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(54) **COMPOSITE LIGHT WEIGHT GYPSUM WALLBOARD**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,500,452	A	*	7/1924	Haggerty	428/337
1,702,729	A	*	2/1929	Hite	106/779
1,769,519	A		7/1930	King	
1,868,671	A		7/1932	Nelson	
1,937,472	A		11/1933	Ericson	
1,953,589	A		4/1934	Camp	
1,971,900	A		8/1934	Cerveny et al.	
2,078,199	A		4/1937	King	
2,083,961	A		6/1937	New	
2,207,339	A		7/1940	Camp	
2,213,603	A		9/1940	Young et al.	
2,322,194	A	*	6/1943	King	106/646
2,340,535	A		2/1944	Jenkins	
2,342,574	A		2/1944	Denning	
2,388,543	A		11/1945	Hoggatt	
2,516,632	A		6/1950	Kesler et al.	
2,526,066	A		10/1950	Croce	
2,698,818	A		1/1955	Staerkle et al.	
2,733,238	A		1/1956	Kerr et al.	
2,744,022	A		5/1956	Croce	
2,803,575	A	*	8/1957	Riddell et al.	428/312.4
2,845,417	A		7/1958	Kesler et al.	
2,853,394	A		9/1958	Riddell et al.	
2,871,146	A		1/1959	Etheridge	
2,884,413	A		4/1959	Kerr et al.	
3,179,529	A		4/1965	Hikey et al.	
3,260,027	A		7/1966	Page et al.	
3,359,146	A		12/1967	Lane et al.	
3,382,636	A		5/1968	Green	
3,423,238	A		1/1969	Weiland	
3,454,456	A		7/1969	Willey	
3,459,571	A		8/1969	Shannon	
3,513,009	A	*	5/1970	Austin et al.	427/277
3,573,947	A	*	4/1971	Kinkade	106/779
3,649,319	A		3/1972	Smith	
3,666,581	A		5/1972	Lane	
3,674,726	A		7/1972	Kirk	
3,719,513	A		3/1973	Bragg et al.	
3,741,929	A		6/1973	Burton	
3,797,758	A		3/1974	Cherdron	
3,830,687	A		8/1974	Re et al.	
3,847,630	A		11/1974	Compernass et al.	
3,908,062	A		9/1975	Roberts	
3,913,571	A		10/1975	Bayer et al.	
3,944,698	A	*	3/1976	Dierks et al.	428/219
3,957,715	A		5/1976	Lirones et al.	
3,981,831	A		9/1976	Markusch et al.	
3,988,199	A		10/1976	Hillmer et al.	
3,989,534	A		11/1976	Plunguian et al.	
3,993,822	A	*	11/1976	Knauf et al.	428/213
4,009,062	A		2/1977	Long	

(Continued)

FOREIGN PATENT DOCUMENTS

AT	406048		1/2000
AU	486746	*	11/1975

(Continued)

OTHER PUBLICATIONS

"Standard Test Method for Physical Testing of Gypsum Panel Products", Annual Book of ASTM Standards, Designations: C 473-97, vol. 0401 1998, pp. 253-264.*

U.S. Appl. No. 08/916,058, filed Aug. 21, 1997, Yu.

U.S. Appl. No. 11/267,125, filed Nov. 4, 2005, Baig.

Camp, T. F., "The Manufacture of Gypsum Board", Chapter III, Section II, The Manufacture and Technology of Gypsum Products, Dec. 22, 1950.

GEO Specialty Chemicals, Aero Technology, Jan. 14, 2002, two pages.

Grace Specialty Vermiculite, "VCX Vermiculite Ore Concentrate", W.R. Grace & Co., Conn. USA (2008).

