THE INFLUENCE OF STEAM-RECOVERING CONDITIONS ON THE QUALITY OF RECYCLED PARTICLEBOARDS

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ABSTRACT

The effects, on the properties of recycled particleboards made from recovered wood particles, when subjected to four different hydrothermal board treatments (2bar/ 119°C/ 480min, 4bar/ 140°C/ 120min, 6bar/ 156°C/ 45min, 8bar/ 167°C/ 20min) were investigated in the present work. Furthermore, the impact of a 2nd recycling process on the properties of recycled particleboards was studied. Although the mechanical properties such as the internal bond, the screw holding strength and the modulus of rupture in static bending of the recycled boards decreased, the modulus of elasticity in static bending increased in comparison with the control boards. Furthermore, the recycling process had an adverse effect on the hygroscopic properties of the recycled boards, while the recycling process had a beneficial effect on the formaldehyde content of the recycled boards, whose values were considerably lower than those of the control boards. Among the four hydrothermal treatments tested for particle recovery, the treatment that was carried out at 6 bar/156°C/45min had the most negative effects on the above-mentioned mechanical and hygroscopic properties of the recycled boards.
The results indicated that when the 1st and 2nd recycling of the boards were compared, it was the 2nd recycling process that caused the strongest deterioration in the quality of the recycled boards. The quality of the recycled boards recovered by hydrothermal treatment of 6 bar/156°C/45min was inferior to that of the boards made from particles which were hydrothermally treated in the above-mentioned conditions.

KEYWORDS: particleboard, hydrothermal treatment, 1st and 2nd recycling, technical properties

INTRODUCTION

The management of urban and industrial wood waste constitutes a problem for which it is essential to find rational solutions. Recycling, due to its overall public acceptance, is today one of the most important ways of resolving the problem mentioned previously [5]. The alternatives of incineration or the disposal of wood waste in landfills constitute low-profit solutions which are also hostile to the environment [3, 6, 13]. On the other hand, the growing shortage of low-price wood in combination with the continuously rising cost of raw materials creates problems for the wood-based panel industries. As a result, they are seeking alternative sources of raw material and they are turning to the option of the recycling of wood waste [1, 15].
A large percentage of wood waste results from old wooden constructions, including furniture, which when they have outlived their usefulness are available for exploitation [7]. The above constructions, as far as Europe is concerned, are mainly manufactured from urea-formaldehyde (UF) bonded particleboards and fibreboards [11]. Since these boards consist of at least 90%

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wood, the recovery and re-cycling of wood from used wood-based panels in the production of new ones constitutes the most rational means of waste exploitation.
Various researchers have dealt with the possibility of re-using board production residues. Sandberg [14] and Pfleiderer Unternehmensverwalt [10] have presented methods which make possible the re-use of board residues, after steaming, in the production of particleboard or other wood-based material. In a related patent published by Moeller [9], a method for the recycling of wood products and waste containing wood is described. The application of the method includes the mechanical handling of waste followed by processing for the production of by-products or end-products. Roffael [12] has presented a method for re-using wood particles and fibres bonded with tannin-based adhesive and formaldehyde, produced by the hydrolytic splitting of adhesives in reused boards during hot pressing. Boehme and Michanickl [2, 8] have presented a method with which it is possible to recover particles and fibres from waste containing wood, old furniture and other wood-product residues. The wood waste was comminuted and then impregnated with a solution consisting of urea, ammonia or soda. After their impregnation, the wood products were heated in order to dissolve the adhesive bonds between the fibres and particles. A patent related to the re-cycling of wood products published by Hesch [4] relates to a method and an apparatus for breaking down wood products like used furniture etc. into usable individual components such as chips and fibres.

AIM

The aim of the present research was to investigate the effects of four different particle-recovery hydrothermal treatments on the properties of recycled particleboards made from recovered wood particles. This applied particle-recovery methodology differed from the above-mentioned methods due to the fact that the boards were neither comminuted nor impregnated with any solution which would assist in their degradation. Research was also carried out concerning the influence of a 2^{nd} recycling process on the quality of the recycled boards.

