CHARACTERIZATION OF POLISHING DUST
FOR
GOLD RECOVERY

By

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ABSTRACT

Gold Jewelry is polished to bring out the brilliance and luster of Gold. Many types of polishing and buffing media are used . The polishing dust generated by the process is collected for the recovery of precious metals. If this polishing dust is subjected to leaching for the gold recovery, the gold recovery is very low. However, if it is roasted prior to leaching (dissolution), the gold recovery dramatically changes. This paper examines the oxidation kinetics of waste polishing dust during roasting, and reasons for high gold recovery.

KEY WORDS

INTRODUCTION

Karat jewelry is generally manufactured from either binary or ternary alloys of Gold containing varying amounts of Gold and Silver. The gold content in the alloy adds the beauty to the jewelry where as the Copper and Silver controls the physical properties, such as melting point, hardness, strength, color etc. Besides, addition of copper and silver, lower the price of jewelry thus making it accessible to a larger number of people. About 1% Zn is also added to the karat alloys to reduce the dissolved oxygen which helps in reducing the surface blisters during the solidification of the casting. Gold jewelry castings are the cleaned by the mass media to remove the oxide layers formed on the surface of the casting. Many types of grinding media is used for this mechanical operation. To provide the final finish on the piece of jewelry, it is normally hand polished on wheels with the aid of different types of polishing compounds. The purpose of this study is to examine the oxidation of the organic layer formed on the gold particles entrapped in the polishing compounds which is removed from the jewelry surface, and the subsequent effects on sampling and recovery of gold. It will be prudent to to discuss, briefly, the characteristics of some of the polishing or buffing compounds itself.

POLISHING COMPOUNDS

In metal finishing industries polishing is generally referred to as an operation that follows grinding and precedes buffing. A clean cleavage surface of a crystal will have a different (and probably lower) surface energy than a ground or abraded surface of the same material, and different also from that after the heat treatment. In particular, polishing of surfaces drastically affects their nature. The mechanical procedure involved in a polishing operation differs considerably from that used in grinding. In grinding, a material as hard as or harder than the surface to be abraded must be employed, whereas, in polishing , the material is relatively soft (e.g., rouge or iron oxide) and is best held by soft material such as leather or fabric. Grinding leads primarily to a mechanical attrition of the surface without greatly changing its molecular crystallinity, polishing leaves a fairly deep and nearly amorphous surface layer.

This surface layer resulting from polishing is generally known as Beilby layer, since Beilby showed that such layers appear amorphous under microscope and have general appearance of a film of viscous liquid that not only covers the surface smoothly but also flows into surface irregularities such as cracks and scratch marks. It appears that the polish layer is formed through a softening if not an actual melting of the metal surface. Studies indicate that the depth of a Beilby layer is in the range of 20 and 100 angstroms.[1]

Two main reasons for polishing are to remove considerable amount of metal or other non metallic and to effect a preliminary smoothing of the surface. Buffing , however , is defined as the operation that follows polishing, has for its prime purpose the refining of a metallic or non metallic surface for the sake of appearance, removing very little material in comparison to the preceding operations. In the jewelry industry, the words polishing and buffing are interchangeably used for the same operation.

In general, the more rigid polishing wheels are employed where there is a need for rapid metal removal or the piece to be polished has a flat surface. Conversely, softer types of polishing wheels are used where the surface is not flat rather contoured and fast removal of metal is not the prime requisite.

The relative hardness of some metals and abrasives commonly employed in the jewelry industry are shown below.

Material	Chemical	Color	Hardness
Gold	Au	Yellow	2.8
Silver	Ag	White	2.8
Copper	Cu	Copper	2.5 - 3.0
Calcium Carbonate	$CaCO_3$	White	3.0 - 4.0
Cuprite	Cu_2O	Red	3.5 - 4.5
Hematite	Fe_2O_3	Red-Brown	5.5 - 6.5
Magnetite	Fe_3O_4	Red-Black	5.5 - 6.5
Silica, Vitreous	SiO_2	White	7.0
Aluminum Oxide	Al_2O_3	White	9.0

Many proprietary abrasives in different combinations are used for polishing or buffing compounds. The abrasives used in the buffing compounds are of very fine sizes. The particle sizes generally are in the range of 1 to 40 microns. From the chart above, it can be concluded that when high luster is required, softer compounds such as calcined lime, copper or iron oxide or a suitable mixture of similar materials will be preferred . Conversely, when fast speed of cutting is required, harder materials such as aluminum oxide (Corundum or Fused Alumina) or Silica (Fused Quartz) should be used.