(Continued)

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(57) **ABSTRACT**

The invention provides a light weight composite gypsum board including a foamed low density set gypsum core, a top non-foamed (or reduced-foamed) bonding high density layer and a bottom non-foamed (or reduced-foamed) bonding high density layer, a top cover sheet bonded to the foamed low density set gypsum core by the top non-foamed (or reduced-foamed) bonding high density layer, and a bottom cover sheet bonded to the foamed low density set gypsum core by the bottom non-foamed (or reduced-foamed) bonding high density layer. The foamed low density set gypsum core is prepared having a density of less than about 30 pcf using soap foam in the gypsum-containing slurry. The combination of components provide a composite gypsum board having light weight and high strength.

65 Claims, No Drawings

U.S. PATENT DOCUMENTS

4,011,392 A 3/1977 Rudolph et al.
4,019,920 A 4/1977 Burkard et al.
4,021,257 A 5/1977 Bernett
4,051,291 A 9/1977 Long
4,061,611 A 12/1977 Glowaky et al.
4,065,413 A 12/1977 MacInnis et al.
4,073,658 A 2/1978 Ohtani et al.
4,097,423 A 6/1978 Dieterich
4,133,784 A 1/1979 Otey et al.
4,159,302 A 6/1979 Greve et al.
4,174,230 A 11/1979 Hashimoto et al.
4,184,887 A * 1/1980 Lange et al. 106/781
4,190,547 A 2/1980 Mahnke et al.
4,195,110 A * 3/1980 Dierks et al. 428/218
4,233,368 A * 11/1980 Baehr et al. 428/187
4,234,345 A 11/1980 Fassle
4,237,260 A * 12/1980 Lange et al. 528/230
4,265,979 A * 5/1981 Baehr et al. 428/171
4,309,391 A 1/1982 O'Neill
4,311,554 A 1/1982 Herr
4,327,146 A * 4/1982 White 428/308.8
4,328,178 A 5/1982 Kossatz
4,392,896 A * 7/1983 Sakakibara 156/39
4,394,411 A 7/1983 Krull et al.
4,451,649 A 5/1984 Teubner et al.
4,487,864 A 12/1984 Bermudez et al.
4,518,652 A 5/1985 Willoughby
4,533,528 A 8/1985 Zascalicky
4,613,627 A 9/1986 Sherman et al.
4,618,642 A 10/1986 Schoenherr
4,624,574 A 11/1986 Mills et al.
4,640,864 A 2/1987 Porter
4,659,385 A 4/1987 Costopoulos et al.
4,725,477 A 2/1988 Kole et al.
4,748,771 A 6/1988 Lehnert et al.
4,753,977 A 6/1988 Merrill
4,837,314 A 6/1989 Eastman
4,842,786 A 6/1989 Betzner
4,853,085 A 8/1989 Johnstone et al.
4,939,192 A 7/1990 T'sas
4,965,031 A 10/1990 Conroy
4,966,739 A 10/1990 Stipek et al.
5,037,929 A 8/1991 Rajagopalan et al.
5,085,929 A * 2/1992 Bruce et al. 428/309.9
5,093,093 A 3/1992 Koslowski
5,114,617 A 5/1992 Smetana et al.
5,116,671 A 5/1992 Bruce et al.
5,120,355 A 6/1992 Imai
5,135,805 A 8/1992 Sellers et al.
5,154,874 A 10/1992 Koslowski
5,207,830 A 5/1993 Cowan et al.
5,227,100 A 7/1993 Koslowski et al.
5,256,222 A 10/1993 Shepherd et al.
5,294,255 A 3/1994 Smetana et al.
5,302,308 A 4/1994 Roe
5,342,566 A 8/1994 Schafer et al.
5,385,607 A 1/1995 Kiesewetter et al.
5,395,438 A 3/1995 Baig et al.
5,401,588 A 3/1995 Garvey et al.
5,449,533 A 9/1995 Morizane
5,534,059 A 7/1996 Immordino, Jr.
5,542,358 A 8/1996 Breslauer
5,558,710 A 9/1996 Baig
5,573,333 A 11/1996 Dahlman
5,575,840 A 11/1996 DeWacker
5,575,844 A * 11/1996 Bradshaw 106/680
5,595,595 A 1/1997 Glenn