MATERIALS AND METHODS

For the purposes of this research, one-layer laboratory particleboards with dimensions of 350 x 300 x 12 mm and with a nominal density of 0.65g/cm^3 were manufactured. The raw materials used were produced by chipping poplar, fir, pine and waste wood obtained from a particleboard manufacturer. In order to minimise potential fine material loss, which would alter the results during the production of the boards, the fraction of k<1.5mm was removed from them. A commercial liquid UF-resin of E2 grade with 50% solids content was applied to the particles in a proportion of 7% (dry resin weight per dry weight of particles). The ammonium chloride (NH_4Cl) hardener was incorporated at 2% per dry weight of adhesive. During hot pressing a maximum pressure of 2.5 N/mm² was applied to the boards at a temperature of 185°C for 240sec.
For particle recovery, the laboratory boards were treated with four different hydrothermal treatments in various pressure-temperature-duration conditions. The conditions applied were: 2bar/ 119°C/ 480min, 4bar/ 140°C/ 120min, 6bar/ 156°C/ 45min, 8bar/ 167°C/ 20min. Under the effects of saturated steam, the UF adhesive bonds were hydrolytically degraded, thus resulting in detachment of wood particles which could then be re-used for the production of new particleboards. Utilizing the particles recovered from the four different hydrothermal treatments, new laboratory boards were produced under the same conditions as the original. From each of the four groups, three boards were separated in order to determine their properties (1^{st} recycling boards), while the rest of them were used in the production of new boards (2^{nd} recycling boards), after steam treatment. Moreover, for the evaluation of effects caused only by hydrothermal treatments (without recycling) on the board properties, boards were manufactured using wood particles which had previously been hydrothermally treated at 6bar/ 156°C/ 45min. The particleboard hydrothermal treatments for wood-particle recovery took place inside the reactor of a laboratory autoclave (Figure 1), which has the ability to produce saturated steam at temperatures ranging from 100 to 170 ° C and absolute pressures ranging from 1 to 8 bar.

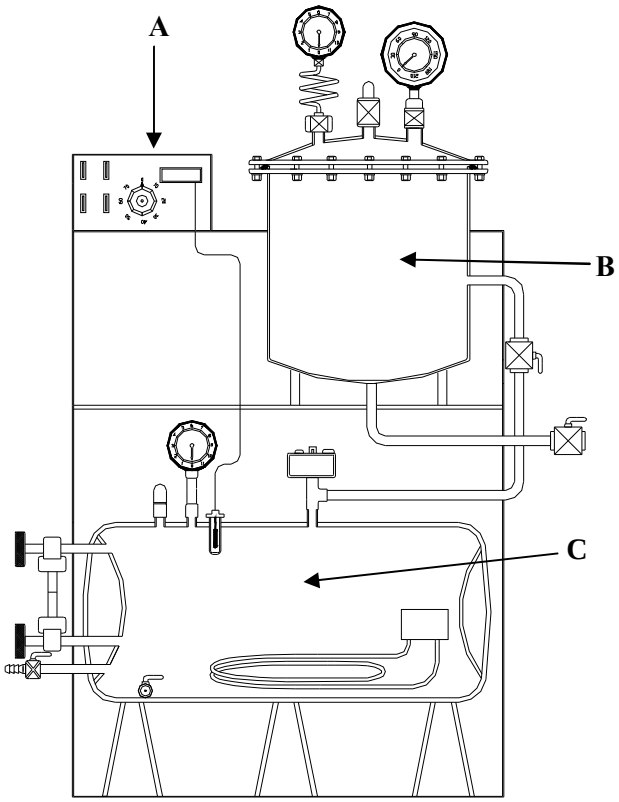

Figure 1 Laboratory autoclave (A. Control panel, B. Reactor (board treatment unit), C. Steam generation unit

Table 1 Steaming conditions and types of experimental particleboards

Para-meter	Treatment	Steaming conditions		
0	None (Control)	-	-	-
A_1	1st Recycling after board steaming → recovery of wood particles	2 bar	119°C	480 min
B_1	1st Recycling after board steaming → recovery of wood particles	4 bar	140°C	120min
C_1	1st Recycling after board steaming → recovery of wood particles	6 bar	156°C	45min
C_1'	Panel production from steamed wood particles	6 bar	156°C	45min
D_1	1st Recycling after board steaming → recovery of wood particles	8 bar	167°C	20min
A_2	2nd Recycling after board steaming → recovery of wood particles	2 bar	119°C	480min
B_2	2nd Recycling after board steaming → recovery of wood particles	4 bar	140°C	120min
C_2	2nd Recycling after board steaming → recovery of wood particles	6 bar	156°C	45min
D_2	2nd Recycling after board steaming → recovery of wood particles	8 bar	167°C	20min

