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Contribution to study and development of PM stainless steels with improved properties

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Properties

ABSTRACT

Purpose: of this paper is to present the studies performed at Politecnico di Torino aimed to the development of innovative composition of PM duplex stainless steels characterized with very high and unique mechanical and corrosion resistance properties. Previously a base research to attain improvement of quality and performances of sintered AISI 316L has been developed. Moreover the possibility to enhance mechanical and corrosion resistance properties through contact infiltration or through the use of reactive sintering techniques has also been demonstrated and discussed.
Design/methodology/approach: The duplex compositions have been obtained using austenitic AISI 316L and AISI 410L as starting base powders. While AISI 316L stainless steel samples have been manufactured using different combinations of compacting pressure and sintering parameters, or a modified composition able to allow reactive sintering process, as well as the contact infiltration with bronze.
Findings: The studies have been forwarded towards the static and dynamic mechanical properties, as well as the corrosion behavior. Lowering the porosity level and increasing the sintering degree, by use of higher compacting pressure or sintering temperature, is of great effectiveness, especially from the point of view of mechanical properties. Moreover, the innovative duplex composition are very promising.
Practical implications: according to achieved results, duplex stainless steels can be obtained starting from austenitic of martensitic stainless steel powders by simple addition of single elements, through a process in vacuum. Concerning traditional austenitic grades, the obtained results demonstrate the benefits of contact infiltration and of reactive sintering techniques to sinter stainless steels components having higher density and better mechanical and corrosion resistance properties than the traditional compositions, compacted at high pressure and sintered at elevated temperature.
Originality/value: very promising results have been obtained with special compositions able to allow the production of real duplex alloys, as well as with a modified composition of AISI 316L grade able to realize a reactive sintering process.
Keywords: Corrosion resistance; Stainless steel; Duplex structures; Reactive sintering; Contact infiltration

1. Introduction

Stainless steels constitute prominent class of valuable iron alloys. They are used in a wide variety of applications when enhanced properties, like corrosion and oxidation resistance, coupled to good mechanical characteristics, are required. Stainless steels are more and more applied also as sintered parts and nowadays represent important segment of powder metallurgy industry. The stainless steel grades currently manufactured by

sintering correspond generally to the grades manufactured with other technologies.

The strength, hardness and work hardening of stainless steel powders make difficult the compacting process and the sintering densification. Generally the sintering furnaces operate at temperatures in the range of 1150 °C, with maximum values of 1250 °C when walking beam furnaces are employed, this means solid state sintering with difficulty for obtain high final densities of the sintered parts. In fact, depending upon the particle size distribution, the compacting pressure and the sintering temperature, the sintered density usually corresponds to 80 ÷ 90 % of the theoretical value. Final low density, coupled with interconnecting porosity, causes poor mechanical and corrosion resistance properties.

About the sintering process, the delubrication stage as well as the choice of the sintering atmosphere strongly influences the properties of the sintered parts. In fact, incomplete lubricant removal will result in an elevated level of C in the part, with the possible consequent precipitation of chromium rich carbides at the grain boundaries, leaving the surrounding matrix depleted in chromium and subjected to corrosive attacks. Moreover, nitrogen based sintering atmospheres can favour the precipitation of chromium nitride, with problems related to sensitisation, while there is a little commercial use of hydrogen atmospheres because of their high cost. Vacuum sintering represents the principal alternative to nitrogen based atmospheres, however, in order to avoid the evaporation of chromium and the resultant surface depletion of the parts, the furnace must be back-filled to a low pressure with an inert gas.

PM stainless steels are object of research and development at Materials Science and Chemical Engineering Department of Politecnico di Torino since many years. At first the effects of the sintering atmospheres on traditional austenitic grades were studied [1, 2], later the activities were referred to the study of the influence of processing parameters, like compacting pressure and sintering temperatures on the sintered density and properties of AISI 316L (1.4404 according to EN 10088) stainless steel, sintered in vacuum or in dry hydrogen. The sintered stainless steel samples were manufactured using different combinations of compacting pressure and sintering parameters (time, temperature, atmosphere), as well as using the contact infiltration process. Moreover, very promising results have been also obtained using a modified composition able to allow reactive sintering process.[3,4]

The modification of the powders composition by addition of elements (such as copper, boron, phosphorus) favoring liquid phase sintering, as well as reactive sintering processes given by nickel additives, are matter of well developed studies [5-10]. Nevertheless, adopting contact infiltration techniques to fill the pores with a liquid metal the steels properties are highly improved, maintaining at the same time good dimensional control [11, 12]. Moreover recent developments of reactive sintering processes demonstrate the possibility to manufacture stainless steel sintered parts with restricted dimensional changes, very high density values and good corrosion resistance properties [13].

Besides the density, the hardness and the tensile mechanical characteristics, as well as the corrosion resistance properties, the attention has been directed towards the dynamic and the fatigue behaviours. In fact, the use of structural sintered parts under cyclic loading conditions becomes more and more important and stimulates an intense research activity to better understand the influence of the porosity on the fatigue behaviour of sintered components and to improve their fatigue strength [14-24]. From this point of view, the control of the level and of the shape of pores is very important, because the morphology of the porosity controls the opening and the propagation of fatigue cracks. It is possible to improve the fatigue life through the sintering process, as well as by means of suitable heat treatments.

