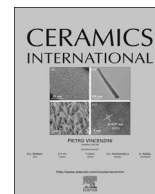




Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

A more representative mechanical testing of green state investment casting shell

Kevin Lee^a, Stuart Blackburn^{a,*}, Stewart T. Welch^b

^a School of Chemical Engineering, University of Birmingham, UK

^b Rolls-Royce Plc, UK

ARTICLE INFO

Keywords:

Mechanical characterisation

Ceramics

Heat treatment

Investment casting

Silica sol aging

ABSTRACT

The influence of de-waxing method and post de-wax treatment on the flexural strength of ceramic shells has been evaluated. De-waxing by autoclave generates the highest strength when dry samples are tested, significantly stronger than when de-waxed by refrigerating. The autoclave-dewaxed shells were found not to be fully de-waxed but to have a coating of wax and some wax penetration into the face coat. This and the curing of the sol by the autoclave process were shown to be responsible for the higher strength.

Treating the shells after initial de-waxing to simulate the conditions in the autoclave by either boiling in water, steaming above water or autoclaving at 180 °C and 0.8 MPa caused changes in the reported flexural strength. For samples initially de-waxed by autoclave the strength was reduced, boiling caused the greatest strength reduction and re-autoclaving gave the least change. Testing wet always gave lower strengths compared to dry. However, initial dry strength was never regained on further drying. The samples prepared by refrigeration lost strength when boiled or steamed but gained strength on autoclave treatment. The strength built to be 57% of the samples de-waxed by autoclave in the dry state. This occurred because the sol cured; however, the shells being essentially free from wax never gained the strength of the samples de-waxed initially by autoclave.

1. Introduction

Investment casting is used to manufacture complex metal parts and had an estimated world part value of US\$11.6 Billion in 2012 [1]. It is favoured where the surface finish and tolerance requirements of the finished component are high. In some applications it allows unique metallurgical properties to be developed such as in the casting of single crystal components for the aerospace industry. The process normally starts with a wax pattern of the component to be cast [2,3] which is then coated in refractory ceramic by dipping into a slurry comprising a sol and filler combination. This wet coating is sprinkled (stuccoed) with refractory grain before drying. The coating process is repeated until a layered shell structure of the desired thickness is attained. The first or primary coat is often made of a different composition to the further backup coats. The wax pattern is then removed from the shell in a process known as de-waxing and the shell fired to give strength and structure, and remove any remnant wax. The final strength of the shell is only developed during the firing stage where sintering of ceramic particles occur. Strength of the shell is different in each stage of the process and shell failures can occur at all stages but an area of

particular concern is the de-waxing stage when the wax is removed from the 'green' shell. The number of failures at this stage depends on the wax composition, the shell make up and the complexity of the part. When a new part, shell system or wax is introduced to the process it would be advantageous to be able to predict the propensity for cracks to form during the de-waxing process.

In order to model the process the most appropriate data should be available to the modeller. One key variable is shell strength which because of the shells inhomogeneous and developing structure is almost certainly not constant under the conditions of the de-wax process. In the raw green state (before de-wax) shell strength comes from a bond formed by the gelation/coagulation of the sol contained in the slurry during drying. It is this rather weak structure which has to take the stresses of removing the wax and is partly why cracking of the shell can occur during de-wax. It is not the whole story, the process is complicated by the wax having a higher thermal expansion coefficient than the green shell that now surrounds it but fortuitously this is countered by the wax's lower thermal conductivity. Without rapid heating these features would combine to cause the shell to frequently fail in tension. Two dewaxing methods are typically used to remove the

* Correspondence to: School of Chemical Engineering, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK.
E-mail address: s.blackburn@bham.ac.uk (S. Blackburn).

<http://dx.doi.org/10.1016/j.ceramint.2016.09.149>

Received 6 July 2016; Received in revised form 21 September 2016; Accepted 21 September 2016

Available online xxx

0272-8842/ Crown Copyright © 2016 Published by Elsevier Ltd. All rights reserved.

wax from the shell: autoclaving [4,5] and flash firing [5]. Steam autoclaving is the most common method, in this process steam is injected at high pressure into a sealed chamber to raise the temperature and pressure to typically around 180 °C and 0.8 MPa respectively in a matter of seconds. Heat from the steam travels through the shell and melts the wax. The surface melting of the wax relieves the pressure on the shell either by drainage from the mould or absorption into the porous shell structure, however, if the expansion stresses imposed on the shell overcome the shells mechanical strength in the green state failure will occur. The wax removal process used often lead to products containing some remnant of the wax after de-waxing. Jones et al. [6] report different test methods where autoclave de-waxed test bars were either soaked in boiling water or returned to the autoclave for a further cycle (putting the shell bars twice in the autoclave) and testing them immediately. It was found that the strength of the shell was significantly reduced to about 50% of the post autoclave dry results. In a further paper, Jones [7] also treated the autoclave de-waxed ceramic shell with steam by suspending the test sample over boiling water and testing the mechanical strength immediately after steaming. With this method variable results were reported depending on the shell type but typically strength loss was in the range 10–50% of the post autoclave dry strength. In both papers the shells were prepared by using autoclave de-waxing, thus the strength of the ceramic shell will have been affected by the extent to which the wax had penetrated into the shell and the damage induced by the de-waxing process. Mechanical testing of the dried autoclave dewaxed specimens would give the normal handling strength of the shell before firing. This represents the most typical condition the foundry sees after dewax but before firing.

