# IRON ALUMINIDE ALLOY DEVELOPMENT USING PLASMA TRANSFERRED ARC COATING PROCESS

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***Abstract.*** *The interest on development of iron aluminide alloy is due to its high oxidation and sulfidation resistance at high temperatures. Barriers against corrosion are of great interest to many industrial fields principally to the chemical and Oil and Gas industries. The objective on development of iron aluminide alloy is the formation of the ordered intermetallics. The intermetallics, which are recognized for its excellent corrosion resistance, are $Fe_3Al$ and FeAl. In addition to the good behavior at corrosion environmental, the aluminides has low density and low material cost. This work presents the iron aluminide development alloy with a welding coating process. The Plasma transferred arc coating process, PTA, is recognized to produce coatings with better properties when compared to the conventional welding coating applications. Besides that was mentioned, the coating material could be feed at powder form becoming possible the formation of different intermetallics and new alloys by the combination of the metallic powders, that will be melt into the plasma arc and will form new constituents. The aluminum powder was deposited using PTA on low carbon steel. The alloy formation with the intermetallics already mentioned is reached with a range of dilution that is correlated with the binary iron-aluminum phase diagram. Two different conditions of processing were tested, were maintained the parameters that supply the energy of the arc, except the powder feeding that was changed to produce more or less dilution. For the two conditions tested, the intermetallics formed are presented distributed homogeneously in the coating. The precipitation of the intermetallics occurs into the grain, producing so a distinct precipitation-free zone near the grain boundary.*

***Keywords***. *Alloy Development, Iron Aluminide Intermetallic, Plasma Transferred Arc*

## 1. Introduction

Iron aluminides intermetallics have been used in many different applications like automotive exhausting systems, turbines, airframe, immersion heaters and on several components from Chemical and Petroquimical industries, due to their excellent corrosion and sulfidation resistance, low densities and high melting points [Structural Intermetallics][ The National Academy of Sciences, 1997].

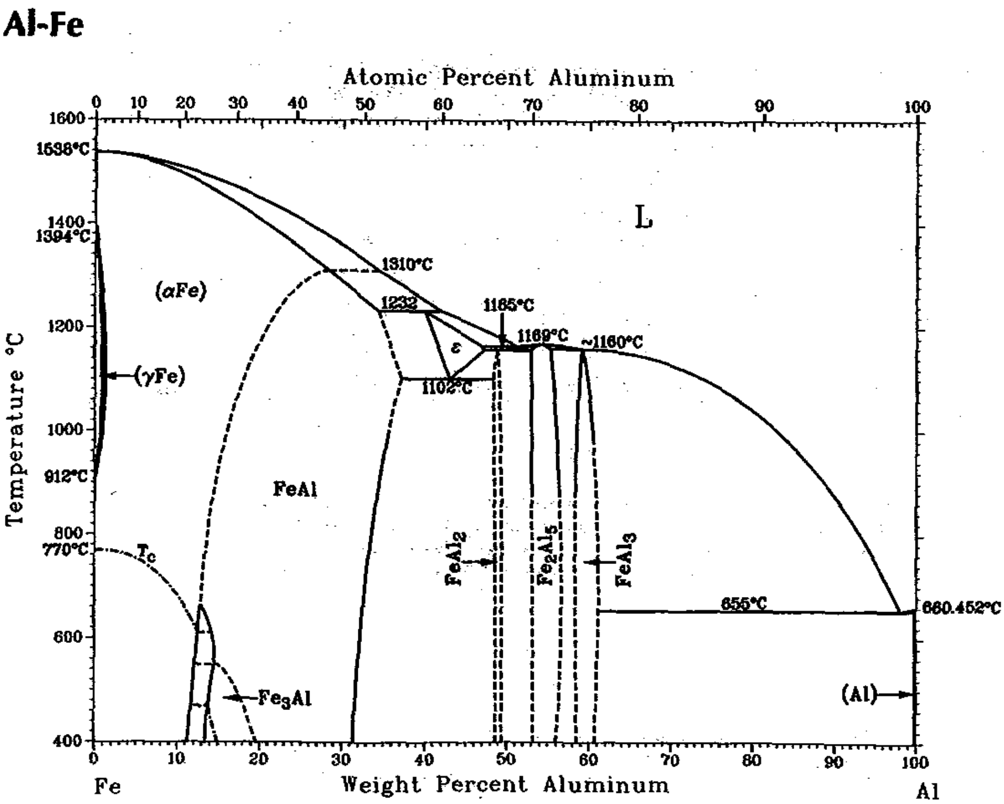



Figure 1. The binary iron-aluminum phase diagram shows composition in which iron aluminides intermetallics can be formed [ASM HANDBOOK].