2. Experimental, first part

Series of samples, constituted by tension and impact tests specimens, were produced by compacting at 500, 600 and 700 [MPa] AISI 316L austenitic stainless steel powders. The samples, after a de-binding stage at 600 °C with N_2 atmosphere, were sintered at 1150, 1200 or 1250 °C for 60 minutes, in pure hydrogen atmosphere or in vacuum with nitrogen back-filling.

A fully alloyed minus 100 mesh powder was produced by water atomization, its chemical composition being: Cr 16.78, Ni 13.48, Mo 2.2, Si 0.77, Mn 0.11, C 0.02, P 0.015, S 0.01, Fe bal., O 1900 ppm, N 520 ppm, before compacting it was mixed with lubricant, 0.75 wt%, type Acrawax.

The vacuum sintering process was performed in an industrial furnace with nitrogen back-filling, the cooling rate after sintering was 1.3 °C/sec, while sintering in dry hydrogen, a tubular furnace was employed. It was purged with nitrogen having a dew point lower than - 45 °C, the dew point of hydrogen was lower than -42 °C and during the sintering stage the dew point of the sintering atmosphere was always lower than -25 °C. These conditions at the sintering temperature were adequate to prevent Cr oxidation.

The contact infiltration process has been performed on certain samples with the suitable amount of compacted powder of brass-10% tin directly during the sintering stage.

On the sintered samples chemical analysis by means of LECO instrument was performed in order to check the contents of C, O and N. The green density and the density of sintered samples were measured by water displacement method and the porosity was evaluated by means of mercury porosimeter. Mechanical properties, hardness, tensile strength, elongation and impact energy were measured. Microstructures were characterized by means of light and SEM microscopy. The corrosion resistance was tested by mass loss measurements after increasing immersion periods (7, 14, 21 and 28 days) in 0.5 M sulphuric acid solution.

In order to reach the reactive sintering process the composition of the AISI powder has been modified adding in different amounts Ni, Fe, Cu and Al, the exact quantities are confidential. The powders have been mixed with solid lubricant, namely 0.75% Acrawax, and compacted at 500 or 700 MPa to produce tensile samples (Standard ASTM E8-89, cross section 5.9x5.6 mm) and impact samples (dimensions 55x10x10 mm).

In table 1 the groups of tested samples are indicated together with their manufacturing process. After the dewaxing stage in nitrogen atmosphere (1h at 600 °C), the samples have been sintered in an industrial vacuum furnace with nitrogen backfilling

or in a laboratory tubular furnace with pure hydrogen atmosphere at different temperatures, the reactive sintering process (type E samples) has been done in pusher type industrial furnace with nitrogen-hydrogen atmosphere. The samples type D have been contact infiltrated with copper-tin (10% tin) alloy, using enough quantity of alloy to fill 90% of the porosity at least.

The green density and the density of sintered samples were measured by water displacement method.. On the sintered specimens the hardness properties as well as fatigue, impact and tensile properties were measured. Finally the corrosion resistance of the sintered samples was tested by measuring their mass losses after increasing immersion periods (7, 14, 21 and 28 days) in 0.5 M sulphuric acid solution. The porosity and the microstructure characteristics of the sintered samples were analysed by means of light microscope and of scanning electron microscopy observations.

3. Results and discussion, first part

The sintered density and the measured mechanical properties are listed in table 2, the green density of the samples type A, B and C was 6.43 and 6.75 Mg/m^3 corresponding to the compacting pressure of 500 or 700 MPa, whilst was 6.92 for samples type E, being higher the compressibility of this modified mixture.

The properties of samples type B and C are very similar, the increase of sintering time from 30 to 60 minutes at 1150°C does not allow significant advantages, while the other samples (type A, D and E), even if with different motivations, show better properties. The contact infiltration process causes very high increments of mechanical properties and excellent ductility, even if the powders were compacted at 500 MPa only and the compacts were infiltrated and sintered at lower temperature (0.5 h at 1150 °C) than samples type A and E. The reactive sintering process appears to be advantageous when compared with traditional sintering, however there is no substantial difference of properties with respect to contact infiltration, exception made for higher ductility characteristics as can be observed comparing the values of the elongation % and of the unnotched impact energy.

The observation of the microstructure highlights the influence of the morphology of the porosity on the fracture propagation: pores can put out cracks, but can constitutes zones of high stress intensity, favoring the initiation of a new fracture process which propagates through the matrix.

Generally cracks propagation follows the pores textile, however the reduction of the porosity by infiltration process obstacles fracture process and improves the response of sintered materials to fatigue process, in the same way acts reactive sintering.

In figure 1 the fracture morphology of samples type B and D are compared. The type B samples compacted at 500 MPa and sintered

30 minutes at 1150 °C show, in the as sintered state, high porosity degree and reduced sintering grade, while the infiltrated specimens (type D) show a microstructure and a fracture surface typical of a liquid phase sintered system. In fact, the grains of steel are surrounded by the infiltrant alloy and this justifies the highest ductility, being evident the large deformation degree of this phase due to the fracture process. A few residual pores are sometimes present, however the adhesion between the steel matrix and the infiltrant alloy appears very good and continuous. The porosity observed in type B samples explains their low fatigue strength. This feature can be justified by the different morphology of the pores that are not as rounded as in the infiltered samples so that their action as fracture precursors is emphasized. The fatigue cracks are nucleated from the surface, propagate inwards, reach the pore and restart.