For all types of particleboards produced, a determination of mechanical (internal bond, screw holding strength, modulus of rupture and modulus of elasticity in bending) and hygroscopic (thickness swelling and absorption of water within 24/48h, permanent thickness swelling) properties and also formaldehyde content (Perforator method), were performed according to the current European Norms (EN). Certain particle characteristics (fraction analysis and bulk density) were also determined.
The results were expressed for each property in mean and standard deviation values. Statistical analysis (t-test) with a confidence level of 95% was performed to determine whether there were significant differences among the mean values of the tested parameters.

RESULTS - DISCUSSION

The recovered particles showed higher levels of k<1mm (Figure 2) in comparison with the original material (control), while in certain cases it was observed that the recovered material included a limited number of clustered particles. The recovered material showed higher values of bulk density than the control (Figure 3).

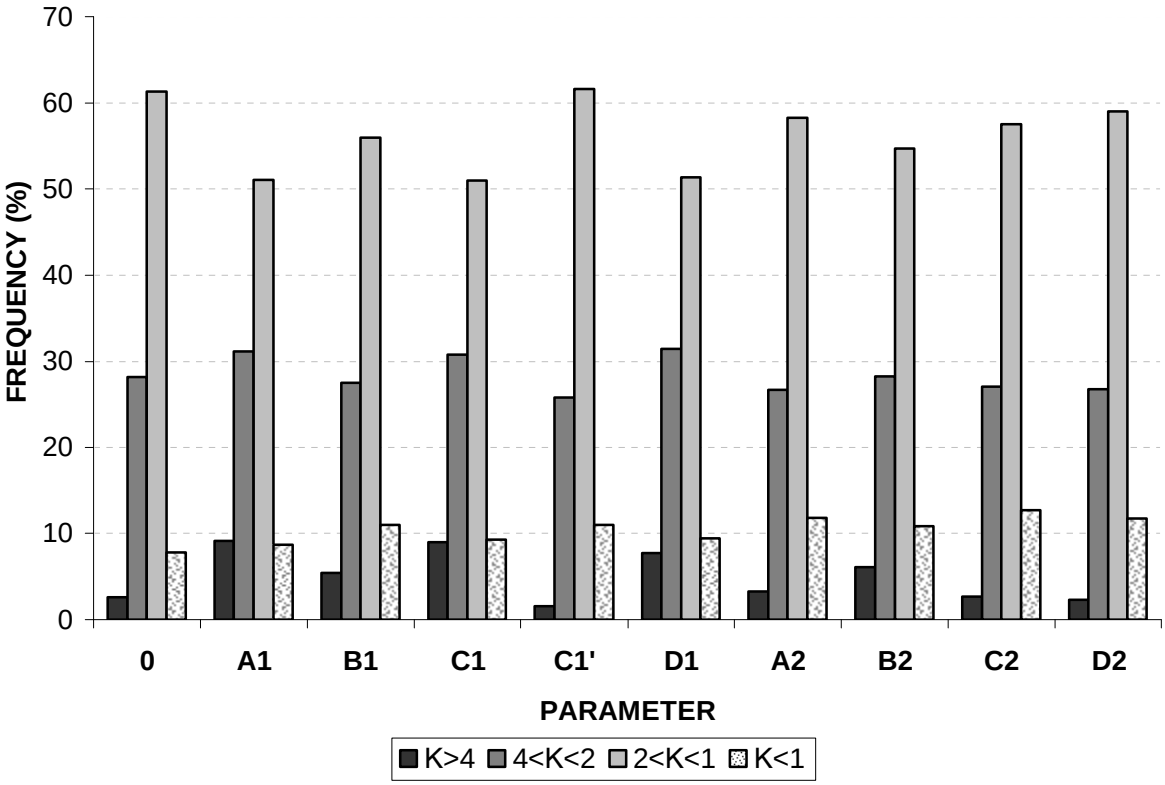

Figure 2 Histogram showing fraction analysis of the particles used in the production of the laboratory boards