Before the production of Fused Quartz and Fused Alumina in the Electric Arc furnace, Turkish Emery, a natural compound of Al_2O_3 and iron oxides, was the standard polishing grain. The edges of the Turkish Emery tend to wear smoothly without fracturing, and although this property decreases the speed of cut, it is sometimes desirable for fine operations, particularly in the cutlery field.

The abrasives are formed into different shapes by the use of binders. The binders are either grease or non-grease based. Most common for the gold buffing are generally Greased-based. Grease based binders are composed of Fats and Waxes derived from animals, vegetables and minerals. Some of the more commonly used are stearic acid, hydrogenated fatty acids, tallow, hydrogenated glyceride, and petrolatum The fatty acids under conditions of buffing, besides their physical properties, seem to have an additional benefit of a chemical effect by the formation of metallic stearates. Producing a color, luster, or mirror finish on metals require the use of finest abrasive powders so that minimum scratches will show in the final finish. Fast cutting is not required and binders are primarily formulated to hold the selected abrasive powders to the wheel allowing it to polish or burnish out the scratch marks left by the previous operation. Bars containing powdered calcined lime as the abrasives are used for polishing nickel plate and brass. Rouge compositions containing the finest red Iron Oxide powders, are widely used in polishing Gold and Silver. The fine red oxide powder has unique burnishing qualities to bring out the required high luster on the soft Precious Metals. Fine Chromium Oxide powder is used for polishing Stainless Steel and Chromium.

POLISHING DUST

The polishing dust generated by the polishing of the jewelry, is collected for the recovery of gold. The gold content of the polishing dust range from 0.008-0.03%. During the polishing operation the some of the gold particles get embedded in the organic binders and make them impermeable to the acidic dissolution process for the complete recovery of gold old. If the dust is roasted prior to leaching (dissolution), the recovery substantially increases.

In this paper we examine a method to improve the recovery of gold from the waste polishing dust or powder. Structural analysis and the effect of roasting temperature on the extraction of gold into the acid solution were investigated. The oxidation rates of polishing dusts were explained using kinetic equation for diffusion controlled process.

EXPERIMENTAL

Three types of industrial polishing dusts were used for the study. The three dust samples were categorized based on the color of the samples as delivered by the jewelry manufacturers to the precious metals refinery. The samples might be a mixture of many types of dust. Chemical and structural analysis of these samples are summarized in Table 1. Effect of roasting temperature and time on recovery of gold in solution was studied using Sample #3 only. As received, samples were dried at 50 °C for 1 hour in air, to remove the moisture from the sample. A 10 g dried samples were roasted varying time and temperature. The roasted samples were cooled under nitrogen gas. The cooled samples were then dissolved in aqua regia solution at 50°C for 2 hours. The amount of gold contained in the solution was determined using AAS. The recovery of gold in solution was calculated as:

(%) Au recovery = { (Wt. Au in Solution) / (Wt. Au in Sample)} x 100

Table 1. Characterization of Industrial Gold Polishing Dust

Sample No	Gold (oz/ton)	Gold Particle Size	Structural Analysis	Comments
1	1.8	< 2 micron	SEM-EDAX analysis Indicated the presence Of large quantity of Fe, Al, and Si Oxides.	Au-Ag-Cu with little Zn.
2	8.1	< 2 micron (80%)	Large Au particle with Irregular shape were observed.	Au-Ag-Cu alloys.
		40 -60 microns (20%)	Fine Au particles were coated with Fe, Al, Si Particles.	
3	6.5	<3 microns (60%)	Large agglomerated Au particles were observed.	Au-Ag-Cu-Zn
		15-25 microns	Fine Au particles were coated with Al, Si,	
		5-10 microns	oxides. No Fe-oxides were observed. Large concentration of Zn was observed.	

