MEDINFO 2007
HISA Ltd Australia
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Fluent Software Implied in the Methodology of Numerical Simulation of Two-Phased Flows (liquid melting – gas) With the Separation Interface Specific for the Filling Process of the Pattern for theFramework of Fixed Partial Dentures

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Abstract

This study presents the methodology of numerical simulation of two-phased flows (liquid melting – gas) with the separation interface specific for the filling process of the pattern for the framework of fixed partial dentures, as well as a series of numerical results for a typical geometry. Considering the presented issues, it is recommended to increase the revolution of the pouring table to 700 rotations / minute in the case of titan, creating similar conditions concerning the volume mass force between the two alloys.

Keywords:

numerical simuation, dental alloys casting, Fluent

Introduction

This study presents the methodology of numerical simulation of two-phased flows (liquid melting – gas) with the separation interface specific for the filling process of the pattern for the framework of fixed partial dentures, as well as a series of numerical results for a typical geometry.

The installation for melting and for pouring of titan - Titanplus (Seit Elettronica, Italy) is composed of a rotating table on which the pouring device is placed in dynamic balance.

The speed capacity of the pouring table is n = 500 rotations/minute, which corresponds to an angular speed of

$$\varpi = \frac{\pi n}{30} = 52.36\, rad / s$$

The heating and the melting of titan is accomplished with the help of high frequency currents. The metal pieces are placed in a crucible furnace that is set in position on the rotating table. When the melting temperature is reached, the rotating table, having the revolution n, the crucible furnace is sliding into position from where the melted metal is flowing into the pattern (the pouring shape). The flow of the melted metal into the pattern takes place especially due to the centrifugal force; the gravitational force can be neglected in this case [3].

Figures 1 and 2 present the field of analysis used to obtain the final study alternatives of the filling of the pouring cavity. Because of the great amount of calculations, two or three processors have been used at the same time as a calculating method. This method requires a partitioning of the main field into subfields, each sub domain being linked to one processor. The partitioning is made in such a way, so that the surface of the interfaces between the subfields has a minimal area and the number of junctions of the digitization network on the interfaces to be minimal. This condition is essential for the minimization (reduction) of data communications between the processors at every iteration of the solution algorithm.

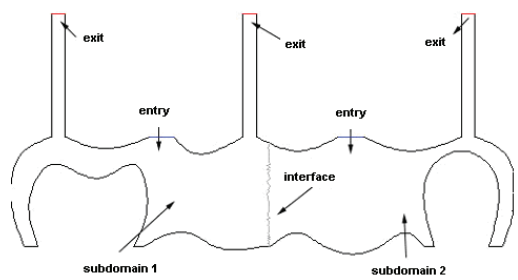

Figure 1 - The field of analysis, with the setting of the entrance/exit sections and partition into two subfields for parallel calculations on two processors

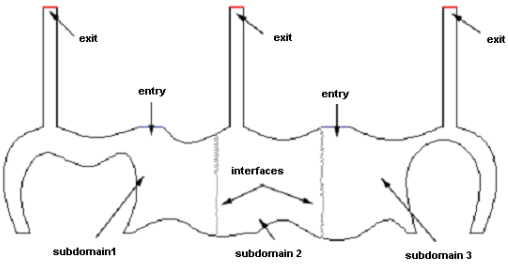

Figure 2 - The field of analysis with the setting of the entrance/exit sections and the partition into three subfields for parallel calculating on three processors

Figure 3 present the digitization network that has been used. In the details of figure 4, the used network of quadrilaterals can be observed in the neighborhood of the wall for a correct representation of the high speed gradients, with the triangulation from the inside (interior) which permits the covering of the fields with complicated geometry.