5,643,510 A * 7/1997 Sucech 264/40.1
5,660,465 A 8/1997 Mason
5,683,625 A 11/1997 Berthiaume et al.
5,683,635 A 11/1997 Sucech et al.
5,718,758 A 2/1998 Breslauer
5,733,367 A 3/1998 Soeda et al.
5,746,822 A 5/1998 Espinoza et al.
5,798,010 A 8/1998 Richards et al.
5,798,425 A 8/1998 Albrecht et al.
5,810,956 A 9/1998 Tanis et al.
5,817,262 A 10/1998 Englert
5,876,563 A 3/1999 Greenwood
5,879,825 A 3/1999 Burke et al.
5,911,818 A 6/1999 Baig
5,922,447 A * 7/1999 Baig 428/292.7
5,962,119 A * 10/1999 Chan 428/312.4
6,051,700 A 4/2000 Wang
6,054,088 A 4/2000 Alhamad
6,059,444 A 5/2000 Johnson et al.
6,102,995 A 8/2000 Hutchings et al.
6,110,271 A 8/2000 Skaggs et al.
6,110,575 A * 8/2000 Haga 428/294.7
6,162,288 A 12/2000 Kindt et al.
6,162,839 A 12/2000 Klauck et al.
6,171,388 B1 * 1/2001 Jobbins 106/778
6,221,521 B1 4/2001 Lynn et al.
6,227,186 B1 5/2001 Seidl et al.
6,228,497 B1 5/2001 Dombeck
6,228,914 B1 5/2001 Ford et al.
6,231,970 B1 5/2001 Anderson et al.
6,241,815 B1 6/2001 Bonen
6,290,769 B1 9/2001 Carkner
6,299,970 B1 10/2001 Richards et al.
6,309,740 B1 10/2001 Shu et al.
6,319,312 B1 11/2001 Luongo
6,340,388 B1 * 1/2002 Luongo 106/675
6,340,389 B1 1/2002 Klus
6,342,284 B1 * 1/2002 Yu et al. 428/70
6,387,171 B1 5/2002 Taylor et al.
6,387,172 B1 * 5/2002 Yu et al. 106/680
6,391,958 B1 * 5/2002 Luongo 524/423
6,398,864 B1 6/2002 Przybysz et al.
6,406,535 B1 6/2002 Shintome
6,406,537 B1 * 6/2002 Immordino 106/778
6,409,819 B1 6/2002 Ko
6,409,824 B1 * 6/2002 Veeramasuneni et al. 106/772
6,409,825 B1 * 6/2002 Yu et al. 106/776
6,443,258 B1 * 9/2002 Putt et al. 181/294
6,475,313 B1 11/2002 Peterson et al.
6,481,171 B2 11/2002 Yu et al.
6,485,821 B1 * 11/2002 Bruce et al. 428/304.4
6,524,679 B2 * 2/2003 Hauber et al. 428/68
6,533,854 B2 3/2003 Kesselring et al.
6,569,541 B1 5/2003 Martin et al.
6,613,424 B1 * 9/2003 Putt et al. 428/312.4
6,632,550 B1 * 10/2003 Yu et al. 428/703
6,641,658 B1 11/2003 Dubey
6,673,144 B2 1/2004 Immordino, Jr. et al.
6,680,127 B2 1/2004 Capps
6,706,112 B2 3/2004 Sironi et al.
6,706,128 B2 3/2004 Sethuraman
6,711,872 B2 3/2004 Anderson
6,743,830 B2 * 6/2004 Soane et al. 521/83
6,746,781 B2 * 6/2004 Francis et al. 428/537.5
6,773,639 B2 8/2004 Moyes et al.
6,774,146 B2 8/2004 Savoly et al.
6,777,517 B1 8/2004 Albrecht et al.
6,780,356 B1 * 8/2004 Putt et al. 264/42
6,780,903 B2 8/2004 Peltonen et al.
6,783,587 B2 * 8/2004 Sethuraman et al. 106/674
6,800,131 B2 * 10/2004 Yu et al. 106/772
6,814,799 B2 11/2004 Sasage et al.
6,822,033 B2 11/2004 Yu et al.
6,831,118 B2 12/2004 Munzenberger
6,832,652 B1 12/2004 Dillenbeck et al.
6,841,232 B2 * 1/2005 Tagge et al. 428/304.4
6,846,357 B2 1/2005 Reddy et al.
6,869,474 B2 3/2005 Perez-Pena et al.
6,878,321 B2 4/2005 Hauber et al.
6,893,752 B2 5/2005 Veeramasuneni et al.
6,902,797 B2 6/2005 Pollock et al.
6,964,704 B2 11/2005 Cox et al.
6,983,821 B2 1/2006 Putt et al.
7,048,794 B2 5/2006 Tagge et al.
7,056,582 B2 6/2006 Carbo et al.
7,090,883 B2 8/2006 Phipps
7,101,426 B2 9/2006 Tagge et al.
7,105,587 B2 9/2006 Tagge et al.
7,172,403 B2 2/2007 Burke
7,217,754 B2 5/2007 Koloski et al.