The rate of reaction between polishing dust and oxygen was measured by continuously, recording the weight change during the oxidation. The experimental set up is shown in Figure 1, which consists of a Kanthal wound resistance furnace, and a continuous recording electro-millibalance with accuracy of 0.001 mg and a capacity of 10 g. A typical experiment was carried out by using 0.28 g of dried sample contained in a 1 cm diameter silica
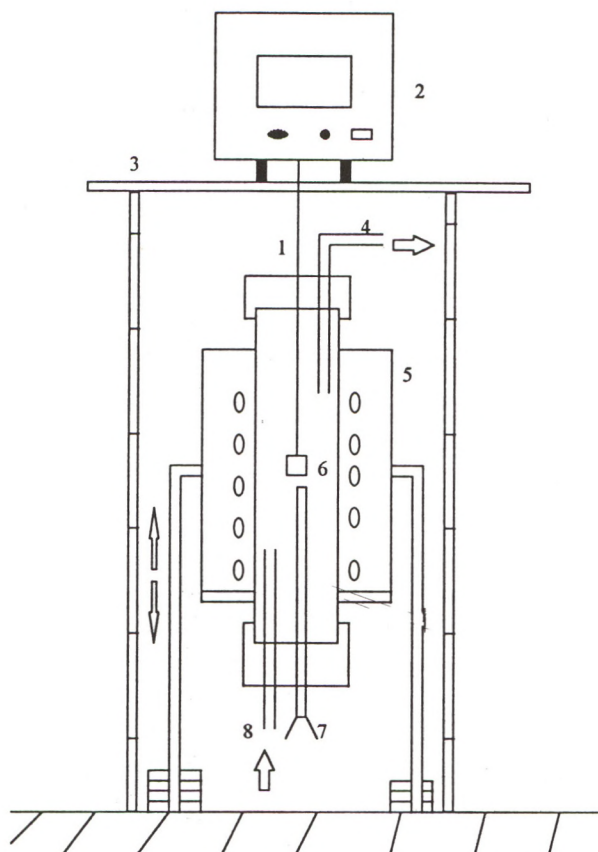
Figure 1. Schematic TGA Setup

1. platinum wire, 2. Cahn microbalance, 3. TGA table, 4. gas outlet, 5. tube furnace, 6. sample, 7. thermocouple, 8. gas inlet.

crucible and suspended from the balance by a Chrome wire. The furnace was heated to the desired temperature. The hot furnace was raised to a level such that crucible was in a constant temperature zone. The purified oxygen-nitrogen gas mixture of a known partial pressure of oxygen (0.2 atm) was introduced into the system. A total gas flow rate of 200 ml/min was used. The crucible temperature was measured by using a chromel/alumel thermocouple, placing it just below the crucible. The balance output, and temperature were recorded continuously by X-Y recorder. After equilibration, when no further change in weight was observed., the furnace was lowered and the sample was cooled under argon atmosphere. The cooled sample was examined by using X-Ray diffraction.

RESULTS AND DISCUSSIONS

(a)   Effect of Roasting on Dissolution

The effect of roasting time and temperature on recovery of gold from the jewelry polishing dust (Sample#3 Only) are shown in Figure 2. The roasting time and temperature has significant effect on gold recovery. As shown in Figure 2, the recovery of gold increased with the increase in roasting time at constant temperature or increase in temperature at constant time. For example, at 600°C , gold recovery increased from 84.0 to 93.0 % as the roasting time increased from 0 (no roasting) to 40 minutes respectively. Similarly, gold recovery increased from 84.0 to 99.5 % with increase in temperature from 500 to 700°C respectively at a roasting time of 40 minutes. Above 40 minutes of roasting time, the increase in gold recovery was only marginal irrespective of the increase in temperature.