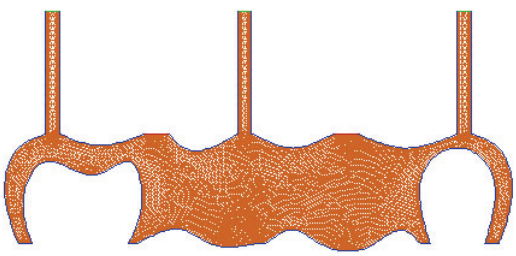

Figure 3 - The mixed digitization network of the field of analysis

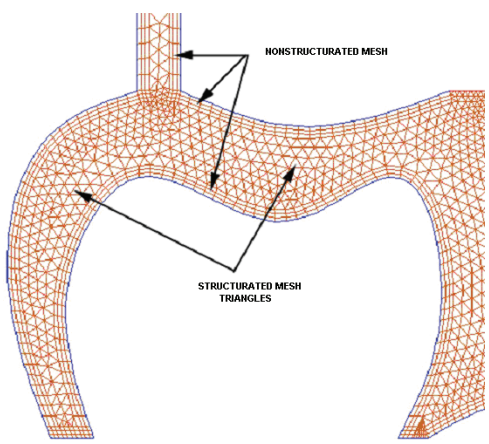

Figure 4 - Detail of the mixed digitization network

The final version for the configuration of the disposition of the ventilation channels, as well as the optimized digitization network represent some of the important accomplishments of the present study and guarantee the accuracy and the power of pointing out of the results obtained through the numerical simulation.

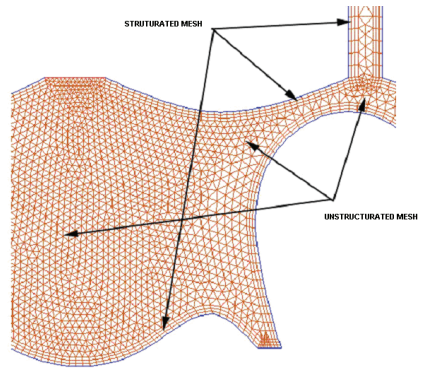

Figure 6 - Detail of the mixed digitization network. In the entrance section no quadrilateral elements are used. The layer of structured network embodies only the solid frontier, where the thick viscid fluid adheres to the wall

The local treatment of the ramifications (embranchments) is reduced to the study of the flow of the fluid into a "T"-type.

Coming back to the estimation of the entering speed of the melted metal into the cavity of the pattern,

with the hypothesis that $v_1 \cong 0$ and $v_2 \approx v$ (the medium speed in the hydraulic alimentation (supply) path) we have

$$v^2 = \frac{2}{1+\zeta}\left[\frac{\omega^2\left(r_2^2 - r_1^2\right)}{2} + \frac{p_1 - p_2}{\rho}\right]$$

In the initial stage – corresponding to the start of the flow, inside the pouring cavity the fall of the entrance/exit pressure is null and the entering speed of the melting is

$$v = \sqrt{\frac{52.36^2\left(0.14^2 - 0.1^2\right)}{2}} = 3.6\, m/s$$

After the crucible furnace has completely been emptied, due to the hydrodynamic resistance of the ventilation paths and because of the viscid chafe afferent to the flow into the pouring cavity, a difference of pressure of approximately 32000 Ps (in case of an Co- Cr alloy) appears between the entrance/exit and the speed decreases to the value of

$$v = \sqrt{\frac{52.36^2\left(0.14^2 - 0.13^2\right)}{2} - \frac{32000}{8700}} = 0.17\, m/s$$

The observation is made, that - during the filling process - the entrance speed of the melting into the cavity is consid-

erably decreasing onto the final [4]. This variation has been taken into consideration in the numerical simulation. Synthesizing the methodology of the numerical simulation, the calculation of the speed in the entrance section is made this way:

1 . first, calculation are made with a speed value of 3,6 m/s, according to the beginning of the emptying of the crucible furnace;
2. after the first interval of time, r_1 is recalculated corresponding to the liquid volume flown into the pouring form and the super- pressure p_2 is noted (p_1 is known as the atmospheric pressure);
3. the speed is recalculated in accordance with the previous relation;
4. the evolution in time continues for the new time span with the new speed value;
5. the time steps are calculated successively until the complete filling of the pouring cavity with melted metal [5].

Material and method

The numerical simulations have taken place at the Laboratory of Numerical Simulation and Parallel Calculation of the National Centre for System Engineering with Complex Fluids that functions at the University of Polytechnics of Timisoara.