7,244,304	B2	7/2007	Yu et al.
7,285,586	B2	10/2007	Helbling et al.
7,347,895	B2	3/2008	Dubey
7,381,261	B1	6/2008	Nelson
7,413,603	B2	8/2008	Miller et al.
7,422,638	B2	9/2008	Trksak et al.
7,425,236	B2	9/2008	Yu et al.
7,455,728	B2	11/2008	Losch et al.
7,524,386	B2	4/2009	George et al.
7,544,242	B2	6/2009	Liu et al.
7,572,328	B2	8/2009	Lettkeman et al.
7,572,329	B2	8/2009	Liu et al.
7,608,347	B2	10/2009	Lettkeman et al.
7,637,996	B2	12/2009	Blackburn et al.
7,644,548	B2	1/2010	Guevara et al.
7,731,794	B2	6/2010	Yu et al.
7,736,431	B2	6/2010	Bui
7,754,006	B2	7/2010	Liu et al.
7,758,980	B2	7/2010	Yu et al.
7,767,019	B2	8/2010	Liu et al.
7,771,851	B2	8/2010	Song et al.
7,776,462	B2	8/2010	Liu et al.
7,803,226	B2	9/2010	Wang et al.
7,811,685	B2	10/2010	Wang et al.
7,819,993	B2	10/2010	Seki et al.
7,849,648	B2	12/2010	Tonyan et al.
7,849,649	B2	12/2010	Tonyan et al.
7,849,650	B2	12/2010	Tonyan et al.
7,851,057	B2	12/2010	Englert et al.
7,892,472	B2	2/2011	Veeramasuneni et al.
7,932,193	B2	4/2011	Kajander
7,935,223	B2	5/2011	Cao et al.
7,964,034	B2	6/2011	Yu et al.
8,133,357	B2	3/2012	Cao et al.
8,142,914	B2	3/2012	Yu et al.
8,197,952	B2	6/2012	Yu et al.
2001/0001218	A1	5/2001	Luongo
2002/0017222	A1	2/2002	Luongo
2002/0096278	A1	7/2002	Foster et al.
2002/0112651	A1	8/2002	Yu et al.
2003/0019176	A1	1/2003	Anderson
2003/0084980	A1	5/2003	Seufert et al.
2003/0092784	A1	5/2003	Tagge et al.
2003/0138614	A1	7/2003	Leclercq
2003/0150360	A1	8/2003	Huntsman et al.
2003/0175478	A1	9/2003	Leclercq
2004/0005484	A1	1/2004	Veeramasuneni et al.
2004/0026002	A1	2/2004	Weldon et al.
2004/0045481	A1	3/2004	Sethuraman et al.
2004/0055720	A1	3/2004	Torras, Sr. et al.
2004/0065232	A1	4/2004	Lykke
2004/0092190	A1	5/2004	Bruce et al.
2004/0092625	A1	5/2004	Pollock et al.
2004/0107872	A1	6/2004	Matsuyama et al.
2004/0121152	A1	6/2004	Toas
2004/0131714	A1	7/2004	Burke
2004/0149170	A1	8/2004	Moran
2004/0152379	A1	8/2004	McLarty, III et al.
2004/0231916	A1	11/2004	Englert et al.
2004/0242861	A1	12/2004	Kightlinger et al.
2004/0244646	A1	12/2004	Larsen et al.
2005/0019618	A1	1/2005	Yu et al.
2005/0126437	A1	6/2005	Tagge et al.
2005/0142348	A1	6/2005	Kajander et al.
2005/0150427	A1	7/2005	Liu et al.
2005/0181693	A1	8/2005	Kajander
2005/0191465	A1	9/2005	Mayers et al.