However, processing and application of iron aluminides intermetallics are very difficult as a consequence of the difference between iron and aluminum melting points, which demands an optimized processing technique, and embrittlement at ambient temperature [Structural Intermetallics][ The National Academy of Sciences, 1997][ Banovic, S. W., 1999]. The embrittlement has been attributed to hydrogen-induced cracking, hydrogen is generated from the chemical reaction shown on Eq. (1) [Banovic, S. W., 1999].

$$2Al + 3H_2O \rightarrow Al_2O_3 + 6H^+ + 6e^- \qquad (1)$$

Atomic hydrogen diffuses into the metal causing severe damages like crack propagation and ductility decrease. In order to improve ductility at room temperature, specially of alloys containing FeAl and $Fe_3Al$, [Structural Intermetallics][ The National Academy of Sciences, 1997] some alloying elements like Boron and Chromium respectively are added. Cracking of iron aluminum coatings has been shown to be directly related to the amount of aluminum present. Pre and post deposition heat treatments contribute to reduce cracks in intermetallic alloys. [Banovic, S. W, 1999].

Different processes have been used to produce iron aluminide intermetallics. Among these thermal spray coating process, where aluminum sprayed on steel substrate, is frequently mentioned [Paredes R. S.C., 2001] [Paredes, R. C., 2002]. However, using only thermal spray process, the aluminum diffuses into steel but does not form intermetallics. Thus it is necessary a second processing stage where a re-melting treatment allows the intermetallic development [Banovic, S. W., 1999].

Processing features mentioned in literature suggests that Plasma Transferred Arc (PTA) process can be an important tool for intermetallic development. In fact, PTA allows for the deposition of almost any kind of material. Therefore, surface properties can be enhanced as intermetallics are developed “in situ” by passing handling difficulties of cast components.

The most important advantages of PTA compared to other conventional surface welding processes are low distortion and low dilution. The inherent characteristics of the process and the greater number of processing parameters which can be controlled, enable optimization which leads to a better control of coating features. In addition to the mentioned advantages, the coating material is powder feed, allowing the development of new alloys and different intermetallics, by mixing metallic powders.

The aim of this work is to evaluate PTA potential as an alloying process. This will be done by adding Al powder to a carbon steel melting pool, in order to produce “in situ” intermetallics.

**2. Experimental Procedures**

Plasma Transferred Arc process was used to develop iron aluminides intermetallics ”in situ”. In this alloying procedure, aluminum was powder feed into an AISI 1020 steel plate (15 mm x 75 mm x 150 mm) melting pool. Two different sets of parameters were used to produce different surface compositions, as is shown on table 1.

Table 1. PTA Processing parameters used to produce the two different coatings.

| Set | Current [A] | Tension [V] | Torch Stand Off [mm] | Plasma Gas Flow [l/min] | Shield Gas Flow [l/min] | Powder Gas Flow [l/min] | Travel Speed [cm/min] | Powder Feed Rate [g/min] |
|---|---|---|---|---|---|---|---|---|
| 1 | 150 | 25 | 7 | 2 | 15 | 2 | 10 | 2 |
| 2 | 150 | 25 | 7 | 2 | 15 | 2 | 10 | 2.5 |

Surface quality was first evaluated analyzing porosities and cracks presence. Dilution level was determined as the area ratio given by Eq. 2. Areas $A_I$ and $A_T$ are presented on Fig (2) and were determined by quantitative metalography.

$$\text{Dilution} = \frac{A_I}{A_T} \times 100 \qquad (2)$$

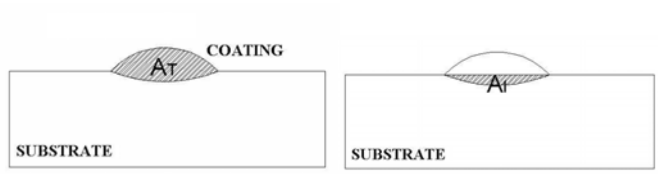



Figure 2. Schematic representation of the areas used to determine dilution levels.