The hardware infrastructure of the laboratory contains:

- 1 Linux Server, dual Pentium III, 1000 MHz, 2 GB RAM memory, 3xHDD 30 GB;
- 1 Windows Server, dual Pentium III, 1000 MHz, 2 GB RAM memory, 2xHDD 30 GB;
- 14 Working Stations, Pentium III, 1000 MHz, 1 GB RAM memory, 2xHDD 30 GB;
- Computer network infrastructure Linux /Windows, 2 Fast Ethernet Switch Allied Telesyn 24x100 Mbit, with management;
- Internet connection with optical fiber;
- uninterruptible tension sources;
- Network Printer Laser Jet HP 2200 DN, Printer DeskJet HP 1100C, Printer Laser XEROX P8 ex.

The software infrastructure of the laboratory is conceived to assure maximum of flexibility for the covering of a large scale of applications, in the educational field, as well as in the scientific performance research. Each working station is able to operate in Windows and Linux sub systems. The Fluent 5.5 program package is available in the Linux cluster configuration, which represents the world standard in the field of numerical simulation of fluid flow [1]. Fluent can be used in the multi-user mode (different problems are resolved simultaneously on different computers), but also in parallel calculation mode (a problem is solved simultaneously on several processors) [2]. In the Linux configuration, the network is used for the developing of parallel calculus algorithms utilizing the « Message Passing Interface » and the « Portable Extensible Toolkit for Scientific Computations » created at Argonne National Laboratory as information sources. In the Windows 2000 network, the whole usual Microsoft infrastructure is available (Visual Studio 6.0, MSDN Universal, Microsoft Office XP).

For the acquisition, processing and analysis of experimental data we use the graphic development tool LabVIEW (Laboratory Virtual Instrument Engineering Workbench). For post processing, analysis and interpretation of numerical data obtained from the simulation of the fluids flow phenomena, the Tecplot 8.0 program is available, together with its special CFD modules and the digitization network generator. A double investigation has taken place - for the titan melting and for the Co-Cr alloy. From the flowing point of view, the essential difference between the two situations is represented by the density of 4500 kg/m^3, respective 8700 kg/m^3. As the acceleration of the mass forces is determined by the rotation speed, its value remains the same in both situations. On the other hand, the mass force per fluid volume unit is equal to the product between density and centrifugal acceleration. The result shows that in case of the Co-Cr alloy, the mass force per volume unit is practically the double of that of the titan melting. This difference is responsible of the more rapid filling (and much more complete, in general) of the pouring form in the case of the Co-Cr alloy. The configurations are presented, in which the liquid phase is found at the following moments of time: 0.01 s, 0.06 s, 0.12 s, 0.25 s, 0.6 s, 1.4 s, 2.0 s and 3.0 s.

The first set of eight figures (tables 1-2) corresponds to the flow of the titan melting. It can be observed that the spurts of melted metal generated at the exit from the supply mouths are getting into contact with the inferior wall (in the following, we will be using the terms inferior/superior, although correctly it would be “at the little/large radius (beam)”, depending on the real disposition on the rotating pouring table) and are generating an ascendant spurt. At the 0.25 seconds moment this spurt enters the central ventilating channel. Subsequently, the filling of the left part of the pouring form starts, being almost filled at 0.6 s. The central area is filled in proportion of 75 % after 1.4 seconds and after 2 seconds approximately 50 % of the right part of the cavity will be filled. The almost complete filling of the cavity is accomplished in 3 seconds, with the visible existence of a few pouring imperfections afferent to the air bubbles trapped between the liquid mass and the solid walls near the supply mouths. We also appreciate the fact, that through the subsequent cover of these little imperfections with the ceramic layers, they will not have a

significant influence on the final quality of the prosthesis. The second set of seven figures (tables 3-4) present the succession of the filling phases with the Co-Cr melting. In the first filling phases, the evolution is almost identical to the titan melting; notable differences appear after 0.6 seconds. The mass force per volume unit is practically double in this case, encouraging a more uniform and complete filling of the pouring cavity. Practically, the pouring process can be considered finished after 2 seconds. The same little flaws or imperfections remain visible as in the case of the Co-Cr alloy.

The essential difference is that under the circumstances of maintaining of the same revolving of the rotating table - the titan pouring process lasts approximately 3 seconds, while for the Co-Cr alloy, there are only 2 seconds necessary to fill the form. Considering that titan is poured at a temperature over 1700 ºC and the Co-Cr alloy at 1300 ºC, the result shows, that the heat loss -and at the same time - the decrease of the temperature of the melting during the pouring process, is much smaller for Co-Cr. This is the main explanation for the different results obtained in practice with the two types of materials, in favor of the Co-Cr alloy.