In figure 2 the SEM analysis performed on the fracture surface, as well as on a polished section of type A specimens highlights the morphology of some porosity and of fracture surface. Brittle and ductile fractures coexist in different amounts and secondary cracks between grains can be observed (fig. 2A). The microstructure of these samples is characterized by the precipitation of Cr nitrides at grain boundary as can be observed on the SEM microphotograph in fig. 2B.

The SEM observation of fracture surface of samples obtained by means of reactive sintering (type E) highlights the presence of some round shaped intermetallic particles (figure 3A), the general aspect of the fracture show a ductile behavior, even if correspondingly to the intermetallic compounds the morphology of the fracture appears as a quasi-cleavage type.

Table 1.
Compacting pressure, temperature, time, furnace atmosphere and additional parameters

Sample	Pressure [Mpa]	Temp. [°C]	Time [min.]	Atmosphere
A	700	1250	60	Vacuum + Nitrogen backfilling
B	500	1150	30	Hydrogen
C	500	1150	60	Hydrogen
D	500	1150	30	Hydrogen + C.I.
E	700	1275	30	50% Hydrogen + 50% Nitrogen

Table 2.
Density, tensile properties, unnotched impact strength and harness of samples

Sample	Density [Mg/m^3]	Yield strength [MPa]	U.T.S. [MPa]	Elongation [%]	U.I.S. [J/cm^2]	[HRB]
A	7.05	361	549	14	73	77
B	6.59	170	270	8	30	31
C	6.70	175	287	12	44	34
D	7.45	290	540	30	100	64
E	7.45	350	510	24	130	63

In figure 3B the SEM microphotograph highlights the presence of the intermetallic compound at the boundary of grain, where it fills the former empty space between the stainless steel particles and close down the porosity channels. EDS microprobe was helpful to analyze the chemical composition of the compound: close to the austenitic matrix of the steel (zone 1) the concentration of Al is about 20 wt% and it tends to increase towards the centre of the particle, reaching the highest value of about 31 wt%. Probably the central layer of the compound is constituted by (Fe,Ni)Al, while in the external part $(Fe,Ni)_3Al$ could be present, because it is the thermodynamically favorite one [6]. It was formed near interface between Al particle and the other metallic ones: so the compound acts as barrier diffusion and it prevents the total reaction of Al. In the left part of the compound there is a pore: its presence can be due to the Kirkendall effect.

The corrosion resistance of the sintered samples is dependent upon their porosity and their chemical composition. The histogram of figure 4 shows the mass losses of the studied samples weekly measured after their immersion in 0.5 M sulphuric acid solution at room temperature. The corrosion rates of samples type A, B and C are comparable but with different motivations. In fact, the precipitation of chromium nitride on the samples sintered in vacuum at 1250 °C with nitrogen backfilling (type A) causes Cr depletion of the matrix and consequently a decrease of the corrosion resistance, while in the specimens (type B and C) sintered in hydrogen the corrosion is determined mainly by the high degree of porosity, in this case the decrease of weight loss during the fourth week more than to a passivation phenomena may be due to the filling of pores with corrosion products.