Further analysis including microstructural characterization by optical and scanning electronic microscopy made on transversal and longitudinal sections, Vickers microhardness profiles under 500 g load, X-Ray Diffraction using Co K$\alpha$ target and semi-quantitative chemical analysis by EDS, completed surface characterization.

## 3. Results and Discussion

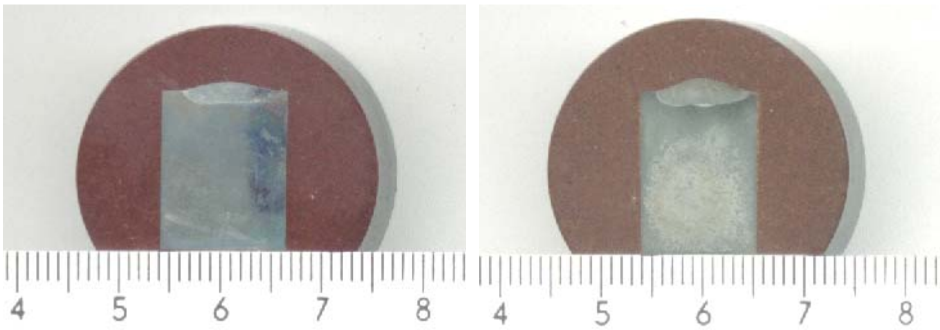
### 3.1 Surface characterization

Surface evaluation revealed a roughness surface without porosities, although cracks were possible to identify after processing particulary in specimens from set 2. Transversal cross section observation confirmed the presence of intergranular and transgranular cracks. These have been reported before in iron aluminides development by conventional welding processes and were attributed to hydrogen-induced cracking [Banovic, S. W., 1999 ].

Dilution measured on specimens transversal cross section, Fig (3), showed levels which are expected for alloying operations, table (2). As predicted, for the same plasma arc energy, an increase on powder feeding rate resulted on lower dilution levels.

Table 2. Dilution levels measured for the two powder feed rate.

| Set | Dilution level % |
|---|---|
| 1 – 2g/min | 70 |
| 2 – 2.5g/min | 60 |




**(a)** **(b)**

Figure 3. Surface cross-sections from samples of: set 1(a) and set 2 (b).

Transverse cross section microhardness profiles, Fig (4), exhibited an increase on surface hardness after the addition of aluminum to the melt pool. A more significant hardness increase was measure for the richer aluminum surface. This difference is understood as X-Ray diffraction results, Fig (5) and (6) showed differences on the spectrums obtained as function of the feeding rate.

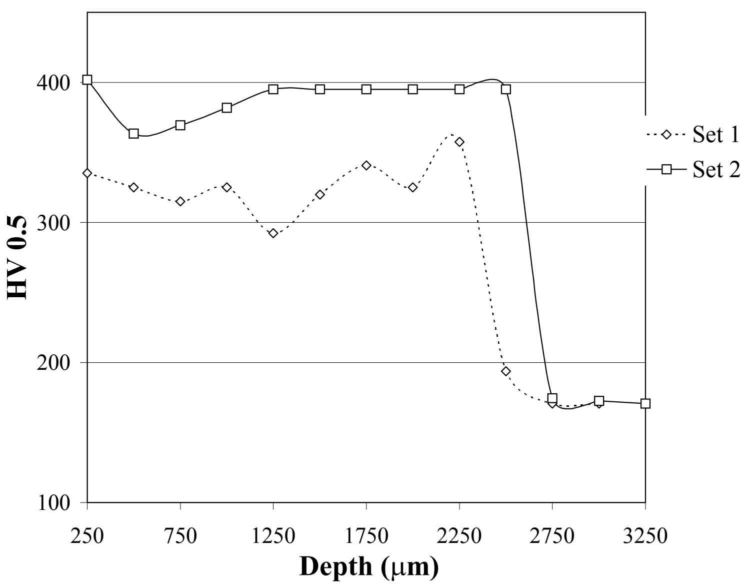



Figure 4. Microhardness profiles measured on transversal cross section of alloyed surfaces, for both different sets.

