Research Journal of Applied Sciences Engineering and Technology 4(4): 367-370, 2012
ISSN: 2040-7467

Submitted: September 25, 2011 Accepted: November 04, 2011 Published: February 15, 2012

Analysis of Cooking Utensils Containing Aluminium Scrap in Senegal

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Abstract: The purpose of this study is to analyze the metallurgical quality cooking utensils containing aluminum scrap in Senegal. Indeed, in this country, the recycling of metallic materials is a very interesting income generating activity. A whole chain, from collection to revaluation, has been set up and operate this vein with the support of partners, for the most foreigners. For aluminum scrap mostly issued from the automotive industry, they are essentially recycled in cooking utensils by the technique of molding sand. A study was then proposed to analyze the reconstituted aluminum alloy, the artisan technique and the quality of final products. This first part focuses on the quality of alloys and their mechanical properties. The results show that all the alloys have levels higher than the maximum allowed by the standard NF EN 601 (July 2004). They also proven that the finished products have a high porosity due to the low amount of water control and linked to the quality of sand. That's why our analysis allowed to propose a change in preventive than half of the sand every three (03) months.

Key words: Aluminum alloy, kitchen utensils, molding sand

INTRODUCTION

Waste recycling is a source of raw material and energy that can be exploit and develop in a perspective of sustainable development as it was stated at the summit in Kyoto (UN Reports, 1997). In developing countries, this practice is supported by different motivations essentially economic. This is why the chain of collection and processing is often quite active in these countries. Moreover, these activities provide jobs for people in the "informal" sector, artisanal or industrial, hence their impact on economic and social (Ministry of Environment and Conservation of Senegal, 1994). Among the fields of recycling and processing, those from the automotive are present in most countries like Senegal where our study is located. There, as in many countries with low GDP, the recycling of low melting point materials like aluminum is done by the artisans. Their production is mainly oriented to cooking utensils such as ladles, skimmers and pans. At the present time no study has yet been conducted to investigate the quality of these alloys and their compatibility with existing standards. Therefore those kitchen utensils, made from materials designed to mechanical use, may not be suitable for use in food environment .

Users, aware of environmental problems and public health wondering about the potential risks of such objects to their health, concern reinforced by the absence of local regulation and control in manufacturing (National TV RTS1, 2006) In collaboration with the direction of the handicraft, the association of artisans founders of Senegal and the Senegalese Standards Association, we initiated this study to analyze the quality of these alloys and their compliance with relevant standards and looks at the properties of the sand used for molds in order to improve the quality of finished products.

MATERIALS AND METHODS

Quality of aluminum alloys produced by artisans in Senegal:

The European regulatory context: In order to establish the study on recognized norms, we have referred to European legislation which set through a norm (EN 601), the quality of materials intended to come into contact with food. With regard to it, the only requirement focuses on the chemical composition of the alloys (Table 1).

Analysis of the artisan technique: The technique of sand molding practiced by the founders of Senegal is very classic but it is remarkably well used and implemented, although it had not benefited on progress and knowledge gained has long been by industrialized societies due to a lack of resources. This is certainly the fruit of long experience optimized over time on a given product line. To assess the level of performance of the technique, we can see a significant criterion: the minimum thickness of pieces produced by casting. Manufacture parts with low thickness is a delicate exercise when the only energy

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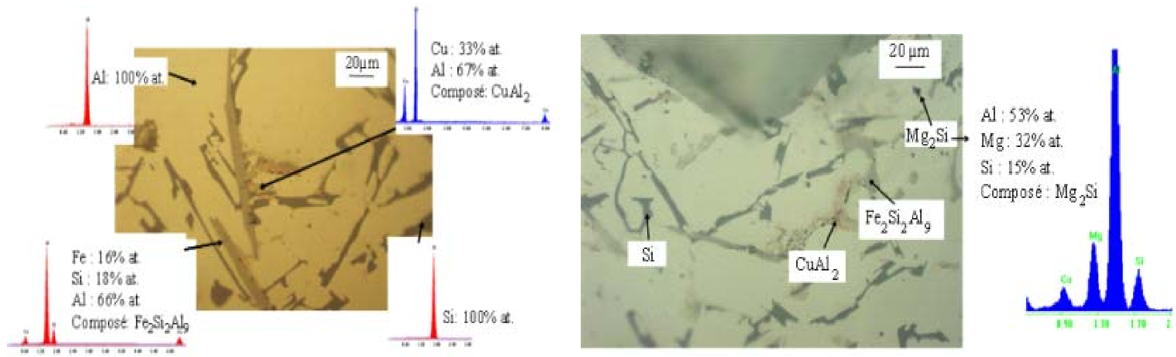

Fig. 1: Identitation of the different phases of an alloy craft Senegal

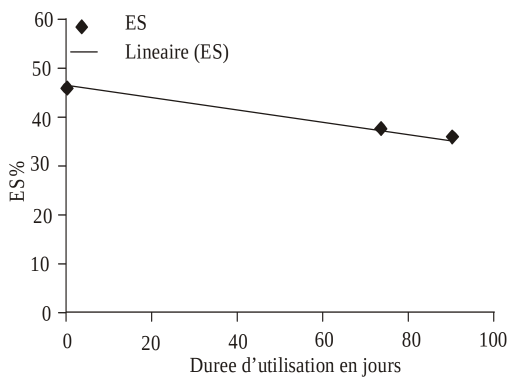

Fig. 2: Evolution over time of the ES for the sand used by the founders of Colobane

available to fill the mold is rooted in gravity. Thus, when the thickness is too low, the mold will not fill properly.