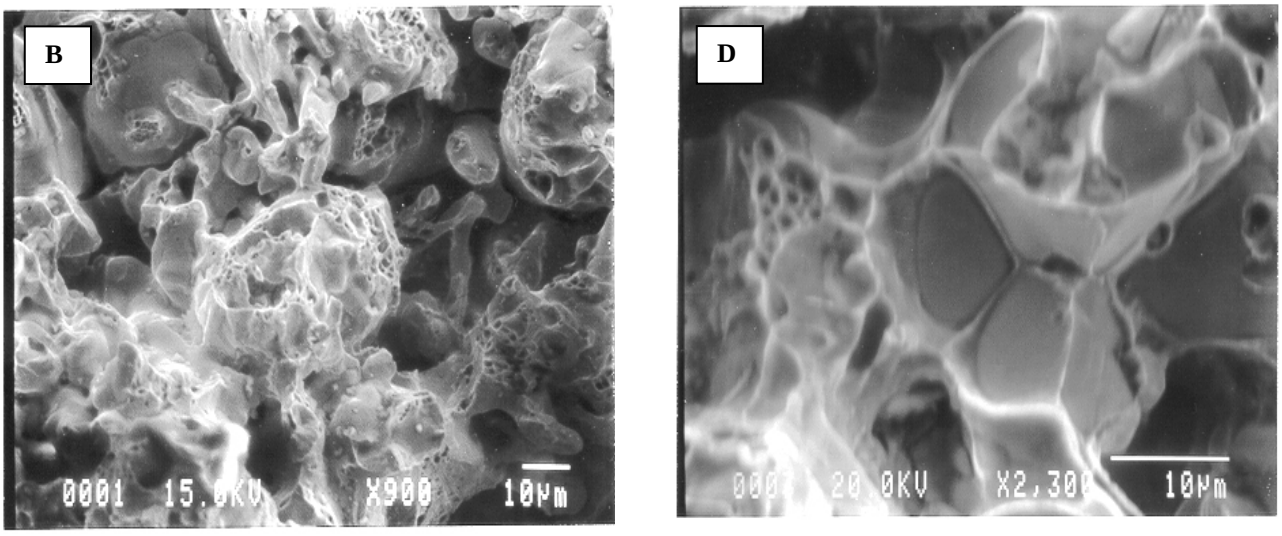


Fig. 1. Fracture morphology of type B and type D samples after impact test

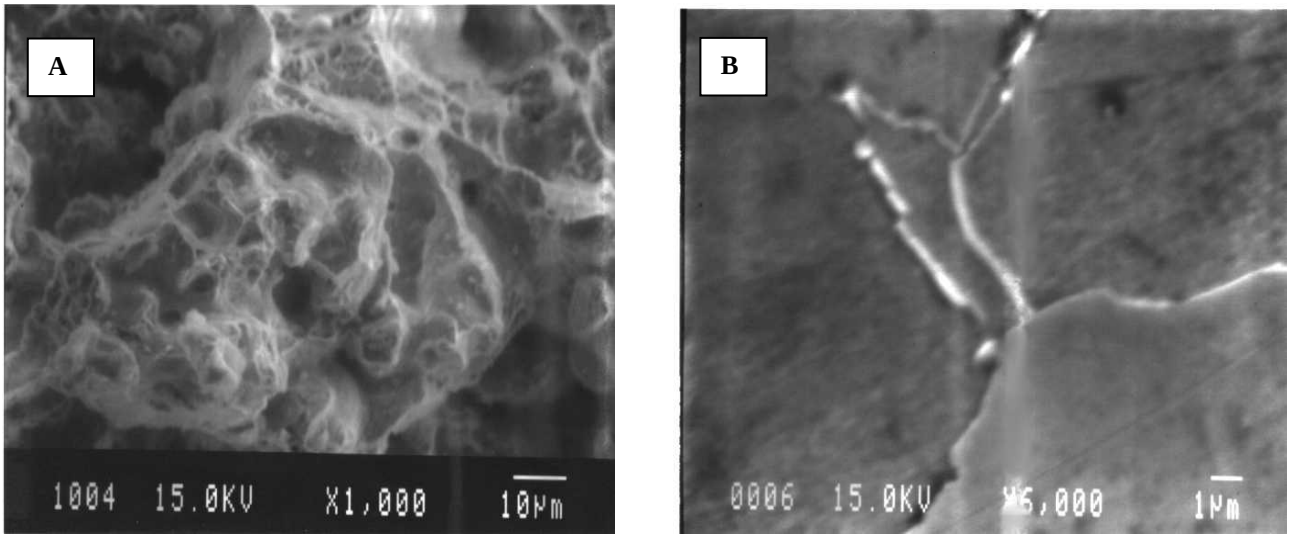


Fig. 2. Fracture morphology of type A samples, after impact test (A) and Cr precipitates at the grain boundary (B)

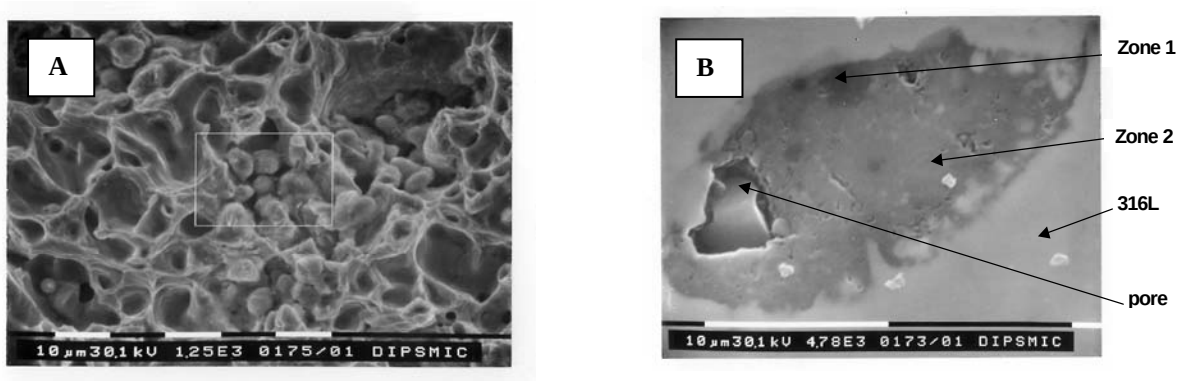


Fig. 3. Type E samples: morphology of fracture surface (A) and SEM micrograph of a an intermetallic compound (B)