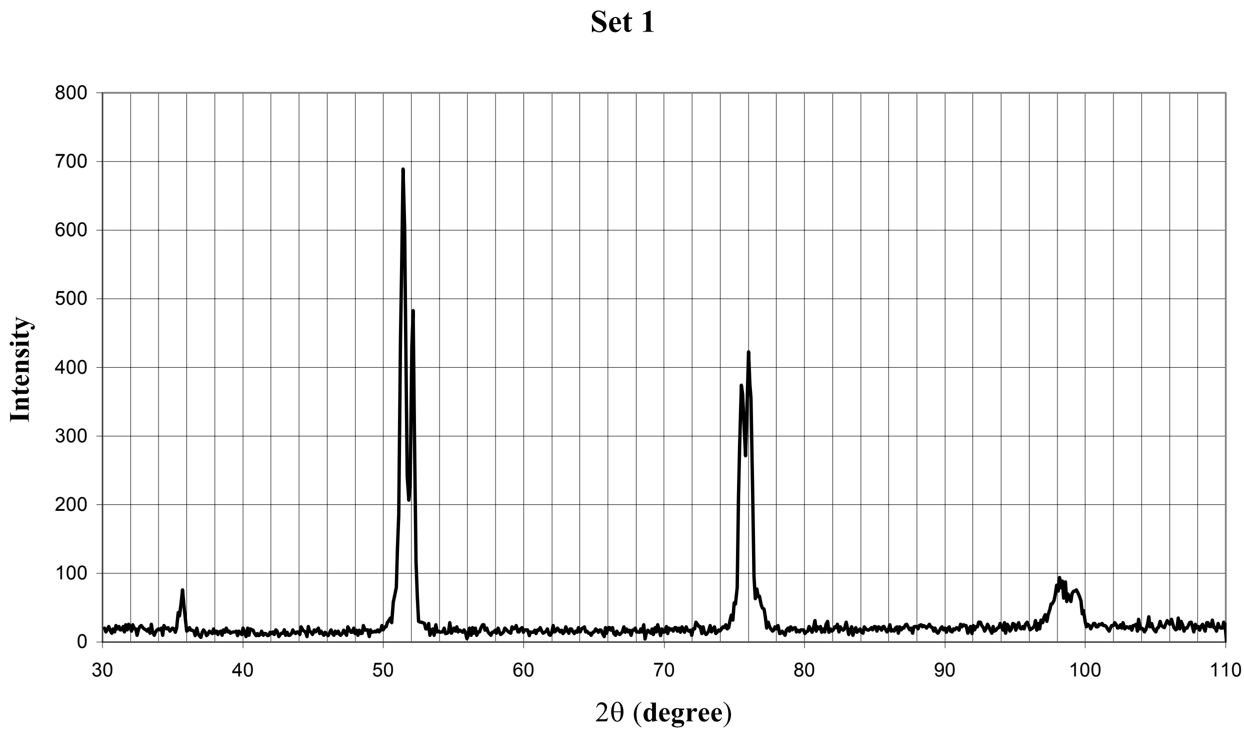



Figure 5. X-Ray Diffraction result of lower powder feed rate specimens.