2005/0223949	A1	10/2005	Bailey, Jr. et al.
2005/0241541	A1	11/2005	Hohn et al.
2005/0250888	A1	11/2005	Lettkeman et al.
2005/0263925	A1	12/2005	Heseltine et al.
2005/0266225	A1	12/2005	Currier et al.
2005/0281999	A1	12/2005	Hoffmann et al.
2006/0029785	A1	2/2006	Wang et al.
2006/0054060	A1	3/2006	Dubey
2006/0090674	A1	5/2006	Fukuda et al.
2006/0150868	A1	7/2006	Spickemann et al.
2006/0162839	A1	7/2006	Seki et al.
2006/0278127	A1	12/2006	Liu et al.
2006/0278128	A1	12/2006	Liu et al.
2006/0278129	A1	12/2006	Liu et al.
2006/0278132	A1	12/2006	Yu et al.
2006/0278133	A1	12/2006	Yu et al.
2006/0280898	A1	12/2006	Lettkeman et al.
2006/0280899	A1	12/2006	Liu et al.
2007/0022913	A1	2/2007	Wang et al.
2007/0032393	A1	2/2007	Patel et al.
2007/0048490	A1	3/2007	Yu et al.
2007/0056478	A1	3/2007	Miller et al.
2007/0082170	A1	4/2007	Colbert et al.
2007/0102237	A1	5/2007	Baig
2007/0221098	A1	9/2007	Wolbers et al.
2007/0251628	A1	11/2007	Yu
2007/0255032	A1	11/2007	Bichler et al.
2008/0000392	A1	1/2008	Blackburn et al.
2008/0066651	A1	3/2008	Park
2008/0070026	A1	3/2008	Yu et al.
2008/0087366	A1	4/2008	Yu et al.
2008/0090068	A1	4/2008	Yu
2008/0148997	A1	6/2008	Blackburn et al.
2008/0152945	A1	6/2008	Miller et al.
2008/0190062	A1	8/2008	Engbrecht et al.
2008/0202415	A1	8/2008	Miller et al.
2008/0227891	A1	9/2008	Jarvie et al.
2008/0299413	A1	12/2008	Song et al.
2008/0308968	A1	12/2008	Immordino, Jr.
2009/0010093	A1	1/2009	Sethuraman et al.
2009/0011207	A1	1/2009	Dubey
2009/0038248	A1	2/2009	Koslowski
2009/0053544	A1	2/2009	Sethuraman
2009/0123727	A1	5/2009	Martin et al.
2009/0126300	A1	5/2009	Fujiwara et al.
2009/0130452	A1	5/2009	Surace et al.
2009/0151602	A1	6/2009	Francis
2009/0169864	A1	7/2009	Wang et al.
2009/0169878	A1	7/2009	Rigaudon et al.
2009/0252941	A1	10/2009	Mueller et al.
2009/0253323	A1	10/2009	Mueller et al.
2010/0031853	A1	2/2010	Visocekas et al.
2010/0088984	A1	4/2010	Guevara et al.
2010/0136269	A1	6/2010	Andersen et al.
2010/0139528	A1	6/2010	Yu et al.
2010/0143682	A1	6/2010	Shake et al.
2010/0221402	A1	9/2010	Wang et al.
2010/0247937	A1	9/2010	Liu et al.
2010/0291305	A1	11/2010	Wittbold et al.
2011/0009564	A1	1/2011	Wang et al.
2011/0054053	A1	3/2011	Lee et al.
2011/0132235	A1	6/2011	Yu et al.
2011/0195241	A1	8/2011	Yu et al.