The abacus of Roinet (Facy and Pompidou, 1983) evaluates the minimum thickness in accordance with a shape parameter (D) calculated from the dimensions of the object to achieve. For example, for a cooking pot of 1 kg (210 mm diameter × 120 December 3, 2011mm high × 4 mm thick), the parameter D is about 337 mm and thickness given by the abacus (a type alloy $Al\text{-}Si_{13}$) is about 4.7 mm while the measure on the pot is 4 mm. And generally, the thicknesses measured on the cooking pots are smaller than those extracted from the abacus (Table 2).

We can conclude that in terms of thickness, the method has been very well optimized by the Senegalese artisans. In another side, other parameters may have been overlooked or sacrificed. We can mention in this regard the metallurgical quality of the metal on which we focus our attention in the rest of this study.

Analysis of molding sand: The sands used in foundries for the manufacture of molds have specific properties to ensure the quality of manufactured objects (Jasson, 1989; Perrier and Jacob, 2004). These are especially: the refractivity, the resistance to thermal shock, a low thermal expansion, the cohesion, the plasticity, the permeability, the granulometry and the recycling ability. Indeed, the mold must reproduce as faithfully as possible the form and details of the model, should not deteriorate or react with the molten metal and must be permeable to gases. To ensure the cohesion of the mold, the sand grains (chromite, zirconia, silica, etc.) of appropriate diameter (0.1 to 1 mm depending on the desired surface finish on the final piece) must be related to each others. These binders may be organic (linseed oil, starch, sugar, etc.), synthetic (urea, formaldehyde, resins) or natural (clay) (Jasson, 1989; Perrier and Jacob, 2004). In Senegal, the molding material used by the artisans is the natural sand silicate-clay.

In use conditions (i.e., during the successive re-use), the molding sand is gradually losing its properties. The binder is changing because the sand is in charge of impurities (mainly ash charcoal added to interface between the mold and the molten metal). This gradual deterioration of the quality of the molding sand is manifested by the appearance of defects on the pieces.

Despite their lack of resources, the founders are aware of this development and rely once more to their experience to know-how to adapt. Indeed, to overcome this drawback, the sand is recycled and mixed with new one when he recognizes an impairment loss of its properties. This regeneration of part of the sand is generally preferred to a complete renewal. To go further in this work we have analyzed the evolution of the molding sand used in Dakar by the founders of the district Colobane. To do this, refer to standardized tests: the test of "the equivalent of sand (ES)" (EN 933-8) and the "Sieve" (standard P18-560).

On February 27th, the founder, having found that the sand had lost its properties, has made a partial replacement of it (about 1/3 according to our measurements). To follow the evolution of the nature of the sand we took several samples whose analysis helped to establish Table 3.

Table 1: Maximum levels permitted according to the norm EN 601

Elements	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Sb	Sn	Sr	Zr	Ti	Other	Al
%Mass max	13.5	2	0.6	4	11	0.35	3	0.25	0.4	0.1	0.2	0.3	0.3	$\sum$<0.15	rest

Table 2: Comparison between thicknesses

Capacity of the cooking pots	1 kg	1.5 kg	2 kg	3 kg
Real thickness in mm	4.0	4.0	4.0	5.0
Thickness from the abacus of roinet in mm	4.6	5.5	5.5	5.8

Table 3: Results of the analysis of sand used by the founders

Date	Feb.	27th May	12th May	29thNew	Sand
Proportion of fine sand	42	1%33±1%	13±1%		
Proportion of coarse sand	57	65±1%	85±1%		
Visual ES	46	37±2%	35±2%	77±2%	35±2%

Table 4: Medium hardness HV3 of aluminum alloys studied

Sample n°	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Ref
HV3±5	82	73	84	84	64	72	62	65	64	63	73	92	90	80	70