(b)   Oxidation Kinetics

Figure 3 shows the effect of time on oxidation of all three polishing dust samples at a temperature of 500 C and the oxygen partial pressure of 0.2 atm. Significant weight loss in the case of Sample #3 as compared to Sample#1 and #2 was observed. Weight loss increased with increase in time and reached an equilibrium in about 15 minutes for Sample#3 and about 5
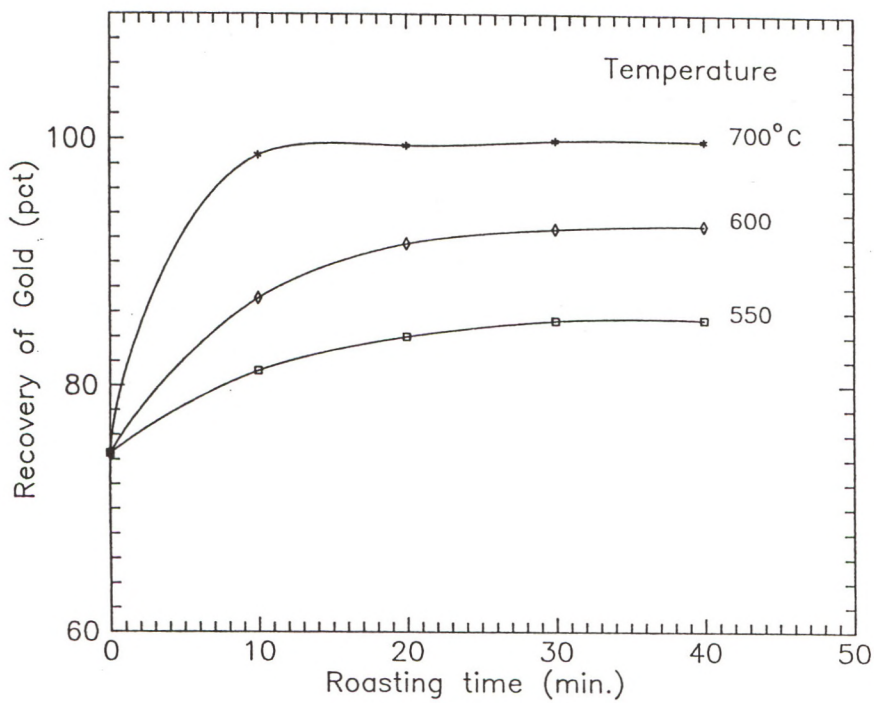
Figure 2.   Effect of roasting time and temperature
on Recovery of Gold (Sample #3).

minutes for Sample#2 and about 2 minutes for Sample#1. The increase in gold recovery with roasting time as observed in Figure 2, can be explained with the use of weight loss data shown in Figure 3. The gold particles in Sample #3 were coated with organic matter. During the oxidation these hydrocarbons were burned off thus exposing the gold surface for acid to dissolve it.

Rate curves for the oxidation of polishing dust (Sample #3) are shown in Figure 4. Several models were proposed to explain the kinetics of solid state reactions [3-7]. It was found that the kinetics of oxidation experimental data fits the parabolic rate expression. This indicates that the rate is inversely proportional to the thickness of the coating layer for constant area.

$$\frac{dx}{dt} = \left(\frac{K_o}{x}\right) \tag{1}$$

where x is the thickness of the protective coating at time t and K_o is the rate constant containing the specific rate constant. Integrating equation (1) results in

$$x^2 = 2K_o t \tag{2}$$

Since the fraction reacted, x, is proportional to the thickness x of the protective coating. Then

$$(x)^2 = \theta x^2 = 2\theta K_o t \tag{3}$$

$$(\alpha)^2 = K_d t \tag{4}$$

where is conversion factor. K_d is the rate constant, which can be expressed in the form [8]