FOREIGN PATENT DOCUMENTS

CN	1238312		12/1999
CN	1396138		2/2003
DE	4316518		11/1994
EP	216497		4/1987
EP	335405		10/1989
EP	409781	A2	1/1991
EP	955277	A1	11/1999
EP	1008568		6/2000
FR	2673620		9/1992
GB	941399	A	11/1963
GB	1028890		5/1966
GB	1250713		10/1971
GB	1381457	A	1/1975
GB	1504929	A	3/1978
GB	2053779	A	2/1981
JP	05-293350	A	11/1993
JP	08-231258	A	9/1996
JP	09-165244	A	6/1997
JP	2001-504795		4/2001
JP	2003-020262	A	1/2003
KR	1020060123582		10/2006
NO	126524		2/1973
RU	2215708	C2	11/2003
SU	885178	A	11/1981
SU	887506	A	12/1981
UA	27041	C1	2/2000

UA	52047	A	12/2002
UA	88764	C2	11/2009
WO	WO 95/31415	A1	11/1995
WO	WO 99/08978	A1	2/1999
WO	WO 99/08979	A1	2/1999
WO	WO 00/06518		2/2000
WO	WO 01/34534	A2	5/2001
WO	WO 01/45932	A1	6/2001
WO	WO 01/81263	A1	11/2001
WO	WO 01/81264		11/2001
WO	WO 03/000620	A1	1/2003
WO	WO 03/040055	A1	5/2003
WO	WO 03/053878	A1	7/2003
WO	WO 03/082766	A1	10/2003
WO	WO 2004/002916	A1	1/2004
WO	WO 2004/033581	A1	4/2004
WO	WO 2004/039749	A1	5/2004
WO	WO 2004/061042	A1	7/2004
WO	WO 2004/083146	A2	9/2004
WO	WO 2005/080294	A1	9/2005
WO	WO 2006/071116	A1	7/2006
WO	WO 2006/135613	A2	12/2006
WO	WO 2006/135707		12/2006
WO	WO 2006/138273	A2	12/2006
WO	WO 2007/024420	A2	3/2007

OTHER PUBLICATIONS

Grace Specialty Vermiculite, "Zonolite #3 Agricultural/Horticultural Vermiculite" W.R. Grace & Co., Conn. USA (1999).

Grodzka, P. et al.; On the Development of Heat Storage Building Materials; Conf-820814--23; DE82 020814; Library of Congress Newspaper RM (Aug. 1, 1982).

Hannant, D.J. et al.; Polyolefin Fibrous Networks in Cement Matrices for Low Cost Sheeting; Phil. Trans. R. Soc. Land; 1980; pp. 591-597; A 294; Civil Engineering Department Univ. of Surrey, Guildford, Surrey GU2 5XH, U.K.

K.F.Mikhaylov—Manual for manufacturing prefabricated reinforced concrete articles, Moscow, Stroyizdat, 1982, pp. 42,44.

Karni, J.; Thin Gypsum Panels; Materiaux et Constructions; 1980; pp. 383-389; vol. 13, No. 77; Bordas-Dunod; Israel.