Results

At first, a demonstration of the flow properties of titan, respective Co-Cr is presented; then, there is an explanation of the mathematic model that stands at the base of the FLUENT program that has been used for calculating. The capacity (the abilities) and limitations of this model are pointed out and the VOF type is found as proper for these particular investigations. The next step is represented by the analysis of the hydrodynamic of the supply path of the pouring form in order to evaluate the entrance speed of the melting into the cavity, as well as the variation in time of this speed.

For the numerical experiments, a typical geometry has been established for the fixed partial dentures and study versions have been carried out – with and without the taking into consideration of the embranchment of the supply channel, together with two versions of disposition of the ventilation channels. Initially, the field of analysis has been digitized with an unstructured network, this assuring the necessary flexibility for the approach of complex geometries. After that, a mixed network has been constructed, with quadrilateral elements near the solid wall and a triangulation inside the domain. This mixed network leads to the best numerical results.

The numerical simulations are the result of a great volume of calculations. As an example, the used time step (restricted because of stability considerations) is 10^{-4} seconds, which means that for a sequence of three seconds, $3x10^4$ time steps are needed. For every time step, the equation system that governs the two-phased flow is calculated iteratively, with a medium number of 3 iterations; this means a total of almost 10^5 iterations. The version of parallel calculation on three processors shows as a result a single iteration per second in its best shape, which gives us a rolling time of 10^5 seconds, which represent 28 hours. It must be said, that this version is the final result of multiple optimizations after more than 500 hours of pure calculation.

In the case of the version with a single processor (in our case PIII/GHz), one study version lasts three an a half days when optimized. Although this might seem an excessively large time span, the calculation effort is fully justified by the quality of the obtained results.

The preliminary numerical results have pointed out a series o problems of pure hydrodynamic origin, which may lead to the incomplete filling of the cavity of the pattern:

- The asymmetry of the embranchment of the supply channel, corroborated with the geometry of the cavity, may lead to a preferential filling of only one part of the cavity; this is why a careful execution of the distribution network of the melting to the cavity, with the best choice of the entrance angles into the cavity.
- even when assured of an even (uniform) repartition of the melting flow through the supply mouths of the cavity, there may appear difficulties caused by the improper disposition of the ventilation channels. This problem expresses the necessity of placing the ventilation channels on the same side with the supply mouths of the cavity.

As a result of these preliminary observations, an optimal disposition of the ventilation channels has been established (a number of three for the investigated case)- on the same side with the supply mouths. The calculation of the time variation of the effective flow supply permitted a realistic estimation of the length of the pouring process.

For titan three seconds are necessary, while for the Co-Cr alloy only two seconds are needed to accomplish a complete filling of the cavity. This difference is explainable by the significant difference of density (from simple to double).

Conclusion

Considering the presented issues, it is recommended to increase the revolution of the pouring table to 700 rotations / minute in the case of titan, creating similar conditions concerning the volume mass force between the two alloys.

The results presented in this study are no final solution for the problem of the geometric design of patterns for the pouring of frameworks for fixed partial dentures, but they

clearly point out the drawbacks that appear in practice and offer alternatives for eliminating them. We feel that these investigations must be extended and thoroughly analyzed, the numeric experiments being less costly and offering much more details about the intimacy of the pouring phenomena than physical experiments. The physical experiment should only be considered as a final validation of the results proposed by the numerical studies.

References

[1] **FLUENT 5 User's Guide, Volume 3**, Fluent Incorporated, 1998.

[2] **GAMBIT User's Guide,** Fluent Incorporated, 1998.

[3] R. Resiga, **Complemente de Mecanica Fluidelor si Tehnici de Solutionare Numerica**, Editura Orizonturi Universitare, Timisoara, 1999.

[4] S. Bernad, **Optimizarea supapelor hidraulice in regim stationar si dinamic**, Teza de Doctorat, Timisoara, 2000.

[5] S. Bernad, R. Resiga, I. Anton, V. Ancusa, **Vortex flow modeling inside the poppet valve chamber**, The Seventh Scandinavian International Conference on Fluid Power, Linkoping, Sweden, 2001.

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