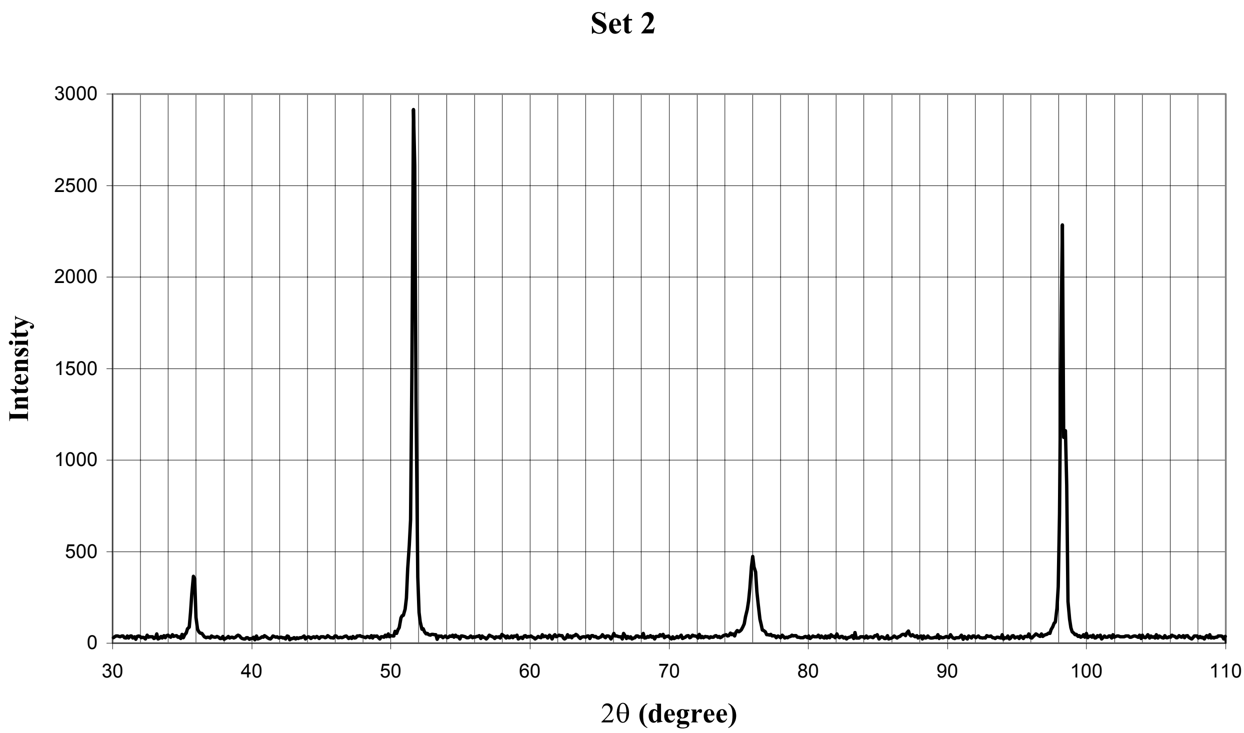


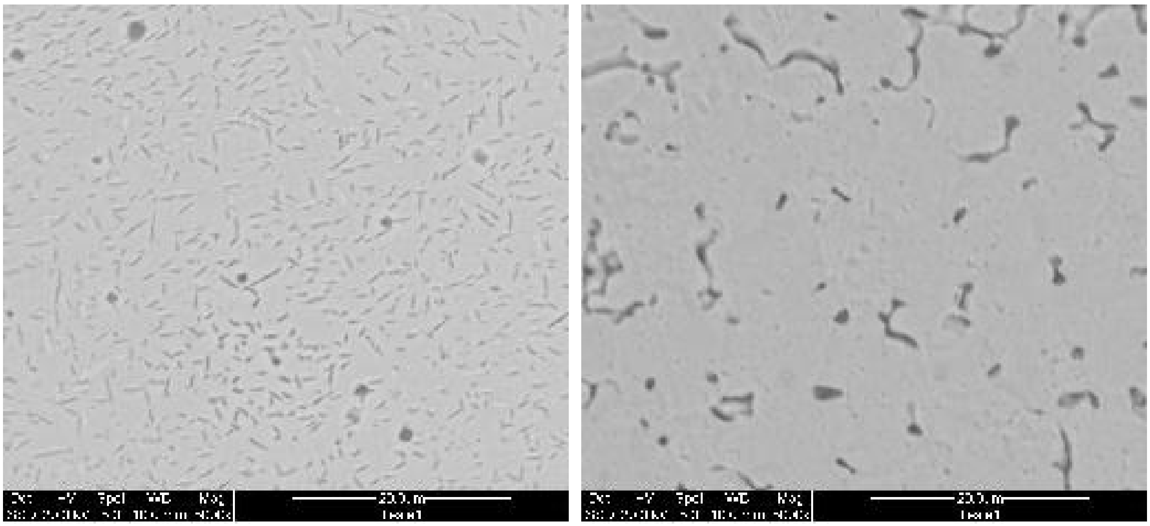

Figure 6. X-Ray Diffraction result of higher powder feed rate specimens.