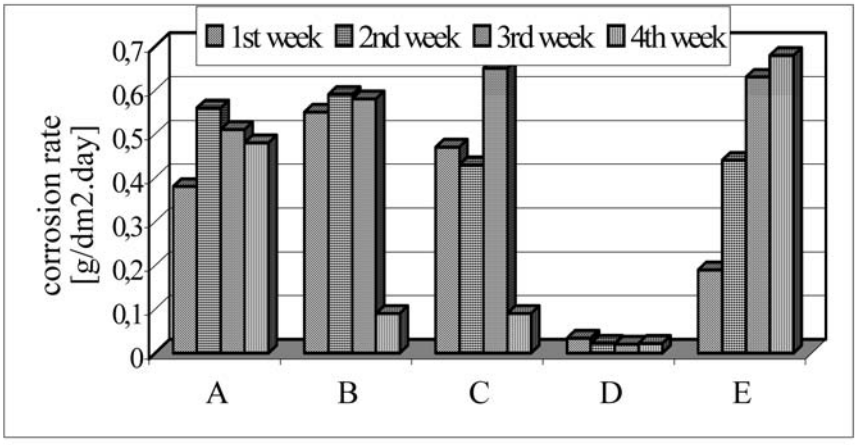


Fig. 4. Corrosion rate in 0.5 M sulphuric acid solution of studied samples

The infiltrated samples show very high corrosion resistance because of the quasi absence of porosity, filled with Cu-10%Sn alloy, moreover sintering in hydrogen atmosphere avoided also any Cr depletion phenomena. Whilst in the case of type E samples, even if characterised by very low porosity and high density, the corrosion rate is higher than for the infiltrated ones because the sintering process was performed in nitrogen containing atmosphere with possible Cr depletion. However the process, with respect to the samples type A, B and C, starts with lower rates, these progressively increase probably due to the effect of intermetallic compounds. The obtained results fit very well with studies performed on the impact strength and energy absorption during crack initiation and propagation on the same steel grades and published elsewhere [26].

4. The development of innovative duplex stainless steels

The chance of getting duplex structures via PM has led, in the last ten years, to the development of several studies aimed at getting a bi-phase product. Austeno ferritic structures, characterised by the combination of the properties of the 100% mono-phase structures, could finally increase the market of PM products in the sector of stainless steels. An example of new applications for duplex products is presented and discussed in [27]. The approaches found in literature are different: direct atomisation of duplex powders, mixing of fully prealloyed mono-phase powders or mixing of prealloyed powders with single alloying elements.

The study carried out in [28] on atomised duplex powders shows that compressibility is relatively low; nevertheless the opportunity of introducing nitrogen inside the powders could be of a great advantage for the corrosion resistance and for the increase of mechanical properties.

In [29] the corrosion resistance of 316L-430L mixes to different medias was evaluated, as well as the influence of copper added to different mixes of 316L and 434L. In the field of mono-phase steels, copper enhances the corrosion resistance when added to 316L, mainly as consequence of an increase of the passivating effect due to the cathodic de-polarising of the evolution of hydrogen and to the oxygen reduction. Copper reduces the attack of 316L in H2SO4 moving the corrosion potential from an active to a passive state. On the contrary copper has a negative effect on the passivity of ferritic stainless steel. In

the field of traditional wrought duplex, two opposite factors co-exist; in fact while the precipitation of copper rich secondary phases could determine the nucleation of pitting, on the other side copper has positive synergies with Mo, present in ferrite, and with N in austenite.

In [30] different structures deriving from 316L - 434L mixes have been examined, after sintering in vacuum at 1250°C for 30 minutes. In [31] the resistance to fatigue crack propagation of several stainless steels characterised by different microstructures was studied.

Nevertheless a different approach is possible to obtain real and not only nominal duplex structures, through the admixing of single alloying elements. The first results of the research were published in [32] and were based on the use of martensitic and ferritic stainless powders added with Ni, Mn, Mo and Cr and sintered under industrial conditions. It was clear since the beginning that, though partially duplex structures were obtained, the precipitation of secondary phases constituted a high limit to the mechanical properties. The evolution of the research led to a change in the sintering conditions, to 100% hydrogen atmosphere; results were published in [33]. The work included also the evaluation of boron addition to different systems. However, the main problem for getting high mechanical properties was still determined by the presence of secondary phases, determined by the low applied cooling rate. Actually it couldn't be possible to refer to properly real duplex structures in those cases, a part from the composition.

It was therefore needed to apply a secondary heat treatment in hydrogen, followed by rapid cooling, with a cooling rate of 600-700 °C/min. This processing led to the formation of duplex structures, free of precipitates, with high mechanical properties and corrosion resistance, with austenite present in percentages variable from 40 to 60 %, as consequence of the considered mix [34]. In [35] it was then studied the possibility of getting duplex structures using 316L.

In another work [36] the influence of the addition of different quantity of Si in a fully austenitic powder was studied. An increase in the densification rate was observed, mainly due to the fact that Si has a stabilising effect on ferrite and activates sintering processes as consequence of a higher diffusion speed in the CCC structure of ferrite rather than in the CFC of austenite. It was noted that, for addition of Si higher than 5% the final microstructure is made of partial interleaving austeno-ferritic structures. In [37], 434L powder was admixed with Ni, Mn and Si, trying to predict the final structure on the bases of Schaffler's diagram. Nevertheless sintering in hydrogen with low cooling rate applied determined the formation of complex structures, with partially un-identified secondary phases.

