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Modelling hybrid production systems through the ACD specification: a case study in the fibre-glass industry

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4. Test

This section is devoted to testing the proposed approach by applying it to a production system belonging to the fibre-glass industry (see figure 6) and composed of furnace, distribution channels and spooling and bushing departments.

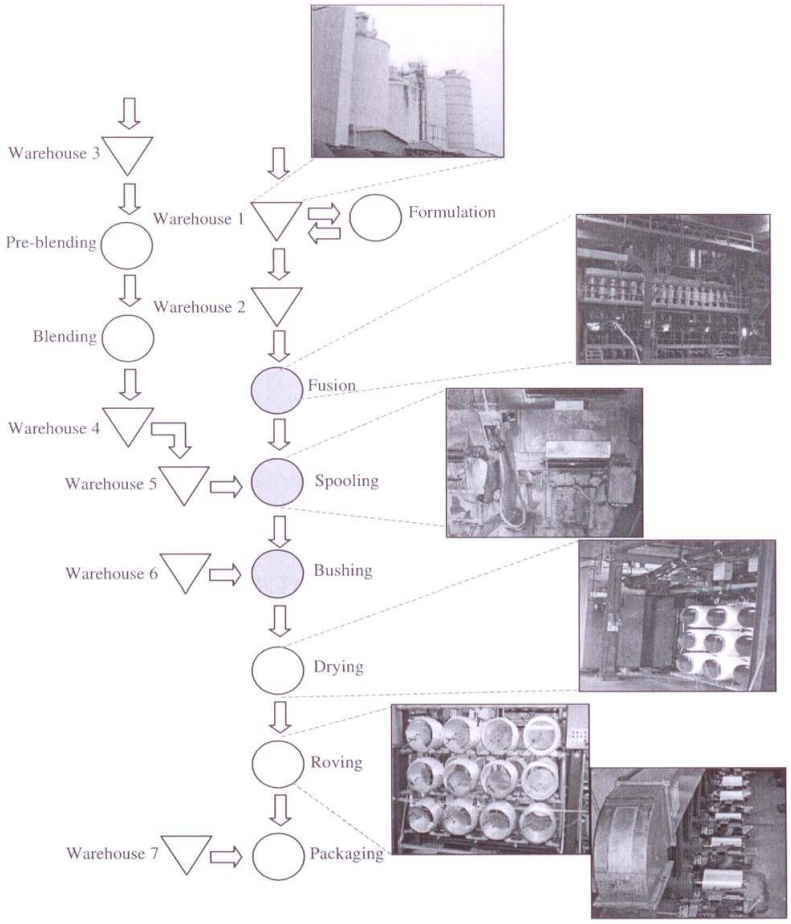

Figure 6. Production flow of the whole manufacturing system; the shaded circles represent the considered hybrid system.

4.1 *Production system configuration*

The furnace, where the vitrifiable mixture is continuously introduced and the fusion process takes place, has two series of 16 burners, each of them composed of a tank containing warm air and a methane pipe. The air is introduced in the system by means of a huge fan placed under the furnace floor; then the air is heated by passing twice along the external layers of the chimney that expels the fusion fumes.

Once air and methane have been mixed, they are introduced in the furnace where, due to a temperature of more than 1300°C, they catch fire thus heating the

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furnace roof. The heat radiated by the roof transforms the vitrifiable mixture into a fluid mass, whose temperature is determined by the radiation intensity and by the threefold action of: (i) two series of electrodes placed on the furnace floor; (ii) the convection motions inside the fluid mass; (iii) the gaseous and vitrifiable mixtures introduced in the furnace. Since the furnace cannot be switched off before the end of its life cycle time (i.e. about 9 years), production is organized on a 365 days per year basis.

The fused glass is transferred to the spooling department by means of a distribution system composed of one main and two secondary channels, where—due to the heat dispersion—temperature is reduced.

The channels have control and process thermocouples for checking and increasing the fluid mass temperature respectively. The spooling department under study is composed of 24 spooling machines (12 for each secondary channel), which transforms the fused glass pouring in them into fibres. Spooling machines are specified by the theoretical production capacity (in terms of kilograms per day referred to the fluid mass processed). Each machine switches from the 'in-operation' status to the 'not-in-operation' status when a fibre-glass breaking occurs. This minor stoppage, which represents the impact of furnace and distribution channels on the downstream departments, is due to either impurities on the fluid mass or wrong values of the pouring fused glass temperature: too high or too low temperatures correspond respectively to too fluid or too rigid fused glass; in both cases the spooling process can be uneven and the fibres can be broken. Since the pouring mass in the channels is a continuum, whenever the fused glass temperature is wrong for a spooling machine, the same occurs also to the adjacent machines. As a result breakings in adjacent machines often occur within a very limited time fence, while also isolated breakings due to the impurities on the fluid mass can occur.

The bushing department is similar to the spooling one, consisting of 24 machines (one for each spooling resource) that wind up the fibre-glass in coils around cardboard cores. Each bushing machine is equipped with a working and a stand-by position (see also figure 7); if the spooling machine is not in operation the corresponding bushing one cannot work and *vice versa*, while the bushing machine is forced to stop only when both its working and stand-by positions are occupied by finished coils. For this reason, when the spooling process is forced to stop due to a breaking, the coil in the corresponding bushing machine stops being processed, generally it does not reach the standard weight of 32 kg, and the fused glass continues to pour (thus producing wastes) until the spooling machine is re-started. The technical time required for re-starting the spooling process ranges between 3 and 5 minutes and two operators are assigned to repair the fibre-glass breakings (one every 12 machines).

As a consequence, the spooling and bushing departments (and each couple of spooling and bushing machines) can be considered as one department and one machine respectively and hereinafter referred to as 'spooling-bushing' department/machine. Moreover, two robots (one each series of 12 machines) are used to remove the finished coils from the stand-by positions and to bring them to a pre-assigned loading area: the distance between two adjacent bushing machines is four metres; the robots speed is equal to 0.2 m/s and the technical loading/unloading time is around 30 seconds. In the loading area, coils are loaded on six-slot metal cores, depending on

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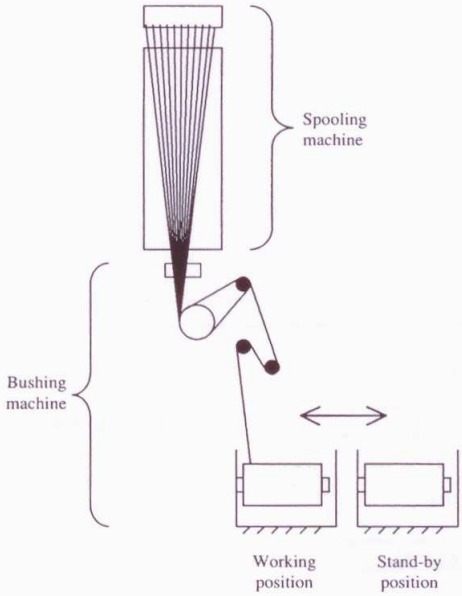

Figure 7. Scheme of the spooling and bushing machines.

the kind of glass they are made of. Once all the slots are occupied, the cores are transferred to the downstream production phases.

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