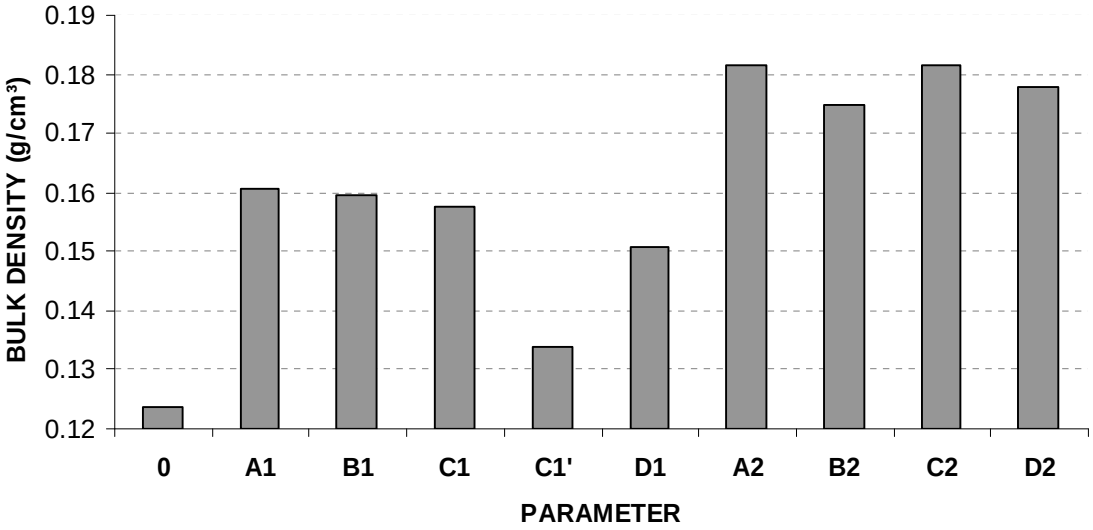

Figure 3 Histogram showing bulk density of the particles used in the production of the laboratory boards

The results of the determination of the mechanical - hygroscopic properties and formaldehyde content of the boards are presented in Tables 2 and 3. As can be distinguished from Table 2, the recycling of particleboards with wood particle recovery via hydrothermal treatments in conditions 2 bar/119°C/480min, 4 bar/140°C/120min, 6 bar/156°C/45min and 8 bar/167°C/20min influenced the quality of recycled boards negatively, concerning mechanical properties (with the exception of the modulus of elasticity) and hygroscopic properties. More specifically, in comparison with non-recycled boards (control), the internal bond, the screw holding strength, and the modulus of rupture in static bending of recycled boards decreased considerably (statistically significant differences), a finding which corresponds with results reported by other authors [2, 5]. On the contrary, the modulus of elasticity in static bending of the recycled boards showed a statistically significant improvement compared with the control boards, which is also reported in related works [2, 5]. Regarding hygroscopic properties, the recycled particleboards showed a statistically significant increase in thickness swelling, water absorption and permanent thickness swelling in comparison with the control boards (Table 3). The strongest deterioration in both the mechanical and hygroscopic properties of the recycled boards was caused when particle recovery was carried out by the hydrothermal treatment of 6 bar/156°C/45min.

As far as formaldehyde content is concerned, the recycled boards had considerably lower values compared with the control boards, which indicates that they could release lower levels of formaldehyde if used as construction material in interior fittings (Table 3). The above-mentioned result matched with other related results already referred to [5, 6].