In addition to the conventional processes described above the shell may be released from the wax by cooling. The wax shrinks more than the ceramic and therefore separates. It results in shell samples that are wax free and not treated by heat above that required for moisture removal. Comparing dewaxing by cooling and by autoclave would allow the influence of these phenomena to be examined. Branscomb [8] determined the flexural strength of ceramic shells without a prime coat at various temperatures and following various preparation conditions. The samples were prepared by carefully removing the shell from the wax without heating. Branscomb prepared the shell with different compositions of slurry and the flexural strength was determined at different temperatures and conditions – 21 °C dry, 93 °C dry, 232 °C dry, 21 °C wet and 93 °C wet. However, for the wet test it is unclear if the shells were dipped in water and tested or the shell was tested while submerged water. Here again a general loss of strength was reported when the materials were wet compared to dry, with values ranging from 11% to 54% lower depending on condition.

The aim of this study was to understand the development of shell strength in the green and autoclaved state. These results can be used to represent mechanical strength of shell when modelling the autoclave de-waxing processes commonly used in the investment casting industry.

2. Experimental procedures

Wax bars measuring 200×30×5 mm were formed by injection moulding a filled pattern wax. The wax patterns were cleaned with wax cleaner solution and dried before being dipped into a primary ceramic slurry, the composition of which is given in Table 1. The primary slurry coat was stuccoed by hand with a zircon grain the specification of which is given in Table 3. A further 6 coats were applied with a secondary slurry composition given in Table 2 and hand sprinkled with a molochite stucco described in Table 3. Between each slurry coat the bars were dried at 50% RH and 21 °C. A final seal coat of the secondary slurry was applied before a final dry under the same conditions. The primary slurry had about four times higher viscosity than the secondary slurry. The stucco compositions are given in Table 3

along with the dipping and stuccoing sequence.

Bars for mechanical testing measuring 50×20 mm×the shell thickness were prepared by either de-waxing the 200×30×5 mm shelled wax by conventional autoclave treatment with a dwell at 0.8 MPa and 180 °C for at least 3 min, followed by a controlled de-pressurisation cycle at 0.33 kPa s⁻¹ or by first cutting the 200×30×5 mm shelled wax to the desired shape followed by chilling overnight (12 h) at around 5 °C to release the wax from the shell. Fig. 1 illustrates preparation of test bars by the chilling method. All cutting was undertaken by diamond saw.

The bars were stored under atmospheric conditions until mechanical strength evaluation or further treatment was undertaken. A number of these samples were re-entered into the autoclave and heat treated with the same cycle described above giving a total of four different bar types for subsequent mechanical testing. These test bars were treated in one of three ways before testing. They were either tested as stored, boiled in water for 20 min or steamed over boiling water for the same duration (with each of the last two options the material could be tested wet directly after treatment or dried before testing). Additionally the bars could be evaluated with prime coat in tension or seal coat in tension. This gives 48 permutations of the experiment, however not all were evaluated and the 16 selected permutations are given in Table 4.

For each tested permutation a minimum of 10 bars were tested. It is important to note that the mechanical strength of samples vary from batch to batch in these brittle and often rather weak ceramic structures. To compensate for this, the results listed in each table are from the same batch of samples. Comparison between tables and thus batch requires caution. The flexural strength of the shell was measured using a 3-point bend test geometry on Instron 4467 load frame with a 1 kN load cell and a loading speed of 1 mm min⁻¹ (0.0167 mm s⁻¹). The span was set at 50 mm. The failure strength of ceramic shell, σ_{max} was calculated using:

$$\sigma_{max} = \frac{3P_{max}L}{2WH^2} \quad (1)$$

where P_{max} is the fracture load, W and H are the width and thickness of sample fracture area respectively.

3. Results and discussion

3.1. Part 1: effect of different preparation method on shell mechanical strength

The flexural strength results are given in Tables 5–7 for different batches of shell build and allow different interrelationships to be examined systematically. Some results are duplicated in Tables 5 and 7 and show that there is variability in the returned values batch to batch (Figs. 2 and 3). For example, when samples produced by Method 1 are compared, the flexural strengths range from 5.99 to 6.26 MPa across the repeats. Thus only results within a particular data set and table will be compared. De-waxing by autoclave and testing with the primary coat in compression (method 1 (a)) gave flexural strengths approximately 2.7 MPa greater than samples prepared by the fridge de-wax method (method 2 (a)). The change in strength was the same when

Table 1
Standard steel primary slurry composition.

Initial formulation	Mass (wt%)
Filler (200 mesh)	79.83
Silica binder	17.00
Polymer	1.20
Wetting agent	0.06
Antifoam	0.10
Deionised water	1.81

Download English Version:

<https://daneshyari.com/en/article/5438142>

Download Persian Version:

<https://daneshyari.com/article/5438142>

[Daneshyari.com](https://daneshyari.com)