$$K_d = \psi \frac{KT}{h} \cdot \exp\left(-\frac{\Delta H^+}{RT}\right) \cdot \exp\left(\frac{\Delta S^+}{R}\right) = \psi K'$$
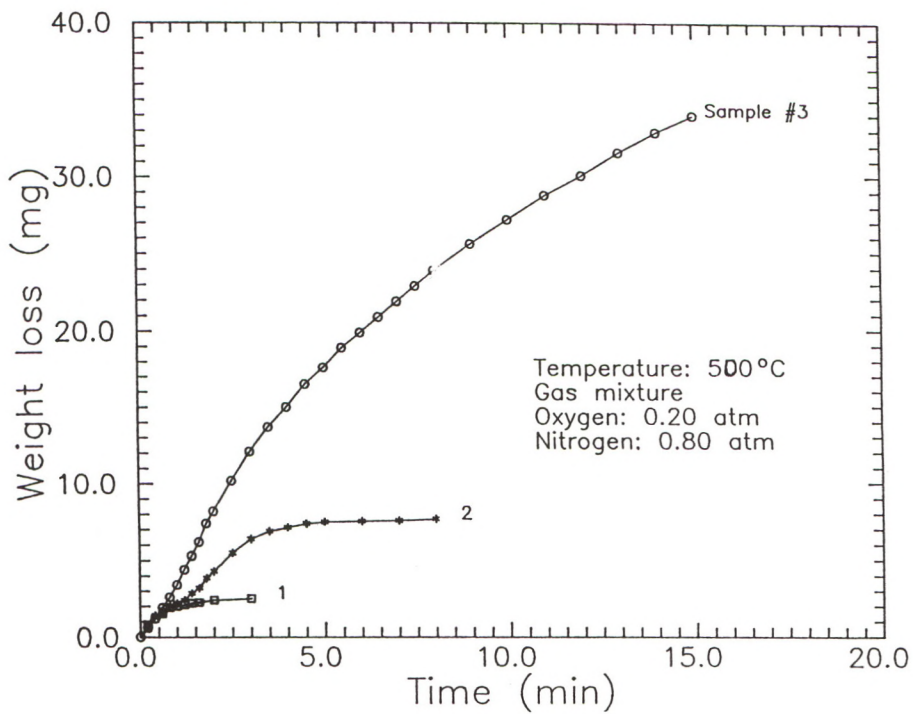
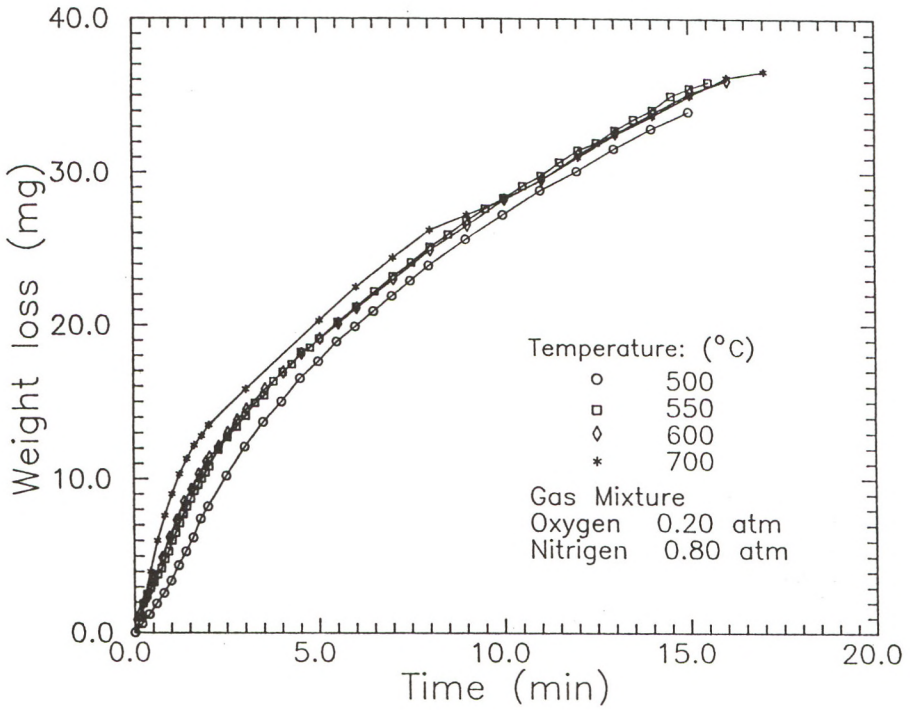Figure 3.   Weight loss as a function of time
             (Samples #1, #2, #3).

Figure 4.   Weight loss as a function of time and temperature (Sample #3).

Where ψ contains appropriate conversion units and K' is the specific rate constant. The slope of $(\alpha)^2$ versus time plot, as shown in Figure 5, gives values of $_{KD}$. In Figure 6, plot of log (slope/T) versus (1/T) is presented. From a least square evaluation of this plot, yielded an enthalpy of activation ΔH^+ equal to 2828 Cal/Mole. The activation enthalpy for diffusion suggests that the diffusing species are hydrocarbon ions rather than the oxygen ions. The standard enthalpy of Benzene units $\{(CH_2)_n\}$ vary from 0.5 to 4.2 Kcal/mole [9]. Gingery and Lecron [10] found activation energy of 69 Kcal / mole for oxygen ion diffusion in silicate glass. The derived value of activation enthalpy for diffusion suggests that the diffusion of hydrocarbon ions through the protective coating may be the rate limiting reaction.

