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COMPUTATIONAL FLUID DYNAMICS MODELING OF A LOW PRESSURE COLD SPRAYING NOZZLE

Introduction. In order to produce coatings throughout the Cold Spraying Method it is necessary to accelerate the metal powder particles to high velocities by the means of a supersonic gas flow taking advantage of the drag force produced in the interaction of particles with the gas stream and the heat transferred to the particles [1]. Many laboratories around the world are working on efforts to optimize the gas stream in order to achieve higher particle velocities and temperature [1-8].

While in the Cold Spraying Process the particle velocity is the main responsible for powder deposition it is important to firstly understand how the process parameters (operating gas, pressure and temperature) and the nozzle geometry affect the particles acceleration. The in-flight particles velocities through a nozzle can only be limited by the gas velocity itself while certain parameters will help the particles to easier reach the gas velocity [7]. The use of higher pressures, long nozzles, high gas temperatures, smaller particles and low molecular gas weight can improve the particles acceleration. For practical uses, it is desirable the use of lower pressure and lower operating temperatures to reduce gas flow and operative costs [9].

Table 1 - Commercial powder material properties provided by the Obnisk Center for Powder Spraying (OCPS)

Powder Code	Material %wt. and Size	Zinc %wt. and Size	Alumina %wt. and Size
C-01-11	65%wt. Cu l Size: 20μm SD 5	25%wt. Zn l Size: 10μm SD 5	10%wt. AL2O3 l Size: 22μm SD 7
A-20-11	60%wt. AL l Size: 22μm SD 6	25%wt. Zn l Size: 10μm SD 5	15%wt. AL2O3 l Size: 22μm SD 7
N7-00-14	65%wt. Ni l Size: 25μm SD 8	25%wt. Zn l Size: 10μm SD 5	10%wt. AL2O3 l Size: 22μm SD7

The conventional approach in order to study the Cold Spraying process is by a isentropic model of the gas flow which is described in detail in [10-11]; this model implies that the flow is isentropic (the flow is adiabatic and does not have friction) for this same reason the model ignores the existence of the boundary layer on the nozzle walls where the gas moves slower than in the centerline of the nozzle and usually shows higher results than the data obtained from experimentation [1]. The gas parameters (total temperature and stagnation pressure) depend directly on the nozzle geometry and are functions of the Mach number while they are being accelerated in the diverging part of the nozzle. While the flow enters into the nozzle's cavity the flow is accelerated or decelerated depending on the cross sectional area [12-14].

In this study the DYMET 405 Low Pressure Cold Spraying Equipment is analyzed by the Computational Fluid Dynamics (CFD) methodology using Solidworks Flow Simulation software. The objective of this analysis is to determine the in-flight velocity and temperature of selected powder materials C-01-11, A-20-11 and N7-00-14. In order to simplify the analyses, the powder material blends in this study are assumed to be completely spherical and pure, showing the same physical properties as in their original bulk state. Table 3.1 shows the properties of the commercial powders provided by the Obnisk Center for Powder Spraying (OCPS). In the model, first the gas stream through the nozzle is introduced, to subsequently calculate the effects of the gas in the particle's heating and acceleration. In order to corroborate the results from the CFD model, the calculated Mach number is compared with experimentation using a supersonic pitot tube and the Rayleigh equation for supersonic gas streams.

Computational Fluid Dynamics model. In order to study the gas dynamic parameters of the air being expanded through the divergent part of the nozzle, the Computational Fluid Dynamics (CFD) method is used. Solidworks Flow Simulation© is used in order to simulate the fluid dynamic properties of the expanded flow on which the thermal energy is transformed into kinetic energy by the variation of the area in the SK-20 nozzle. The SK-20 nozzle is drawn and several simulations runs are performed for 424 C, 526 C and 632 C stagnation temperatures *T0* with a stagnation pressure *P0* of 0.8 MPa in all the cases. A substrate is located at 10 mm from the nozzle exit in order to simulate the gas shock while impacting a surface.

The simulation is performed for a 2-Dimensional plane of the nozzle which is considered symmetrical for the complete geometry. The computational domain is restricted for *X* between -8mm and 142mm and for *Y* between -7.5 and 7.5mm. The fluid cells for the model are 119422 cells while the cells for the solid are 31108. The calculations are performed with a reference ambient pressure of 0.1MPa and a reference ambient temperature of 20.05 C. A turbulence intensity of 2% is considered with a length of 1e-4m. The boundary layer is considered turbulent for this case. Fig. 1 shows the SK-20 nozzle geometry with an initial mesh.