X-Ray results showed that similar iron aluminum intermetallics were formed on both surfaces. The major difference between the two feeding rates being the intermetallic volume fraction present on each surface. According to X-Ray reference database, the observed peeks can be associated with three intermetallic patterns, namely $Fe_3Al$, FeAl and $Fe_{0.5}$ $Al_{0.5.}$

### 3.2 Microstructure

A columnar solidification structure was identified on the processed surfaces, as it can be observed on the transverse and longitudinal cross section of specimen with both feeding rates. Optical microscopy revealed the presence of a fine and homogeneous intermetallics distribution within the grains and also a precipitate-free zone near the grain boundaries. The precipitate-free zone near the grain boundaries can be attributed to two distinct causes. The rapidly cooling of the alloys, which makes possible a high vacancy concentration. The distribution of the precipitates is affected by the former because the main sink for excess vacancies are the grain boundaries. On the other hand the presence of precipitates of the grain boundaries drain solute from solid solution in their vicinity resulting on a precipitate-free zone [Porter D. A. and K. E. Easterling,1984].

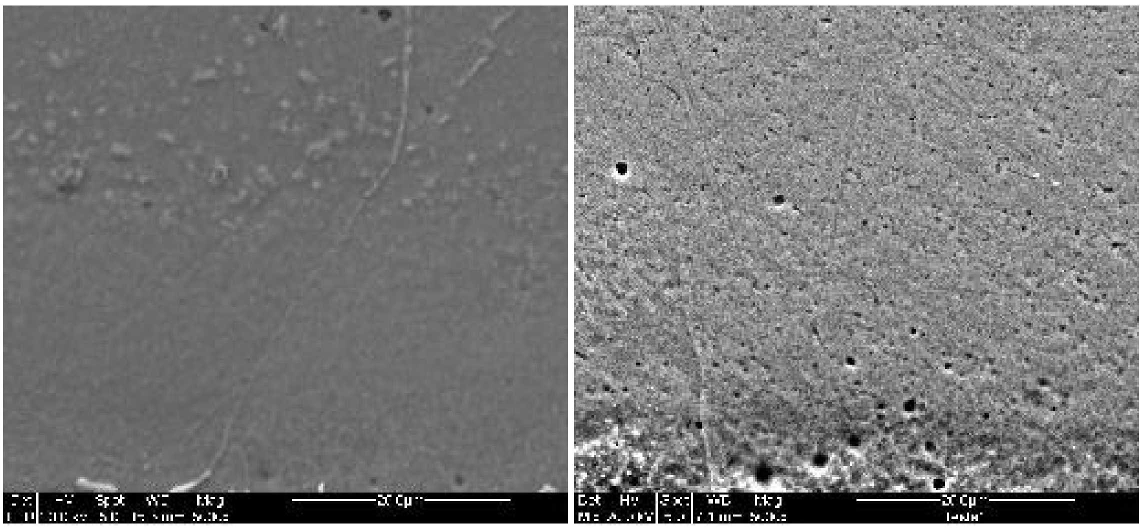
Intermetallics, as observed under scanning microscopy, presented different morphology for each set of specimen. Precipitates in set 1 exhibited a needle shape, whereas for the richer aluminum surface intermetallics interface with the matrix is smoother in spite of their random morphology, Fig (7a) and (7b). EDS analysis revealed higher aluminium content in the precipitates of higher feeding rate specimens, 8.52 wt. % against 6.97 wt. % for set 1.