The approach chosen at Politecnico di Torino was to start with prealloyed stainless steels powders, added with alloying elements, and to look for a sintering/cooling process that could determine the formation of duplex structures within one single thermal process. In this way there were developed studies related to innovative duplex statinless steels compositions and very excellent and unique results were obtained [38 – 40]. The properties highlighted by the developed innovative compositions are difficult to reach using more traditional stainless steel grades [41-47]. However, the high mechanical strength and corrosion resistance properties of the innovative compositions were also obtained thank to the use of vacuum or of hydrogen based atmospheres during sintering and providing a fast cooling step after the sintering process. These kind of atmospheres, more than other sintering aids, are always the most convenient way to produce stainless steel parts with very good properties.

5. Experimental second part: duplex

Different compositions have been tested, using commercial austenitic 316L and martensitic 410L as starting base powders. Table 3 reports all the prepared compositions. Base powders were mixed with single elements using a laboratory Turbula mixer. Acrawax was used as lubricant in a quantity of 0.75 wt.% in excess 100 for all compositions produced. Samples were obtained using a 2000 kN hydraulic press applying a pressure of 700 MPa.

The dewaxing was carried out at 550°C for 30 minutes in a nitrogen atmosphere. Samples were then sintered in a vacuum furnace with argon backfilling at 1240°C for 1 h. Rapid cooling was applied, with an average cooling rate of 650 °C/min. Densities were evaluated using the water displacement method. Microstructure observations were carried out using LEICA MEF4A light microscope and scanning electron microscope (SEM) LEO 1450 VP, the latter being used, together with EDS microprobe, for phases distribution and mapping. Evaluations of the phase composition were made using ARL X'TRA 48 X-ray spectrometer, with the filtered copper lamp rays with the voltage of 45kV and heater current of 40mA. Quantity calculations of individual structural components in the structure of manufactured steels were made using Averbach and Cohen method. Charpy impact test and tensile tests were made according to the respective EN standards. Hardness test was carried out in order to determine HRA and HV10 values.

Table 3.
Chemical composition of investigated powder mixes

Base powders	Designation	Chemical Composition, wt. %							PREw
		Ni	Cr	Si	Cu	Mn	Mo	Fe	
316L	316-1	10.52	26.40	0.80	0.80	--	2.02	Bal	33.08
	316-2	11.51	21.33	0.84	2.00	--	2.21	Bal	28.63
410L	410-1	8.10	22.72	0.70	--	0.06	2.00	Bal	29.32
	410-2	8.09	26.23	0.65	2.00	0.06	2.00	Bal	32.83

The dewaxing was carried out at 550°C for 30 minutes in a nitrogen atmosphere. Samples were then sintered in a vacuum furnace with argon backfilling at 1240°C for 1 h. Rapid cooling was applied, with an average cooling rate of 650 °C/min. Densities were evaluated using the water displacement method. Microstructure observations were carried out using LEICA MEF4A light microscope and scanning electron microscope (SEM) LEO 1450 VP, the latter being used, together with EDS microprobe, for phases distribution and mapping. Evaluations of the phase composition were made using ARL X'TRA 48 X-ray spectrometer, with the filtered copper lamp rays with the voltage of 45kV and heater current of 40mA. Quantity calculations of individual structural components in the structure of manufactured steels were made using Averbach and Cohen method. Charpy impact test and tensile tests were made according to the respective EN standards. Hardness test was carried out in order to determine HRA and HV10 values.

6. Results and discussion duplex

As for the martensitic based mixtures densities were close to 7,2 Mg/m3. For the austenitic based powders, instead, lower values were obtained, close to 7,0 Mg/m3, even though starting with green values similar to the other compositions. It is remarkable to notice that, in case of 316-2, an approximate dimensional stability was obtained.

According to metallographic examinations of obtained materials, the presence of a fine microstructure with no recollection of precipitates can be seen (Figures 5 - 8).

Precipitations of undesired phases may cause drastic decrease of corrosion resistance and mechanical properties. Lack of precipitates shows that applied technology and the way of achieving mixtures results in proper final structure.

Austenite and ferrite are strictly interleaved with an observed overall balancing between the two structures present throughout the samples.