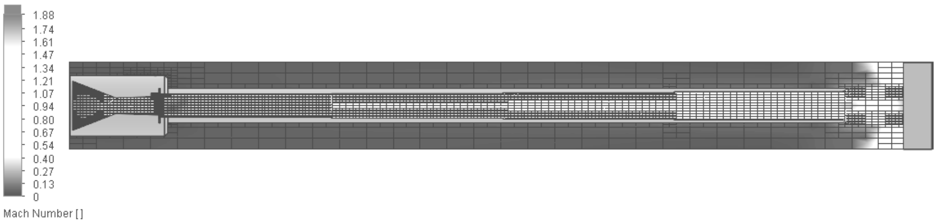

Fig. 1- SK-20 Nozzle profile with a contour plot of the developed Mach number at T0=632 C and P0=0.8MPa with an initial mesh.

In order to study the interaction of the gas with the injected powder materials a "particle study" for each for the particles mentioned at the begging of this chapter is performed. Solidworks Flow Simulation© particle study unlike to the isentropic method, calculates the particles interaction with the gas taking into account a variable drag coefficient as a function of the Reynolds and the Mach number of the particle, and with heat capacity as a function of temperature. As well, the "particle study" takes into account the stochastic nature of turbulence and how it affects the particles trajectory through the SK-20 Nozzle. Fig. 2-4 show the results for of the performed simulations for multiple stagnation temperatures studied in this model.