Table 2 Mechanical properties of laboratory boards

Board type	Thickness (mm)	Density (g/cm³)	Modulus Of Rupture (N/mm²)	Modulus Of Elasticity (N/mm²)	Internal Bond (N/mm²)	Screw Holding Strength (N/mm)
0	11.66[1)] (0.062)[2)]	0.65 (0.048)	17.15 (2.034)	2137 (180.707)	0.938 (0.150)	96.72 (14.786)
A_1	11.43 (0.130)	0.67 (0.039)	14.24 (2.013)	2248 (208.693)	0.652 (0.099)	77.29 (14.260)
B_1	11.34 (0.072)	0.67 (0.036)	13.28 (1.690)	2357 (274.302)	0.518 (0.081)	76.24 (9.479)
C_1	11.47 (0.137)	0.66 (0.037)	12.11 (1.317)	2343 (219.177)	0.379 (0.064)	68.51 (13.454)
C_1'	11.40 (0.151)	0.67 (0.048)	13.03 (2.172)	2198 (320.921)	0.712 (0.099)	78.90 (9.755)
D_1	11.32 (0.095)	0.69 (0.048)	13.15 (2.014)	2402 (361.943)	0.501 (0.098)	72.18 (15.160)
A_2	11.25 (0.076)	0.68 (0.043)	13.55 (2.023)	2379 (348.273)	0.504 (0.082)	73.49 (12.813)
B_2	11.31 (0.132)	0.67 (0.038)	12.55 (1.512)	2518 (261.986)	0.382 (0.068)	65.69 (12.761)
C_2	11.38 (0.223)	0.67 (0.044)	9.52 (2.203)	2453 (551.661)	0.177 (0.067)	47.37 (8.772)
D_2	11.24 (0.106)	0.65 (0.045)	11.47 (1.736)	2581 (389.895)	0.262 (0.062)	62.49 (13.551)
n[3)]	60	60	15	15	20	20

[1)]: mean value
[2)]: standard deviation
[3)]: number of specimens

Comparison between 1st and 2nd recycling particleboards showed that, regarding the internal bond, the screw holding strength and the modulus of rupture in static bending and the hygroscopic properties, the 2nd recycling process caused further deterioration (statistically significant differences) in the board properties. On the contrary, the modulus of elasticity in static bending showed no statistically significant differences between the 1st and 2nd recycling boards.
Boards made from hydrothermally treated wood particles in conditions 6 bar/156°C/45min were of significantly better quality than recycled particleboards produced from particles that were recovered using the same hydrothermal treatment (compare board types C_1' and C_1). This fact leads one to the conclusion that besides the wood particle degradation caused by hydrothermal treatment, there are obviously some other factors related to the recycling process which influence the properties of recycled boards negatively. For the specification of these factors, further research is needed.

Table 3 Hygroscopic properties and formaldehyde content of laboratory boards

Board Type	Thickness Swelling 24h (%)	Thickness Swelling 48h (%)	Water Absorption 24h (%)	Water Absorption 48h (%)	Permanent Thickness Swelling (%)	Formaldehyde Content (mg/100g)
0	28.45[1)] (2.561)[2)]	29.73 (2.768)	82.71 (7.100)	89.77 (8.456)	19.28 (2.147)	10.16
A_1	37.03 (4.226)	38.82 (4.050)	92.47 (7.053)	97.75 (7.398)	24.82 (2.811)	3.95
B_1	38.89 (2.861)	40.79 (3.019)	95.43 (5.801)	101.45 (6.110)	25.32 (2.413)	2.70
C_1	42.10 (2.941)	44.17 (3.143)	101.33 (5.463)	110.81 (5.768)	28.05 (2.443)	1.61
C_1'	26.18 (0.025)	27.09 (0.026)	78.97 (0.060)	83.42 (0.062)	17.49 (0.021)	10.26
D_1	37.20 (4.125)	38.78 (4.280)	95.08 (7.858)	101.96 (14.279)	24.11 (3.016)	2.78
A_2	39.21 (3.343)	40.48 (3.671)	93.76 (6.323)	98.90 (6.974)	23.79 (2.870)	1.60
B_2	39.87 (2.959)	41.80 (3.042)	96.01 (5.070)	101.88 (5.374)	24.72 (2.397)	2.31
C_2	59.11 (4.847)	61.21 (4.754)	119.61 (4.933)	125.56 (10.363)	41.10 (3.707)	2.11
D_2	47.62 (3.888)	48.83 (3.973)	105.44 (7.941)	113.90 (9.097)	29.42 (3.166)	1.75
n[3)]	20	20	20	20	20	2

[1)]: mean value
[2)]: standard deviation
[3)]: number of specimens

As a result of hydrothermal treatment, the recovered particles, and thus the recycled boards, obtained a darker colour, the darkness of which depended on the temperature and the duration of treatment.