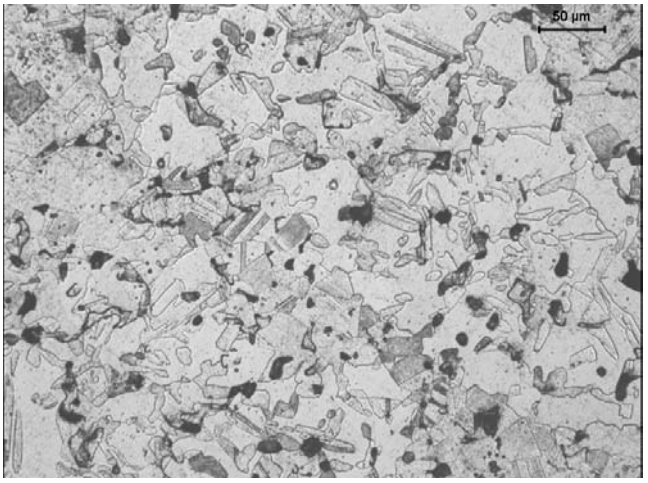


Fig. 5. Microstructure of composition 316-1

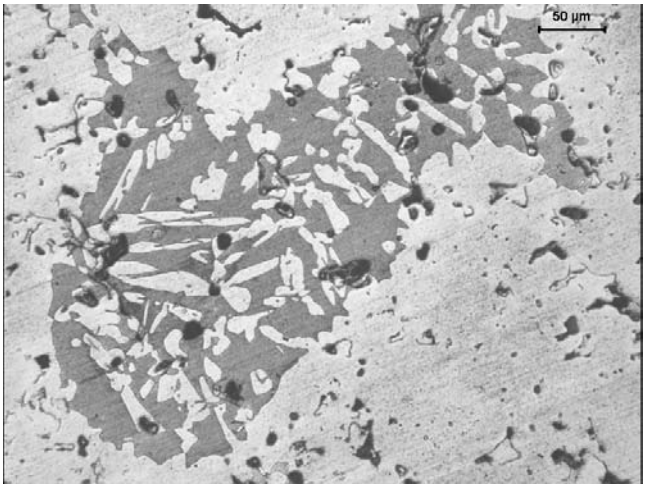


Fig. 6. Microstructure of composition 316-2

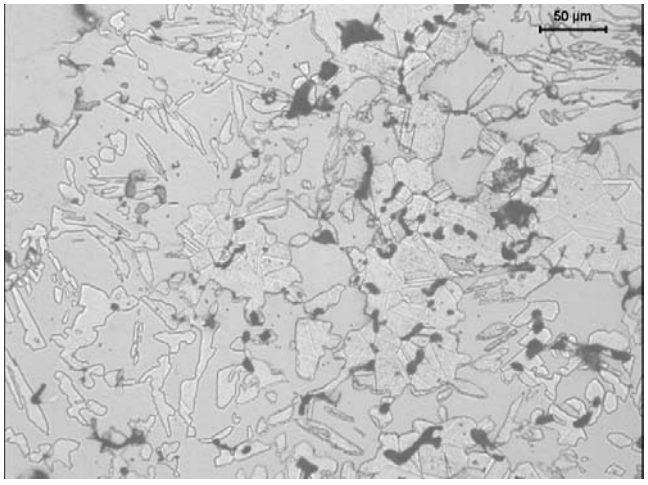


Fig. 7. Microstructure of composition 410-1

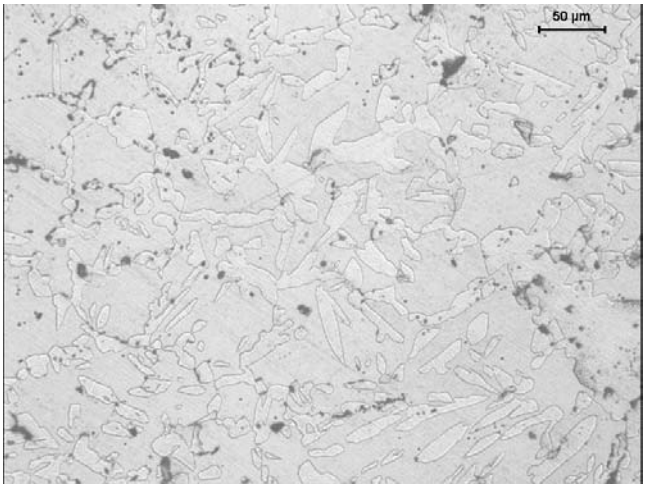
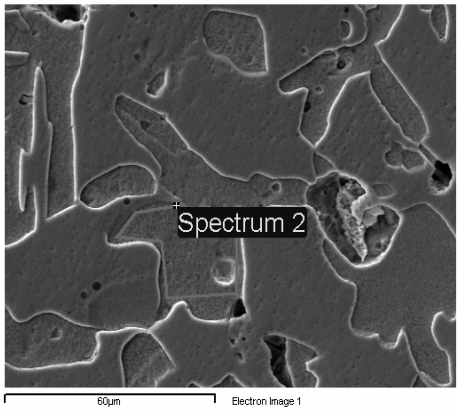
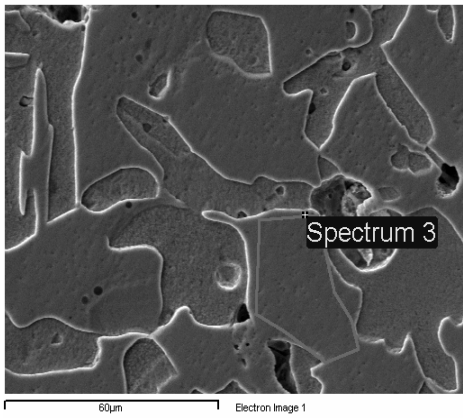


Fig. 8. Microstructure of composition 410-2



Element	Weight%
Si K	0.99
Cr K	22.14
Fe K	65.73
Ni K	9.03
Mo L	2.11
Totals	100.00



Element	Weight%
Si K	0.74
Cr K	30.09
Fe K	60.58
Ni K	4.66
Mo L	3.94
Totals	100.00

Fig. 9. SEM analysis of different areas of sample 410-1; chemical characteristics of the different phases

The evaluation of the percentages of the different phases present inside the four compositions was carried out both through the analysis of Xray spectra and through the image analysis of the products' characteristic microstructure.

Composition 410-1 results the closest to the exact bi-phase composition (50-50), while 316-1 and 410-2 are characterised by the higher amount of ferrite. Standard deviation from the average amounts of ferrite and austenite was evaluated, in all cases, included in the range ±1%.