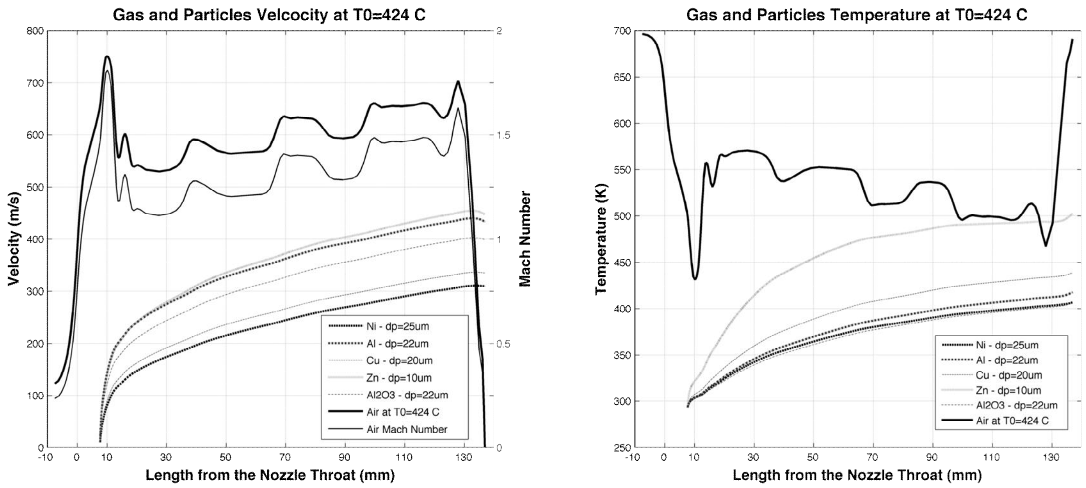

Fig. 2 - CFD results at T0=424

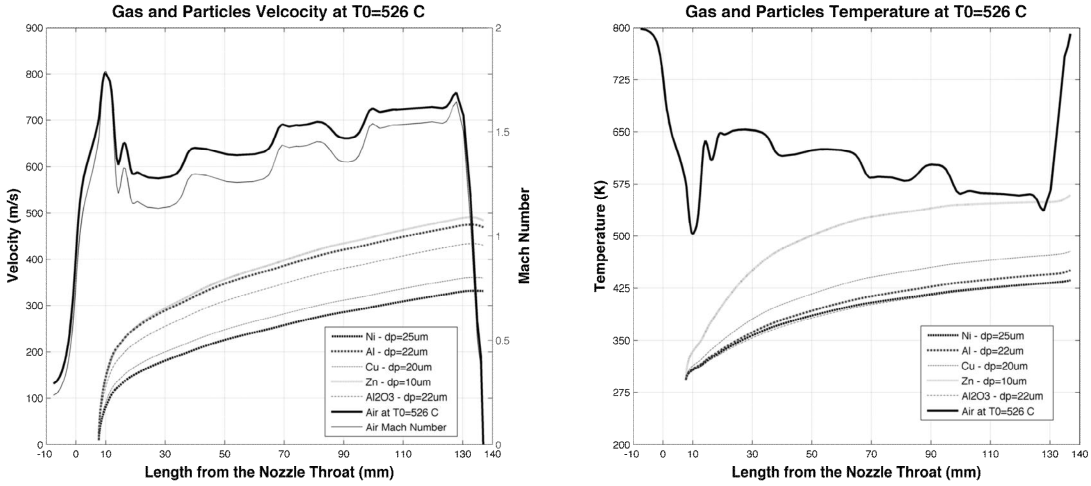

Fig. 3 - CFD results at T0=526

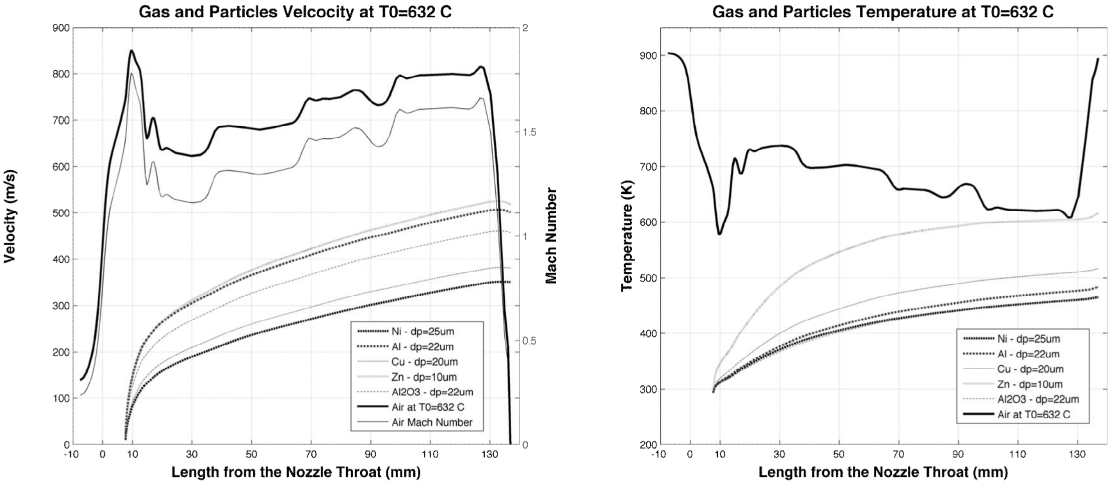

Fig. 4 - CFD results at T0=632

Pitot tube experimentation. This section presents the experimentation performed in order to quantify the effects of the boundary layer thickness on the Mach number of the exhausted gas and corroborate the CFD model. The experimentation is performed with the use a Pitot tube at the nozzle exit of the DYMET 405 Low Pressure Cold Spraying equipment. Fig. 5 shows photography of the setup for the experiment.

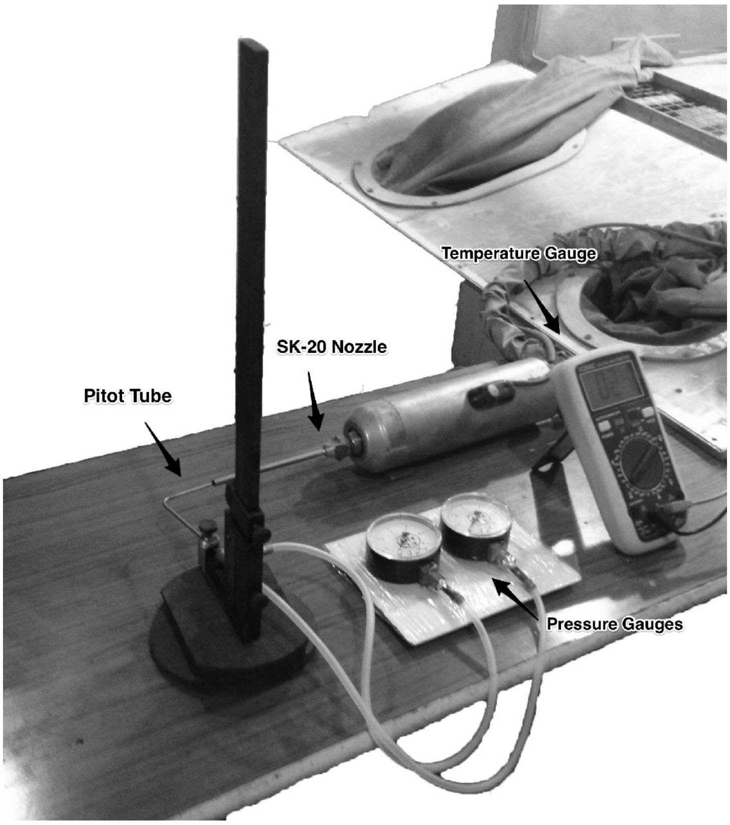

Fig. 5 - Mach Number Measurement experimental setup

During the experimentation the dynamic pressure q_c and the static pressure p_s are measured and evaluated for the Mach number M using the Rayleigh Supersonic Pitot equation Eq. 1,

$$\frac{q_c}{p_s}=\left(\frac{k+1}{2}M^2\right)^{\frac{k}{k-1}}\cdot\left(\frac{k+1}{(1-k+2kM^2)}\right)^{\frac{1}{k-1}} \tag{1}$$