CONCLUSIONS

Particleboards produced from steam-recovered wood particles showed a quality (with the exception of the modulus of elasticity in static bending and formaldehyde content) inferior to that of particleboards made from original particles (control). The 2nd recycling process caused further quality degradation in the boards compared with the 1st recycling. Among the four hydrothermal treatments applied for particle recovery, the treatment of 6 bar/156°C/45min resulted in the strongest degree of deterioration in quality in the recycled boards.

Regarding the exploitation of the above results, the recycling methodology presented in this work can be applied in industry using mixtures of recovered and fresh wood particles in such proportions as to avoid a significant deterioration in the quality of the board. The degree of degradation in quality of the recycled particleboards can be significantly reduced by using milder conditions during hydrothermal treatments for particle recovery.

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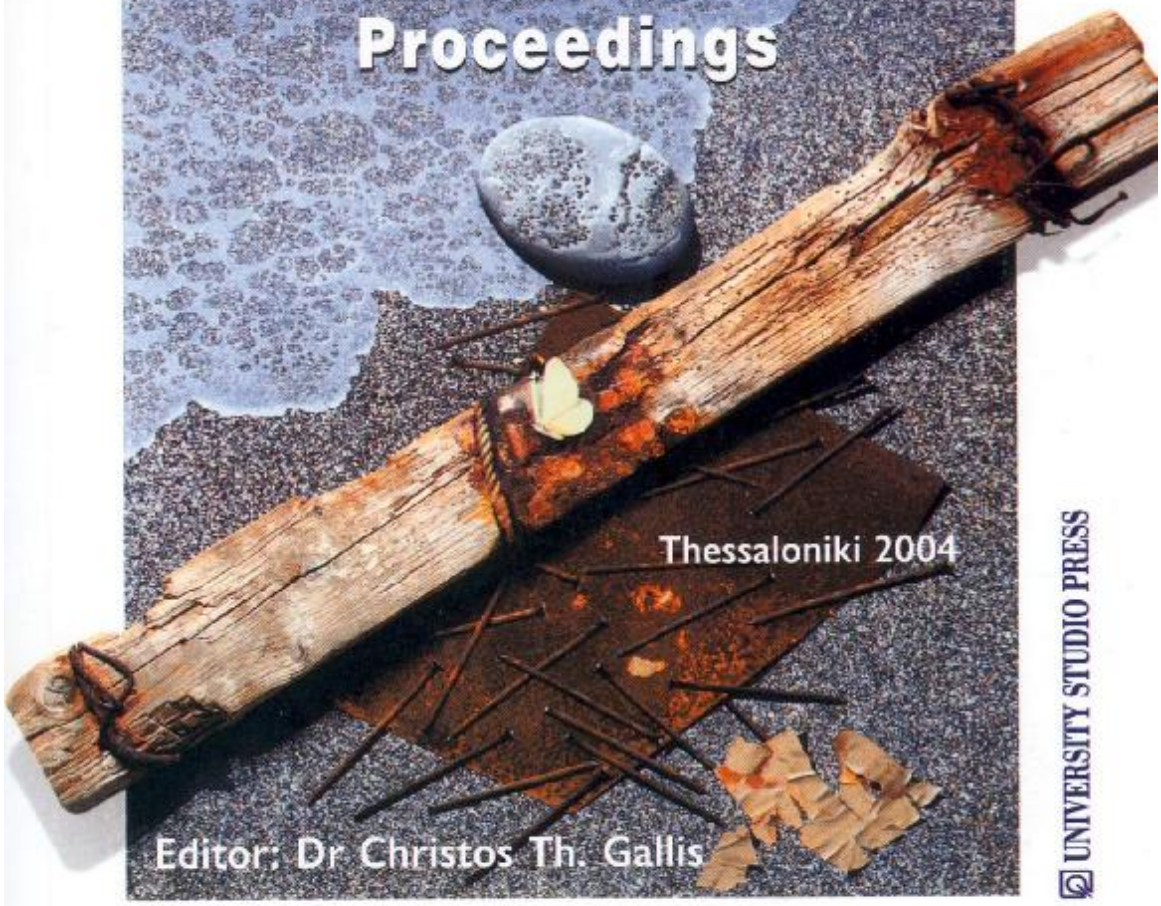

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