in 2017 a resolution promoting "values-based" education.

The French case is particularly relevant and points out several conflicts that this process could arise. The French Ministry of Sports, after defending the notion of "doping behaviour" based on the recommendations of experts in addictology, strives to formally define and delimit the competences of the various institutions concerned and their missions. Their approach has triggered particularly tense meetings as some *preventologists* consider that they must give up prevention as understood by them. The outcome of the process is for now unknown, but our interviews make it possible to envisage some forms of demobilization, resignation or even resistant actions, as it can be read in two excerpts of our interviews with *preventologues*: "*we will quickly explain the regulatory elements of the Code but we will continue to insist on health*"; "*we refuse to prevent only to the risk of having a positive control*". WADA's willingness to implement International Standard of Education, despite all the suggestions to let NADOs organize it as they see fit, will probably harden the debate.

By following the approach of the sociology of work that invites us to clarify the meaning that the actors give to their work we manage to identify, not two or three ways of "doing prevention", but five ways, to which institutions are committed differently. It has become difficult to observe coordination among institutions; hard to state if it explicitly exists. The described panorama rather shows a dispute characterized by a lack of controversy (the debate as such is not tabled anywhere for now), by a form of latent conflict that is juxtaposed with territorial defences and by power games and legitimacy between experts. It does not seem to exist an actor able to definitively close the dispute, even if WADA intends to do so by harmonizing.

### 3. A world based in procedures

We propose to examine a last approach, less theorized for now because it is an ongoing research. It aims to understand the proliferation of regulatory devices by WADA. Once again, as it has been done with the two approaches mentioned previously, we will try to apprehend this normative tendency by taking distance from the object and by relating it to a different social process, the management by procedures based in quality evaluations.

The lexicon used in 2019 WADA's symposium in Lausanne, as well as in the Agency's website, refers to the activity of quality experts and quality managers: "references and guidelines", "compliance and non-compliance", "accreditation", "audit", "corrective actions",

etcetera. These terms are part of a rhetoric that reports all the difficulties to a lack of legislative devices and shows that WADA counts on the full support from its partners, who would be fully engaged in collaborating with other stakeholders in order to implement the necessary practical changes and comply with the new provisions.

Nevertheless, based on empirical evidences found in our researches, we believe that it is important to study WADA's tendency to find solutions essentially in the normative activity and its effects on anti-doping. Many representatives from anti-doping institutions have affirmed to us that they are worried about this tendency of creating new legislative devices as a response to dysfunctions. What can we learn from sociologists who have analysed the social activity surrounding quality procedures? We propose to examine briefly the results of some relevant publications about procedure-based management and quality procedures.

Sociological literature on this issue is not very abundant, but it is interesting. Di Maggio and Powell (1983) revisit the Weberian concept of bureaucratization to propose the notion of "institutional isomorphism", which designates this process of homogenization in the structure, culture and product of these organizations. Certainly, structural isomorphic change is more normative and coercive than mimetic, to use the terminology of Di Maggio and Powell (2004, 2012).

Chauvière (2008), in his study on the general effects of procedure-based management over social activity, affirms that the objective of this type of management, the quality, is a relative and often subjective trait. The researcher also states that the quality of the organizations and professionals is more relevant than the quality of the procedures and the standards and specifies that it is vain and dangerous to disconnect the practices that one wishes to formalize by procedures, of the actual practices of the people involved in these activities.

The effects of this standardization process have been studied in different fields: in information technologies (Mignerat & Rivard, 2005) and in changes in the education system (Herscovitch & Meyer, 2012; Samier, 2002). The book edited by Gallut and Qribi (2010) is also noteworthy. The multidisciplinary researches comprised in the book studied the application of quality standards in public health institutions and completed a list of several possible risks that procedure-based management can bring about, which had been developed previously by Grandjean (2008). According to the authors, such governing procedures can result in the loss of the pleasure of working, denial of inter-subjectivity, emergence of fear, the negation of teamwork (individualization against teamwork), division of work duties, bureaucratization and the emergence of integrated service delivery. A summary of all the identified risks can be found in the following website: <https://www.oedipe.org/actualites/lademarchequaite>.

For some years now, we have been studying some of these listed risks in anti-doping. For that, we have reanalysed our empirical corpus using different methods. For now, we can state that every risk listed above seems to be relevant in the anti-doping system in relation with the current normative activity; further analysis is needed in order to have conclusive results. Some of these risks and the methods used to identify them will be presented hereafter.

One of the effects observed is what Grandjean (2008) called “denial of inter-subjectivity” (*“négation de l’intersubjectivité”* in French). The analysis of our interviews has shown that is particularly relevant among NADO representatives. As they often express, they report their activity to WADA based on the latter’s conception of anti-doping work and compliance, neglecting their own conception based on the knowledge they have about their national reality. It is particularly relevant how often, NADO representatives interviewed by us point out the difference between WADA and themselves when they specify how they work (Trabal, forthcoming; research based on interviews conducted during the 2009 WADA Symposium in Lausanne). “*They want*”, “*They do not want*” and “*They + different verbs + us*” are three segments of sentences that illustrate this differentiation and the predominance of WADA’s conception. Two consequences related to this denial of inter-subjectivity have been identified: on the one hand, they are thus brought to give up on the identification of the difficulties of implementation found in the field; on the other hand, they tend to focus on conformity and on the corrective actions what can result in de-responsibilization. The procedures developed by WADA do not evaluate the lack of responsibility, but the non-respect of a procedure. This can also produce the feeling among NADO representatives that much of the work that is done is not taken into account and valued.