(c)   Polishing Dust

Figures 7, 8 and 9 are the Scanning Electron Micrographs with the EDAX - analysis of the three gold polishing dust samples (see Table 1). In each Figure the A part of the elemental EDAX - analysis is the bright particle in the micrograph where gold particle is entrapped and the B part is for the bulk of the material which show the abrasives with the organic binders. These micrographs are of the mounted and polished sections of the polishing dust. It is clear from the A section EDAX analysis that the very fine gold particles are surrounded by other metallic particles such as Ag, Al, Cu, Si. Section B EDAX analysis shows the particle being totally surrounded or possibly encapsulated by the abrasives in the organic wax and other binders; which in turn make the acid solution impregnable to the gold particles. Figures 10 (sample #1) and 11 (sample#2) are the X-ray diffraction analysis of the materials immediately surrounding the gold particle particles (section B) and are identified as the abrasive media Alumina, Silica, CaO, Fe_2O_3, Fe_3O_4, Cu_2O, ZnO, Ag, and Au. This indicates that either the abrasives were mixed as a result of mixing the dust prior to shipping it to the precious metal refinery or they are part of the proprietary polishing or buffing compound mixtures.
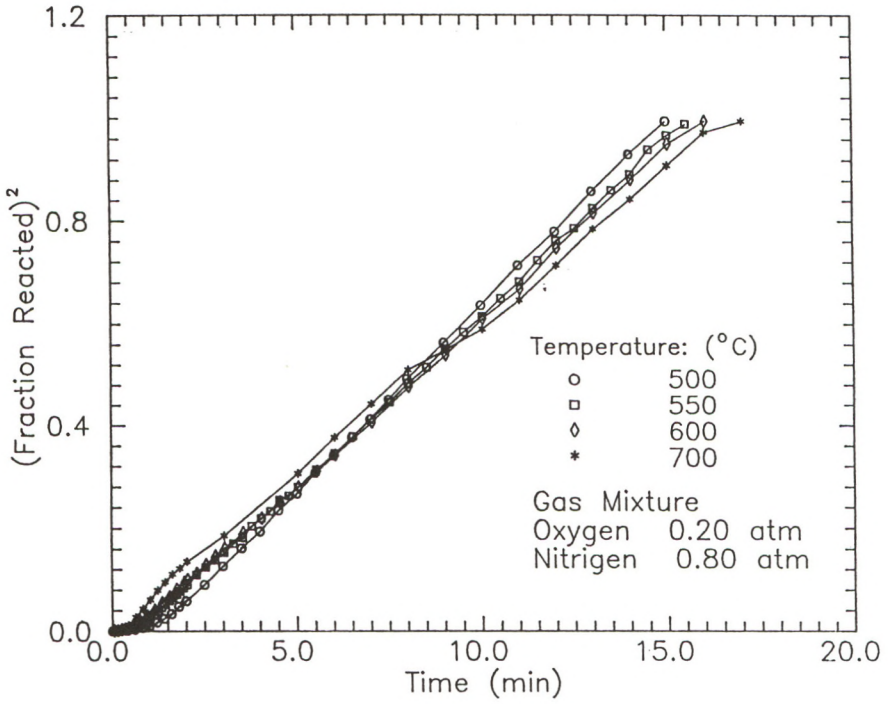
ACKNOWLEDGMENTS
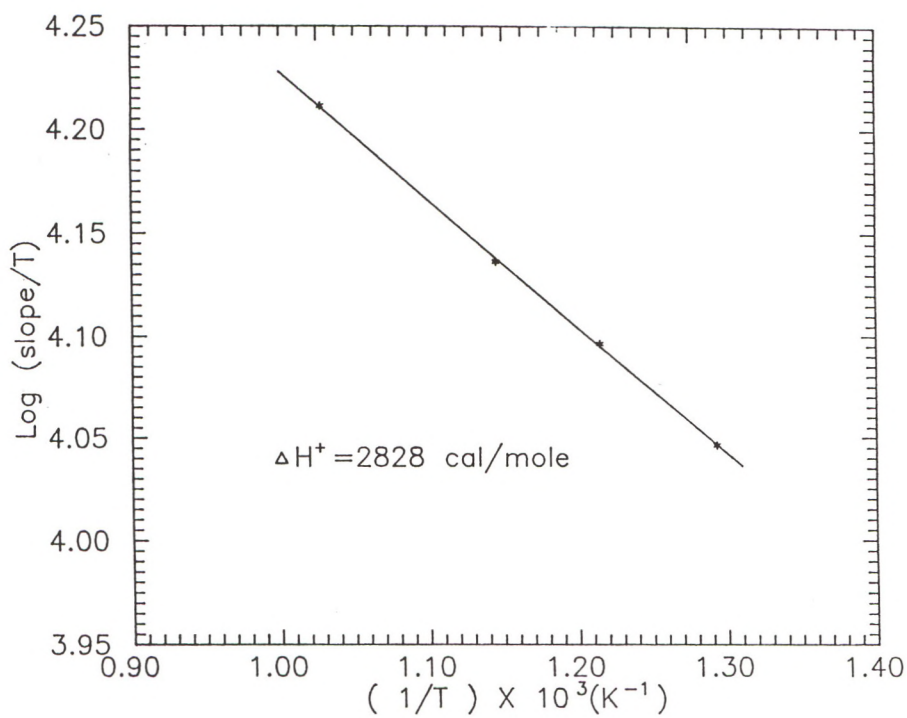
Figure 5   Parabolic rate plot.

