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Safety Issues Improvement in Ceramic Lined Composite Pipe Produced Using SHS Method

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Abstract
Self-Propagating High-Temperature Synthesis (SHS) or combustion synthesis (CS) is an advanced method for producing high temperature materials such as refractory materials, intermetallics, and cermets. Combustion synthesis is characterized by extremely heating rate, high temperatures, and short reaction times. Centrifugal force densification was employing to produce dense ceramic-lined steel pipes. The centrifugal force facilitates phase separation of multi-component products during the process. In this research the safety matters in producing ceramic-lined composite pipes from Fe_2O_3 – Al powder mixture is studied. A SHS centrifugal machine with the acceleration up to a = 350g was developed. Thermite reaction of Fe_2O_3 and Al was occurred inside the pipe to produce Al_2O_3 ceramic in the innermost layer and Fe layer at a region between the outer steel pipe and the ceramic layer.

Keywords
Self-propagation high temperature synthesis (SHS), Ceramic-lined Steel pipes, Centrifugal machine, Safety Management

1. Introduction
Schlick mentions human factors concern the scientific discipline about the interactions between human which are active in a system. The term refers also to the profession that applies theory, principle, data and methods to design overall systems. It aims to preserve, to protect and/or to improve the quality of life of humans, determined by their health, safety, we being as socio-economic status [1].

Ceramic-lined composite pipe is a sort of high-performance, heat-resistant, anti-corrosion and wear-resistant pipe that can be produced by centrifugal thermite (C-T) process. The simple, rapid, and economical C-T process was used to produce various types of metal-ceramic composite pipes. These pipes found applications in several fields such as petrochemical industry, metallurgy, chemical industries and mining industries [2-11]. The product of C-T reaction between Fe_2O_3 and Al is a metal-ceramic composite of Al_2O_3-Fe. The reaction is exothermic. Self-sustained chemical reaction propagates through a premixed powder in form of a high temperature reaction front [12]. Ceramic-lined composite pipes are from the family of combustion synthesis (CS) or self-propagating high-temperature synthesis (SHS). The occurrence of the SHS is accompanied with the melting of the elemental alloy. The combustion temperature of the C-T reaction can reach up to 2400ºC which is higher than boiling point of Al and Fe_2O_3. This means the reaction would occur in the inner surface in gas phase mixture at the first stage. Then it would be followed by phase separation and solidification of Al_2O_3 and Fe products. CS processes are characterized by high-temperatures, fast heating rates and short reaction times. These specifications make CS an attractive method for the manufacture of technologically useful materials at lower costs compared to conventional ceramic processes. CS is known as a superficial and economically feasible technique for the preparation of advanced ceramics, catalysts and nanomaterials [4, 5, 13-15].

Magnitude of violence of the reaction, human factors, and safety matter is not reported in open literature. This gap may cause unpredictable burning, incidents, losses or damages during reaction. Importance of this study is to show safety matters and ergonomic concerns unlike most of the published papers which tried to show ease of the production and low costs aspects. This paper is an experimental base problems solving to address the gap on the safety and ergonomic matters in SHS centrifugal cases of more than two years study. The effects of ceramic particles which are stable in various conditions were studied and it is developed to this study [2, 16].

A Special test rig was designed and developed by author was employed in this research [11]. While reaction was in progress, it was observed molten metal throwing out of the chamber so called side products. The side products of the reaction are such as high temperature flame, hot fumes ceramic containing by more than 2000 degree Celsius coming out of the reaction chamber during reaction from the pipe head.

2. Experimental Procedure

The powders of Al (< 75 μm, 99% purity, Sigma Aldrich) and Fe_2O_3 (< 5 μm, 97% purity, Sigma Aldrich) in stoichiometric ratios, Eq.(1), were dried and mixed at low speed. The carbon steel pipe of 110 mm length with inner and outer diameters of 69 mm and 75 mm was used, respectively. The pipe was charged with the powder mixture when it was rotating in a low speed. It was tried to make a uniform distribution of the mixture inside the pipe before increasing the speed. The rotation speed of the pipe in C-T machine was displayed digitally and controlled during the process [11].

$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe + 836\ kJ \tag{1}$$

Al_2O_3 and ZrO_2 powders were added to the green mixture while keep the stoichiometric ratios, Eq.(1) The rotation speed was stabilized to reach a centrifugal acceleration of a = 350g. Ignition of the mixture charged in the pipe was initiated by Oxyacetylene gas or tungsten filament. The violence of the thermite reaction is a sign of the beginning of the reaction in the pipe. The exothermic reaction between Fe_2O_3 and Al inside the whole pipe was occurred to produce a high temperature Al_2O_3 solid ceramic and molten Fe. Phase formation of products was followed by phase separation under the existing centrifugal force at high rotation speed [6, 9, 13, 17].

The product layers were separated based on their density and featured as a multilayered structure. The pipe was kept to rotate at the high speed until solidification of the products was completed. The cooled ceramic–lined steel pipe was taken out for characterization. The small parts of the pipe were prepared for XRD, SEM, Light Optical Microscopy (LOM) and micro-hardness analysis.

3. Results and discussion

Phase and structure formations were occurred simultaneously with phase separation during centrifugal SHS process [11]. Phase formation and phase separation aspects of centrifugal thermite reaction between Fe_2O_3 and Al powders were studied. The general scheme of experiment set up before and after reaction is shown in figure 1.

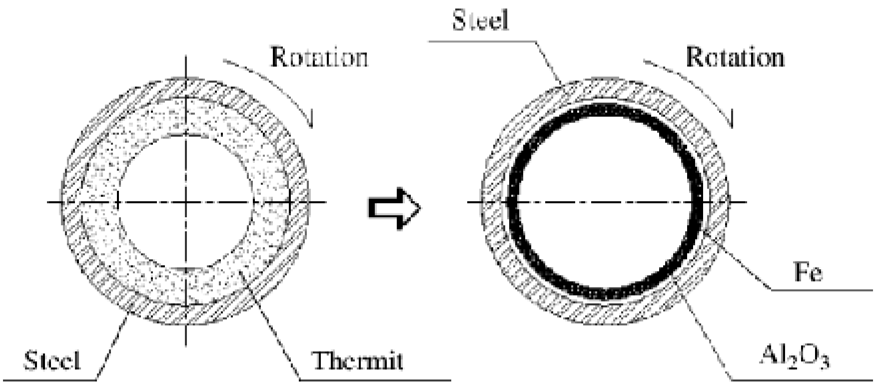

Figure 1. Ceramic Lined Steel Pipes by Centrifugal Force [4]

Unlike previous studies by the current author, the reaction was not violent and desired. Side products like hot fumes and gases containing ceramic were produce less. It achieved by optimization, after using a combination of changes in experiments green mixture by adding Al_2O_3, and tungsten filament instead of oxyacetylene flame as igniter. The presence of that sub product became less. Fume and molten particle throwing decrease significantly.

3. Conclusion

In today's world, where the planet is affected by human, the trend of effects can be reduced by applying some corrections, optimization and information on unforeseen product in production methods. Adding Al_2O_3 to the powder mixture while keep the stoichiometric ratios could control reaction side products in terms of extreme out going heat, ceramic containing gases, and burning risk. By considering adjustments in production method lead us greener production methods. This improvement is directly conjunction with human factors and safety of operator in lab and industries. Although in thin layered products it is more necessary to control reaction violence in order to get good surface properties.

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