As an example, we would like to briefly comment on the challenges that the actual anti-doping system posed to France. In December 2018, the government approved a decree to comply with the Code, a decree that several organisations criticised in the name of respecting French Constitutional Law. One of the critical points was to accept the Court of Arbitration for Sport as appeal body. Regional anti-doping actors claim to have been dispossessed of their work in the name of compliance and the necessity to align with procedures, because following restructuration to align with WADA standards, health education interventions no longer have institutional spaces to be developed and are about to disappear.

In addition to that, we have observed that actors in charge of anti-doping are concerned about the procedures put in place in order to evaluate their work. The concept of cheating in anti-doping is operationally both too general and too severe. Failing in transmitting information about location, concealing a document or participating in an institutionalized fraudulent system can result in being placed in the side of the cheaters and being sanctioned. This fear can create a climate of suspicion unfavourable to an appropriated working environment.

Furthermore, as we have shown in a previously published paper (Le Noé & Trabal, 2019), the use of benchmarking in relation with procedure-based management (classifying NADOs and as “complaint” and “non-compliant” or even making other statements about their quality, e.g. referring to them as “frontrunners”) hinders cooperation between stakeholders that would be interested in exchanging “good practices”. It generates a spirit of competition between them, in the name of the user (athletes in our case). However, the notion of “user” sticks to athletes only partially, even if stakeholders often recall that there is a need to fight for “clean athletes”. They can also be considered as “partners” sometimes, independently of the existence or non-existence of a demand from their side (for example, they have no choice but to submit their appeals to the Court of Arbitration for Sport).

As it has been noted, the research is currently in process and other research avenues are also being taken into consideration. Firstly, the augmentation of administrative activity due to the implementation of procedures merits to be studied. Many representatives complain about the increase in administrative work related to reporting activities. Secondly, the connection between quality procedures put in place by WADA and the reality on the field should also be taken into account. Some representatives criticize the disconnection with the reality of procedures like the questionnaires used for monitoring compliance. As it has been mentioned before, these questionnaires, exactly as other procedures, prioritise WADA's conception of anti-doping and does not reflect the particularities of each national system. Finally, an additional analysis could also be added, using a political approach. The organization of anti-doping activity by procedures and under the direction of an agency refers to a liberal political model, criticized by some governments. The Brazilian case illustrates this fact. Lula da Silva, former president of Brazil, renounced to name the Brazilian NADO including the word "agency" in it in order to fight the liberal world. The word "authority" was used instead and the NADO was named ABCD ("*Autoridade Brasileira de Controle de Dopagem*"). Bolsonaro has not changed the named for now.

It equally prioritises a consequentialist approach that can be resumed by the statement made by a WADA representative in a meeting between representatives from WADA and NADOs in September 2018, where we participated (in order to avoid identification, additional information will not be disclosed): "stakeholders need to understand that non-respect leads to sanctions". Thus, many of the activities of actors in charge of anti-doping institutions are conducted under permanent pressure and with the objective of "pleasing" WADA or avoiding WADA to interpret their action as a defiance. *Ad fine*, it is WADA that NADO representatives need to please and, especially, not displease.

The criticism found in the literature review about quality systems seems to correspond with the information collected in our researches. The preliminary results of the work in progress suggest that WADA is engaged in further developing a quality system based on procedures-based management in collaboration with their other stakeholders, although these do not have the choice to say no. However, as Popper stated, one could object that the same effects (malfunctioning with possible undesirable effects) may not have the same cause. This is only a hypothesis, but we aim to develop it in the coming months. For now it is important to acknowledge that several possible risks exist related to WADA monitoring strategy that may affect anti-doping system in a close future, but despite these possible risks WADA continues developing new legislative devices.

## Conclusion

As Bernard Lahire states (2018), facts do not speak by themselves and, sometimes, great theoretical and methodological efforts are needed to apprehend them and to render them understandable; many of these facts, even if firmly established, cannot be perceived during direct social experiences in reality. The purpose of this quote is widely shared by the

sociological community. Therefore, theory and methodology are two of the essential parts of research in social sciences discipline.

However, papers presenting developed theory analysis and methodology are not so common when it comes to sociological research on doping or anti-doping. We may find a reason taking a look into the history of research on these issues. Historically, medicine and law were the first disciplines to focus on doping and to propose anti-doping regulations (Le Noé, 2000; Le Noé & Brissonneau, 2006). The appointment of Dick Pound since the creation of WADA has helped foster social marketing (he has himself contributed to this literature too), which is largely based on social psychology. Social psychology produces interesting and useful knowledge but not very cumulative. If medicine and law share an approach that tends to individualization (medicine is interested in a patient, the responsibilities of and sanctions always return *ad fine*, to an individual) and exclude sociology, the social marketing system based on social psychology and marked by forms of behaviourism (mostly quantitative and using rather experimental methodologies) has not helped reconnecting and launching dialogue with sociology. Therefore, sociological research on doping remains unstructured and does not really allow comparison. This lack of structuration could be partly resolved by mobilizing theoretical models that can assist in defining research programs, as this paper aims to show.

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