Figure 6   Arhenius plot for calculation of heat of activation.
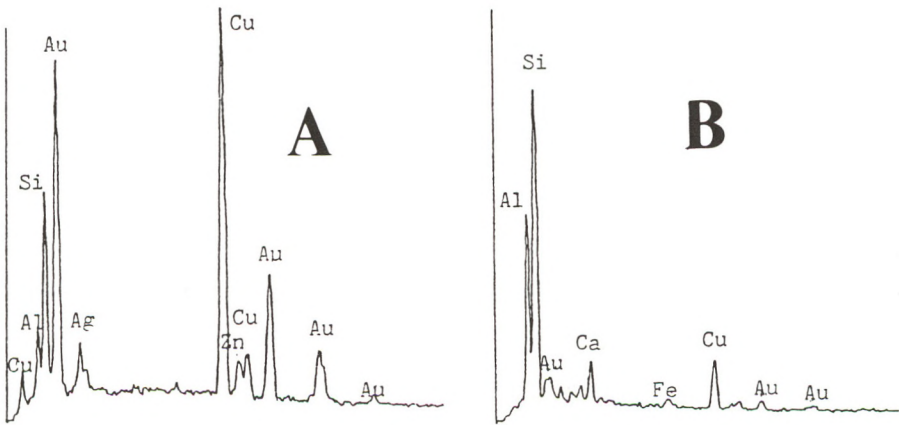
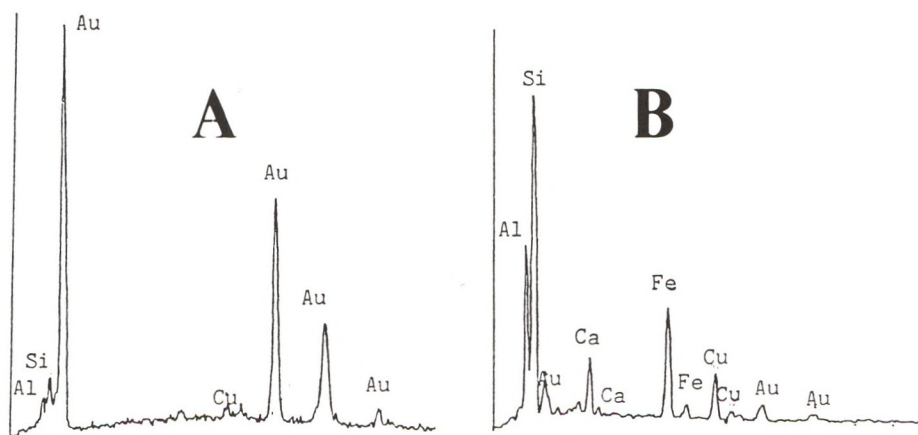Figure 9   Scanning Electron micrograph with EDAX-analysis
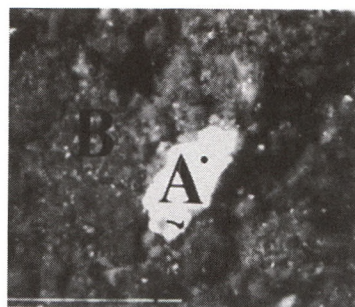(Sample #3).