There is an accuracy level for determining the Mach number when using the Pitot tube method. This accuracy level is in the range of a ±5% mistake and is caused by total pressure losses of the gas when traveling along the nozzle [1]. Fig. 3.6 shows the measurements taken from the experimentation at different stagnation temperatures; it is understandable that the stagnation temperature doesn't affects the Mach number in despite that the boundary layer is a function of the gas velocity. According to experimental data the Mach number at the SK-20 nozzle exit is between the 1.5-1.55 range approximately; these results agree will with the CFD model in a range of ±5%.

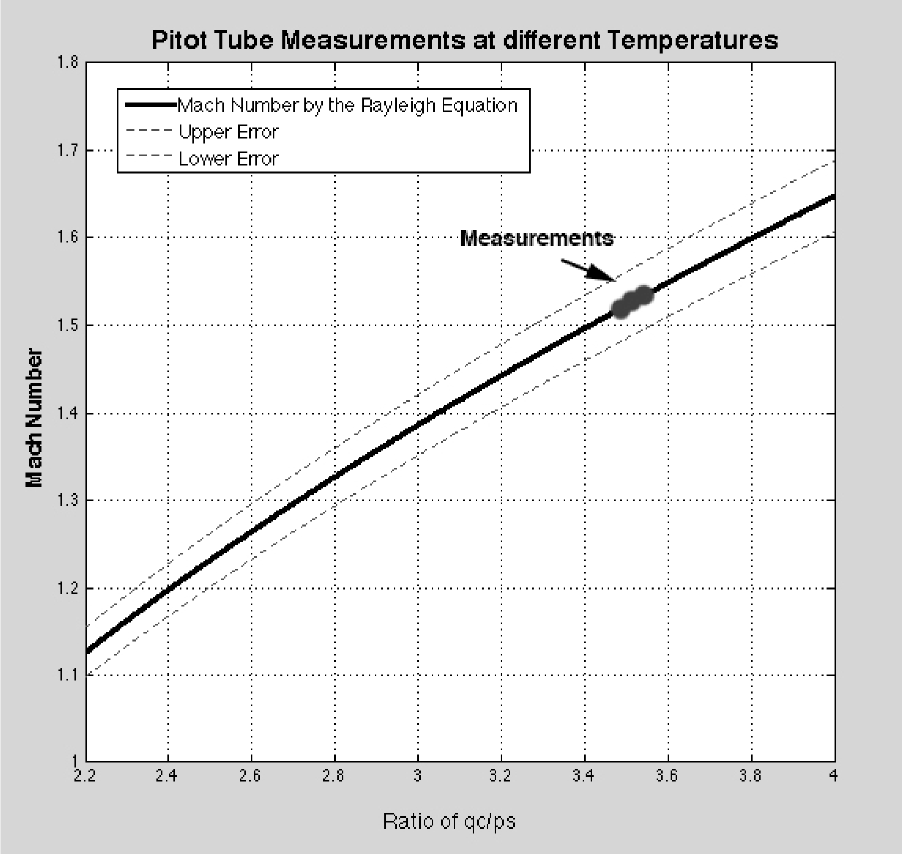

Fig. 3.6 Pitot tube readings for the dynamic and static pressure ratios

Conclusion. In the present study the Computational Fluid Dynamics methodology was applied using Solidworks Flow Simulation software in order to calculate the gas dynamic properties of supersonic expanded air through the SK-20 nozzle. The study was performed for regular operation parameters for the Dymet 405 Low Pressure Cold Spraying system. A particle study was performed in order to determine the particles velocity and temperature of material powder blends C-01-11, A-20-11 and N7-00-14 from the Obnisk Center for Powder Spraying (OCPS). The results were plotted for three different stagnation temperatures showing the gas dynamic characteristics and the particles temperature and acceleration. In order to validate the results from the Computational Gas Dynamic calculations experimentation with a supersonic pitot tube was performed. The static and dynamic pressure readings are used together with the Rayleigh supersonic pitot equation in order to determine the Mach number at the nozzle exit. Static and dynamic pressure readings were performed for several stagnation temperatures and it was found that there is a good agreement with the results from Computational Fluid Dynamics methodology; it was found as well, that even is the gas velocity increases for each stagnation temperature, the thickness of the boundary layer does not increase much for different stagnation temperatures keeping the Mach number at the same range. It is concluded from this study, that the Computational Fluid Dynamics methodology is a tool that can bring accurate results for the study of the gas dynamic properties of the Low Pressure Cold Spraying process.