**(a)** **(b)**

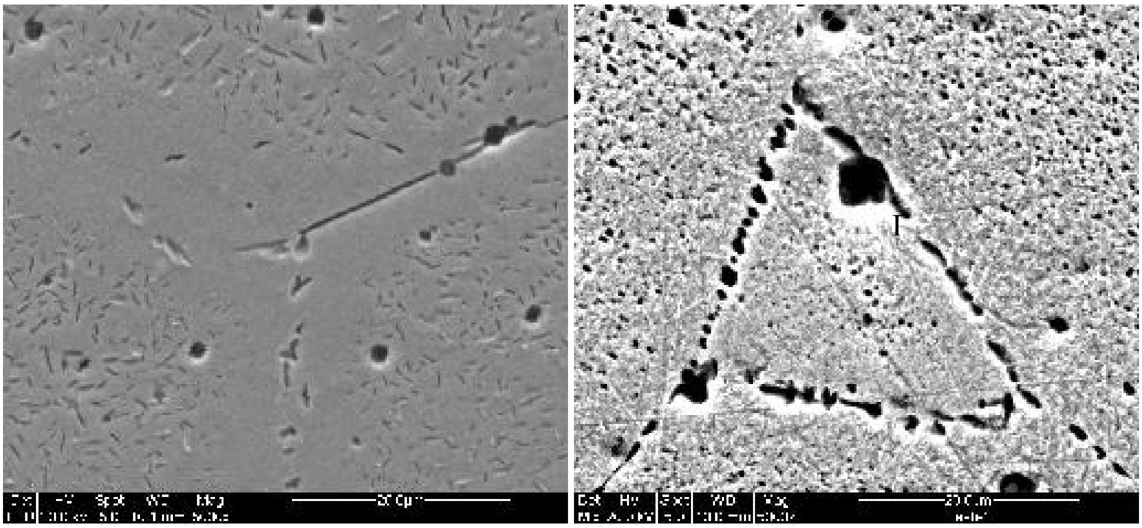
Figure 7. **(a)** Needle shape intermetallics observed on the surface of lower powder feed rate specimens. **(b)** Random intermetallics distribution observed on higher powder feed rate specimens surface.

A solid solution without identifiable precipitation near the fusion line is observed for both processing conditions. Specimens from set 1 have a much lower aluminum content in this region, 3.5 wt.% against 8.8 wt. % for specimens processed with higher powder feeding rate.



**(a)** **(b)**

Figure 8. **(a)** Surface microstructure near the fusion line observed on lower powder feed rate samples. **(b)** Surface microstructure near the fusion line observed on higher powder feed rate samples



(a) (b)

Figure 9. Microstructure near the external surface for lower powder feed rate **s**pecimens **(a)** and for higher powder feed rate **s**pecimens **(b)**.

## 3. Conclusion

The results obtained using the processing conditions tested reveled:

- PTA processing can be use for "in situ" iron aluminides development.
- Iron aluminides account for an increase on hardness.
- Powder feeding rate determines the morfphology and amount of intermetallics formed.

## 4. References


Banovic, S. W., DuPont, J. N., Tortorelli, P. F., Marder, A. R., 1999, "The Role of Aluminum on the Welding and Sulfidation Behavior of Iron-Aluminum Cladding", Welding Research Supplement, pp 23-30.

Paredes R. S.C., d'Oliveira, A. S. C. M., Brunatto, S. F., Rodriguez R. M. P. H., Capra, A., 2001, "Revestimentos Protetores Contra a Corrosão pelo Ácido Naftênico" Proceeding of Cobem 2001.

Paredes, R. C., Rodriguez, R. M. P. H., Bond, D., da Silva, P.S. C. P., Capra, A., Lima, D. F. B., 2002, "Formação de Intermetalicos FeAl através de Aspersão Térmica". Proceedings of Cbecimat 2002.

The National Academy of Sciences, 1997, "Intermetallic Alloy Development, A Program Evaluation". National Academy , Washinrton, D. C.,United States of America, pp 7-51.

Structural Intermetallics, Desk Edition ASM HANDBOOK.

Porter D. A. and K. E. Easterling. "Phase Transformation in metals and alloys", 1984.