Figure 8   Scanning Electron micrograph with EDAX-analysis
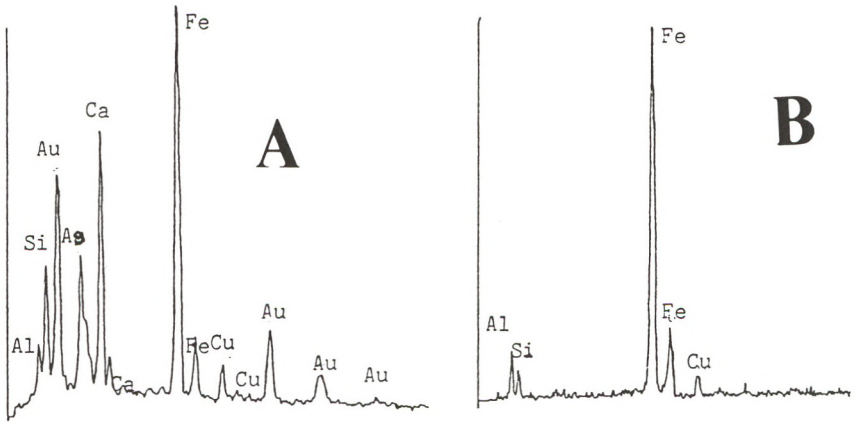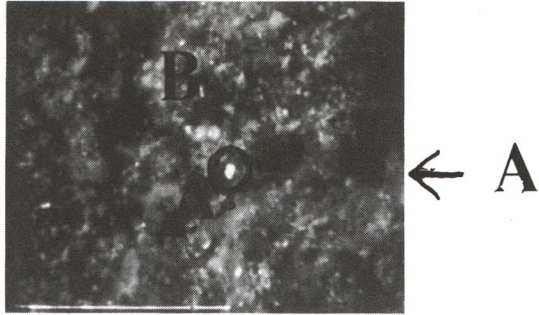   (Sample #2).

Figure 7   Scanning Electron micrograph with EDAX-analysis
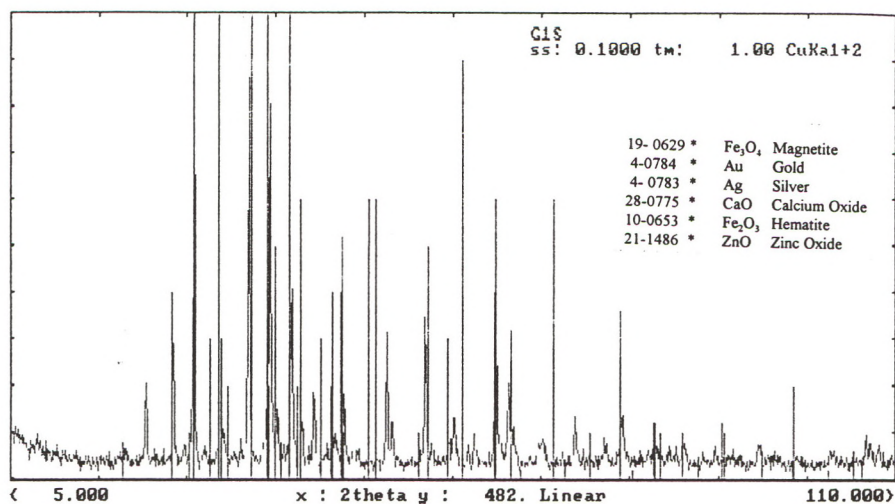   (Sample #1).

Figure 10   X-ray Diffraction of abrasives media surrounding Gold particle (section B, Sample 1)
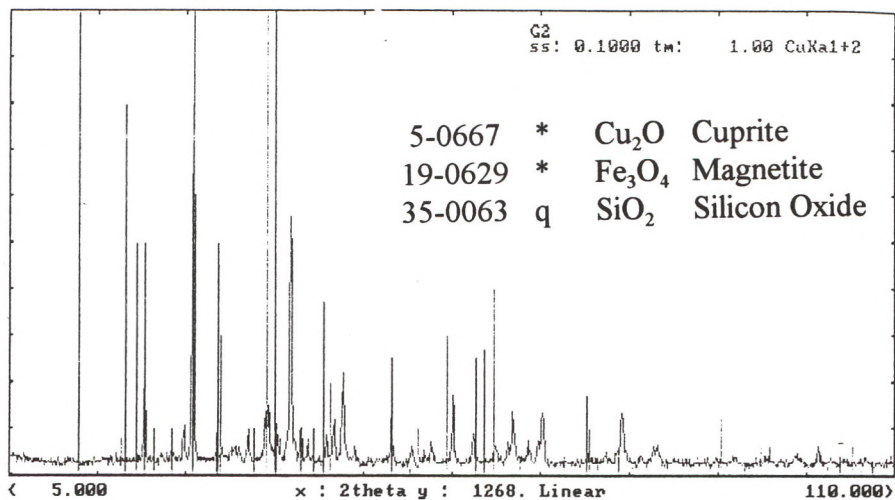

Figure 11   X-ray Diffraction of abrasives media surrounding Gold particle (section B, Sample 2).

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