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The fluid dynamics design and optimization is one of the most important tasks in order to improve the Cold Spraying process. In the present study the Computational Fluid Dynamics methodology is applied in order to study the fluid dynamic characteristics of the supersonic airflow through the SK-20 Low Pressure Cold Spraying nozzle attached to a Dymet 405 Cold spraying system. A particle study was performed in order to determine the particle velocity and temperature of several powder materials commercially available. In order to validate the calculations, the results from the Computational Fluid Dynamics methodology are corroborated with experimentation using a supersonic pitot tube that measures the static and dynamic pressure from which Mach number at the exhaust of the nozzle is determined. In this study, it is found that the experimental data agrees well with the results obtained from the Computational Fluid Dynamics methodology.

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ОБЧИСЛЮВАЛЬНЕ МОДЕЛЮВАННЯ ГІДРОДИНАМІКИ СОПЛА ХОЛОДНОГО НАПИЛЕННЯ НИЗЬКОГО ТИСКУ.

Розробка та оптимізації гідродинаміки сопла є одним з найбільш важливих завдань для того, щоб поліпшити процес холодного напилення. У цьому дослідженні об-

числювальна методика Fluid Dynamics яка застосовується для того, щоб вивчити динамічні характеристики рідини надзвукового повітряного потоку через сопло SK-20 системи холодного напилення низького тиску, що входить до складу системи ДИМЕТ 405. Дослідження частинок було виконано для того, щоб визначити швидкість часток і температуру у кількох розповсюджених порошкових матеріалів. Для підтвердження розрахунків методології Fluid Dynamics, були виконані експерименти з використанням надзвукової трубки Піто, що вимірює статичний і динамічний тиски, від яких визначається число Маха на вихлопі сопла. У цьому дослідженні було виявлено, що експериментальні дані добре узгоджені з результатами, отриманими з обчислювальної методології Fluid Dynamics.

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ВЫЧИСЛИТЕЛЬНОЕ МОДЕЛИРОВАНИЕ ГИДРОДИНАМИКИ СОПЛА ХОЛОДНОГО НАПЫЛЕНИЯ НИЗКОГО ДАВЛЕНИЯ.

Разработка и оптимизация гидродинамики сопла является одним из наиболее важных задач для того, чтобы улучшить процесс холодного напыления. В этом исследовании вычислительная методика Fluid Dynamics которая применяется для того, чтобы изучить динамические характеристики жидкости сверхзвукового воздушного потока через сопло SK-20 системы холодного напыления низкого давления, входящий в состав системы ДИМЕТ 405. Исследование частиц были выполнены для того, чтобы определить скорость частиц и температуру в нескольких распространенных порошковых материалов. Для подтверждения расчетов методологии Fluid Dynamics, были выполнены эксперименты с использованием сверхзвуковой трубки Пито, измеряющий статический и динамический давления, от которых определяется число Маха на выхлопе сопла. В этом исследовании было обнаружено, что экспериментальные данные хорошо согласуются с результатами, полученными с вычислительной методологии Fluid Dynamics.

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ОБЧИСЛЮВАЛЬНЕ МОДЕЛЮВАННЯ ГІДРОДИНАМІКИ СОПЛА ХОЛОДНОГО НАПИЛЕННЯ НИЗЬКОГО ТИСКУ.

Розробка і оптимізація гідродинаміки сопла є одним з найбільш важливих завдань для того, щоб поліпшити процес холодного напилення. У цьому дослідженні обчислювальна методика Fluid Dynamics яка застосовується для того, що б вивчити динамічні характеристики рідини надзвукового повітряного потоку через сопло SK-20 системи холодного напилення низького тиску, що входить до складу системи ДІМЕТ 405. Дослідження частинок були виконані для того, щоб визначити швидкість частинок і температуру в декількох поширених порошкових матеріалів. Для підтвердження розрахунків методології Fluid Dynamics, були виконані експерименти з використанням надзвуковий трубки Піто, що вимірює статичний і динамічний тиску, від яких визначається число Маха на вихлопі сопла. У цьому дослідженні було виявлено, що експериментальні дані добре узгоджуються з результатами, отриманими з обчислювальної методології Fluid Dynamics.