Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 17 (2014) 511 – 516

www.elsevier.com/locate/procedia

Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems

Exergy analysis as a developed concept of energy efficiency optimized processes: The case of thermal spray processes

Kamran Taheri[a], Rainer Gadow[a,b], Andreas Killinger[c]*

[a] *Graduate School of Excellence advanced Manufacturing Engineering (GSaME), 70569 Stuttgart, Germany*

[b,C] *Institut für Fertigungstechnologie keramischer Bauteile (IFKB), Allmandring 7b, 70569 Stuttgart, Germany*

* Corresponding author. Tel.: +49 71168568221; fax: +49 711 685-68299. E-*mail address:* kamran.taheri@gsame.uni-stuttgart.de

Abstract

Given the global economic growth and the rapid manufacturing development, the energy and resource efficiency will become an increasingly competitive factor and scope for the companies in the road of sustainability. Among energy efficiency optimization approaches, thermodynamics methodologies contribute toward the improvement of energy efficiency in manufacturing processes. Besides energy balance, exergy has been recently considered as a practical thermodynamics method for system's energy evaluation. From the exergy analysis, merging both exergy efficiency and exergy destruction highlights the energy inefficiencies within a system and provides useful information to the managers and decision makers for prioritizing the improvement potentials. Exergy analysis is generally an applicable method for the comparison of the alternative processes for a given purpose.

In this study, thermal spray process techniques (APS, SPS, HVOF, HVSFS) as energy intensive manufacturing processes are analyzed and compared on the basis of exergy and energy analysis methods. For a comprehensive evaluation, energy efficiency as well as exergy efficiency and exergy destruction are proposed as the indicators.

This work concludes with a discussion of the advantages of the exergy analysis method in comparison with a conventional energy efficiency evaluation by validation of the results for the case of thermal spray processes.

Selection and peer-review under responsibility of the International Scientific Committee of "The 47th CIRP Conference on Manufacturing Systems" in the person of the Conference Chair Professor Hoda ElMaraghy"

Keywords: Energy and exergy efficiency; Exergy destruction; Thermal spray process

1. Introduction

Nowadays manufacturing companies are facing diverse economic and environmental challenges. Especially the attention to global warming, resource depletion and increasing energy and raw material prices are exerting pressure on companies to implement strategies for sustainability. Energy efficiency is considered as a necessary paradigm toward sustainable manufacturing and company's management issues [1]. Recent studies driven from researches as well as industrial practices also underline the importance of energy efficiency and reduction of energy consumption in manufacturing processes. The main motivation is clearly to decrease energy costs while the contribution towards environmental protection [2]. In manufacturing processes, part of the process energy demand is lost as heat and emissions to the environment as well as through the irreversibilities within the process [1]. The aforementioned energy inefficiencies result in significant losses from the already limited available energy sources and therefore constit-

Selection and peer-review under responsibility of the International Scientific Committee of "The 47th CIRP Conference on Manufacturing Systems" in the person of the Conference Chair Professor Hoda ElMaraghy"
doi:10.1016/j.procir.2014.01.060

Nomenclature

C_p	heat capacity (KJ/kg.k)
E	energy (MJ)
Ex	exergy (MJ)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat rate (KJ/h)
r	specific gas constant
p	pressure
T	temperature (°C or k)
ΔT	temperature difference

Subscripts

0	dead state (environment) condition
De	destructions
in	input
loss	losses
(M)	mechanical
out	output
P	productive
S	system
(T)	thermal

Greek letters

ψ	exergy efficiency (%)
η	energy efficiency (%)

Abbreviations

APS	Air Plasma Spray
FLT	First Law of Thermodynamics
HVOF	High Velocity Oxy-fuel Flame spray
HVSFS	High Velocity Suspension Flame Spray
SLT	Second Law of Thermodynamics
SPS	Suspension Plasma Spray

-ute extra undesirable energy costs and environmental penalties for the companies [2]. With the increase need to reduce the impacts of waste energy on the environment and the need to reduce energy demand, it is becoming extremely important to develop even more accurate and systematic energy efficiency approaches for evaluation of energy optimization potentials and prevention of wrong improvement decisions [4].

Altogether, along with management approaches, thermodynamics methodologies strongly contribute toward the improvement of energy efficiency in manufacturing processes. In contrast to conventional energy balance of the first law of thermodynamics (FLT), process analysis based on second law of thermodynamics (SLT) and exergy definition can realistically determine the location and magnitude of energy losses as well as useful amount of energy recovery potentials from the waste heat [3]. The application of exergy analysis has recently received increasing recognition by many researchers in industry as a powerful tool for assessing and improving energy efficiency [5–6] and as an applicable method for comparing different processes techniques for a given purpose [7]. In the current literature the benefits of exergy analysis in comparison with energy analysis is validated for thermal spray process as an energy intensive manufacturing process. To the best of the author's knowledge, no studies appear in literature to make an effort to exergy and energy based analysis of thermal spray process techniques.

Structure

This study encompasses the following main contents:

- propose exergy analysis as a novel energy optimization approach for manufacturing and industrial processes
- Represent the benefits of exergy analysis compare to conventional energy efficiency analysis method with a case study. Besides energy balance, exergy balance was conducted for evaluation and comparison of thermal spray process techniques - high velocity oxy-fuel flame spray (HVOF), high velocity suspension flame spray (HVSFS), air plasma spray (APS), suspension plasma spray (SPS). Spraying torch and cooling water route were considered as the analyzed boundary.

1.1. Energy and Exergy analysis

True evaluation of energy inefficiencies of processes should now be an important factor in the design and optimization of manufacturing and industrial systems. The exergy method is directed to providing detailed information about the energy losses by a systematic approach that can be easily added to conventional design and performance calculation procedure [3]. Technically, exergy is defined using thermodynamics principles as the maximum amount of work which can be produced by a system or a flow of matter till the system or the flow comes to equilibrium with a reference environment [8-9]. According to the SLT, part of the energy consumption by a manufacturing process is lost due to the irreversibilities and increases entropy within the system. Exergy analysis is relevant for identifying and quantifying both of exergy destruction within a process due to irreversibility (cannot be used to to work and should be possibly eliminated) and the exergy losses e.g. the transportation of exergy to the environment. Exergy destruction is neglected in the evaluation of a system according to energy balance of first of thermodynamics. These energy inefficiencies help to highlight the areas of energy improvement potentials within a system and also from the impact on the environment [4]. The overall energy and exergy balance for a system is illustrated in Fig.1. For the energy analysis we have:

$$E_{in} = E_{out} + E_{loss} \tag{1}$$

$$\eta = \frac{E_{out}}{E_{in}} = \frac{E_{in} - E_{loss}}{E_{in}} \tag{2}$$

Where energy efficiency (η) is defined as the ration of output energy (E_{out}) to the input energy (E_{in}) and the enegy loss is represented by E_{loss}. In contrast to energy balance, exergy balance comprises exergy destruction as an additional indicator of exergy loss. The exergy desctruction is discriminated from the exergy loss since it shows the amount