SEM analysis were carried out in order to further investigate the elements distribution throughout the structure. The images in figure 9 refer to composition marked with 410-1.

Tensile test analysis of investigated sintered steels showed that the UTS values are approximately included in the range 460-580 MPa (figure 10), with elongations at rupture up to 8%.

As for the impact energy values, different results were obtained as function of the composition. In case of samples 410-1 (having approximately the exact bi-phase structure) values close to 150 J/cm2 were obtained. Composition 410-2 shows sensibly lower values, around 80 J/cm2, while the two 316 based compositions respectively 85 and 97 J/cm2.

The main different types of corrosion present in sintered stainless steels are the intergranular and crevice. Corrosion resistance is strongly influenced by porosity, in particular by open or interconnected porosity which tends to increase the specific surface, increasing the material reactivity.

Preliminary corrosion tests carried out in a 0,5M solution of H2SO4 were not significant since no tendency to weight loss was measured after several weeks. Tests were then carried out in a 5M H2SO4 solution. Figure 10 show the trend for the studied compositions.

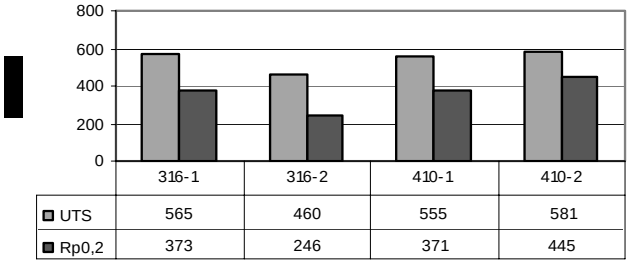


Fig. 10. Tensile strength for the studied compositions

Composition 410-1 shows the higher corrosion rate, while 316-1 and 410-2 are characterised by a similar trend, with higher resistance. In the first phase no passivation effects are present, while, starting from the 4th week corrosion rates diminish for all the systems. It has to be reminded, however, that the test conditions are relatively drastic if compared to more standard tests (Fig.11).

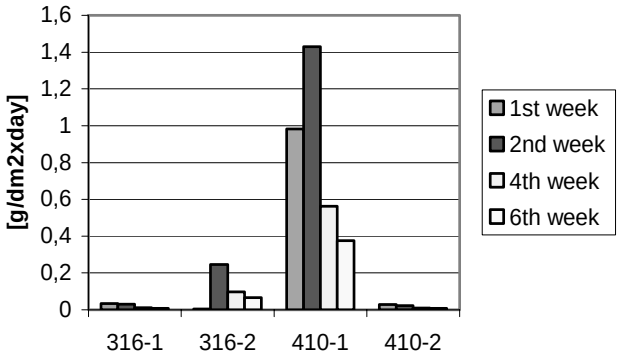


Fig. 11. Corrosion rate expressed as g/dm2 per day of the four duplex compositions

7. Conclusions

The paper present a review of the researches performed at Politecnico di Torino in the field of PM stainless steels and aimed to the attainement of very high performance traditional grades, as well as to the development of novel processes like reactive sintering and of innovative compositions related to austeno-ferritic stainless steels, characterized by very interesting properties.

The sintering processes and the properties of sintered AISI 316L stainless steel have been studied on samples characterized by different porosity level, due to different compacting pressures and sintering conditions, as well as to the application of infiltration process or of reactive sintering technique. The studies have been forwarded towards the statically and dynamic mechanical properties, as well as the corrosion behavior.

Lowering the porosity level and increasing the sintering degree, by use of higher compacting pressure or sintering temperature, is of great effectiveness, especially from the point of view of mechanical properties and fatigue endurance.

The reactive sintering process is able to enhance densification, to reduce the total and open porosity and to guarantee high density levels with properties comparable with those of the samples having the traditional composition and sintered at the highest density.

The contact infiltration process with Cu-Sn alloy applied to low density green compacts (compacting pressure only 500 MPa) and sintered at 1150 °C for 30 minutes only, is suitable to reach properties at least equal or higher than those of samples compacted at 700 MPa and sintered 60 minutes at 1250 °C or of modified samples for reactive sintering.

The corrosion resistance is favored by low porosity and by the absence of precipitation of intermetallic compounds or of phases, like chromium nitrides, which cause Cr depletion of the matrix.

Contact infiltration is tremendously advantageous from the point of view of the corrosion resistance properties, while reactive sintering allows the highest ductility characteristics.

Reactive sintering and contact infiltration represent valid routes to manufacture high density and resistant stainless steel components. Moreover, the infiltration process constitutes an economic and reliable alternative to high compacting pressure and high temperature sintering processes.

According to achieved results, duplex stainless steels can be obtained starting from stainless steels powders (austenitic and martensitic) by simple addition of single elements, through a process in vacuum.

Investigated compositions showed austeno-feritic structures with regular arrangement of both phases and no presence of precipitates. Austenite and ferrite are strictly interleaved in all examined cases, determining high mechanical properties and high corrosion resistance as well.

The results deriving from this approach in sintering are very promising for obtaining a balanced duplex structure, also working with cycles easy to be obtained in industries.

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