Table 5: Chemical composition in wt% of samples

% mass	Si	Cu	Fe	Zn	Mg	Mn	Cr	Ti	Pb	Sn	Ni	Al
1	2.96	0.837	0.726	0.730	0.748	0.204	0.017	0.011	0.041	<0.003	0.084	rest
2	6.66	2.93	0.665	0.468	0.306	0.154	0.030	0.034	0.050	0.372	0.164	rest
3	8.33	3.43	0.777	0.602	0.183	0.172	0.030	0.051	0.094	0.025	0.189	rest
4	4.24	3.43	0.422	0.758	0.448	0.183	0.008	0.033	0.022	<0.003	0.013	rest
5	5.70	4.04	0.601	0.935	0.313	0.201	0.022	0.047	0.040	0.008	0.040	rest
6	8.50	1.44	0.60	0.580	0.210	0.170	0.028	0.033	0.050	0.210	0.150	rest
7	2.85	1.25	0.45	0.510	0.180	0.150	0.016	0.055	0.038	<0.02	0.017	rest
8	2.03	0.95	0.36	0.900	0.510	0.100	0.012	0.042	<0.020	<0.02	0.008	rest
9	2.76	0.63	0.33	0.390	0.180	0.084	0.008	0.041	<0.020	<0.02	0.008	rest
10	8.78	1.12	0.36	0.850	0.049	0.040	0.005	0.023	0.047	<0.02	<0.005	rest
11	4.01	1.03	0.45	0.460	0.120	0.060	0.005	0.031	0.030	0.022	0.010	rest
12	5.48	1.54	0.41	0.440	0.057	0.150	0.011	0.055	0.055	<0.02	0.021	rest
13	9.90	0.96	0.57	0.440	0.093	0.280	0.018	0.029	0.060	<0.02	0.048	rest
14	7.63	1.23	0.58	0.620	0.490	0.200	0.027	0.029	0.120	0.058	0.130	rest

Metallurgical quality of aluminum alloys:

Mechanical characterization: Measurements of Vickers hardness under a load of 3 kg (HV3) were performed on each sample to evaluate the mechanical property. The results were reported in the Table 4 where each value is an average of about 50 measurements.

Chemical composition: To compare the quality of the alloys used by founders to that recommended in Europe, we analyzed the chemical composition of 14 samples produced at different times with large variability of craft production. The spark spectrometer analysis gave the results in Table 5

Analysis of the microstructure: We have identified by spectrometry X several intermetallics characteristics such $CuAl_2$, Mg_2Si, $Fe_2Si_3Al_9$, (Cu, Fe, Mn) Al_6, with silicon present as dark needles (Fig. 1). And sometimes lead which features the appearance of small spherical particles of micron size. All of these phases are included in an aluminum matrix.

Chemical elements such as chlorine, carbon and sodium were also detected locally. Their unexpected presence may be related to practices used by founders to improve the quality of the alloys: dispersion of sodium chloride (salt form) to agglomerate the slag and introduction of chlorinated plastics to "refine" alloys.

RESULTS AND DISCUSSION

The sand: During molding, the fine ash of charcoal added by the founders denatures slowly the sand by coating grains. Their presence is confirmed by the ES whose value decreases gradually (Fig. 2)

We observe an almost linear decrease of approximately 0.11% per day. Considering this evolution average of ES and its value for eroded sand (Table 3), we can say that the sand analyzed on May 29th will be renewed in the coming days, because beyond it risk to have a ES less than the eroded sand's. If May 29th was chosen as the deadline beyond which we must renew part of the sand under penalty of seeing defects on the finished products, it is about three months of use for this sand renewed on February 27th. However for the new sand, by measuring the ES and assuming of 0.11% per day, it can be used during a year.

The aluminum alloy: An inspection of Table 5 reveals that any alloys do comply with the norm (EN 601), because of the levels of copper and zinc systematically too high, and those of lead and tin occasionally too important. Moreover, the silicon is always present in each of the alloys in varying proportions due to the conjunction of several phenomena: Wastes used are derived in large part of automotive industry in which aluminum alloys are rich in silicon, an element improving their castability. They may also contain copper or zinc to improve their mechanical properties (Herbulot, 2001). Also the supply of scrap metal is not regular, both in quality and quantity as a result of the limited size of the resource and the lack of stock and sorting. We also note significant levels of iron compared to those in the conventional industrial aluminum alloys. The excessive presence of this element may be related to prolonged contact of the molten with the iron tools used by founders and also to the reprocessing of waste materials which sometimes contain steel particle. And it is well known that liquid aluminum is very aggressive towards the iron and its alloys (DINNIS *et al*., 2006). The simultaneous presence of many alloying elements in quantity uncontrolled generates metallographic structures partly different from those observed in similar industrial alloys.

CONCLUSION

This study allowed us to identify most of the alloys used in the preparation of artisanal cooking utensils due to the collaboration with the Association of craft founders of Senegal. It appears from this study that:

- The properties of these alloys are acceptable both in terms of the microstructure and the hardness.
- The technique is very well controlled by the Senegalese artisans who are able to produce cooking pots with very small thickness even though they have many pores.
- The sand used must be renewed in part (1/3 the amount) every 3 months for a better quality of finished products.
- All the samples have copper and zinc concentrations higher than the maximum allowed by the norm NF EN 601 (July 2004) which regulates the composition of aluminum alloys intended for food contact.

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