Ockerman, Food Science Sourcebook, Second Edition, Part 1, Terms and Descriptions, pp. 477, 595, 722, New York, NY (1991).

Potter, Michael J., "Vermiculite" US Geological Survey Minerals Yearbook-2001, 5 total pages (p. 82.1-82.3 and two pages of tables) (2001).

Ratinov, V.B. et al. Dobavki v beton (Concrete Admixtures), in Russian, ISBN 5274005667 / 9785274005661 / 5-274-00566-7, Moscow, Stroyizdat, 1989, pp. 20, 21, 105-110.

Salyer, et al., "Utilization of Bagasse in New Composite Building Materials", Ind. Eng. Chem. Prod. Res. Dev. 1982; pp. 17-23; 21; Center for Basic and Applied Polymer Research, Univ. of Dayton, OH 45469.

Van Wazer, *Phosphorus and Its Compounds*, vol. 1, Interscience Publishers, Inc., New York (1958), pp. 419-427 and pp. 6799-6795.

Virginia Vermiculite LLC, "Grade No. 4 Vermiculite Concentrate", VA, USA (Jan. 2008).

Virginia Vermiculite LLC, "Grade No. 45 Vermiculite Concentrate", VA, USA (Jan. 2008).

Weber, Charles, G., "Fiber Building Boards Their Manufacture and Use", Industrial and Engineering Chemistry; Aug. 1935; 27 (8): 896-898; National Bureau of Standards, Washington, D.C.

Blaine, "Accelerating the hydration of calcium sulfate hemihydrate via high energy mixing," Materials and Structures, Jul. 1997, 30:362-365.

Card, J.: "Production of Lightweight Wallboard", Global Gypsum, Mar. 1999, p. 17.

Englert, et al., "Properties of Gypsum Fiberboard Made by the USG Process", Proceedings of the 4th International Inorganic-Bonded Wood & Fiber Composite Materials Conference, Sep. 25-28, 1994, Spokane, WA, A.A. Moslemi ed., 1995, 4:52-58.

Henein, The Development of a Novel Foam Batching and Generating System, Jun. 1977, Masters Thesis, Concordia University, Montreal, Quebec, Canada.

Miller, et al., "Commercial Scale-Up Experience with USG's Gypsum Fiberboard Process", Proceedings of the 7th International Inorganic-Bonded Wood & Fiber Composite Materials Conference, Sun Valley, ID, A.A. Moslemi ed., 2000, 7:337-355.

Miller, et al., "Development and Scale-Up of USG's Gypsum Fiberboard Technology", Proceedings of the 6th International Inorganic-Bonded Wood & Fiber Composite Materials Conference, Sun Valley, ID, A.A. Moslemi, ed., 1998, 6:4-12.

Miller, et al., "USG Process for Manufacturing Fiber Composite Panels", International Cement Review, Nov. 1995, pp. 41-42.

Miller, et al., "USG Process for Manufacturing Gypsum Fiber Composite Panels" Proceedings of the 4th International Inorganic-Bonded Wood & Fiber Composite Materials Conference, Sep. 25-28, 1994, Spokane, WA, A.A. Moslemi ed., 1995, 4:47-51.

Olson, G,B.: "Computational Design of Hierarchically Structured Materials", Science, vol. 277, p. 1237 (1997).

Burrows, "A Decade's Experience of Gypsum Board Weight Reduction in the U.S.", 14. Internationale Baustofftagung (Weimar, Sep. 20-23, 2000), 1.01971-1.0207.

Peterson, Kurt, "Engineered Gypsum Panels, the Development and Application of Densified Zones at the Paper/Core Interface of Gypsum Panels", Proceedings of Gypsum 2000, 6th International Conference on Natural and Synthetic Gypsum, Toronto, Canada, May 2000, pp. 9-1-9-16.

Allen, "Computed Tomography of the Antikythera Mechanism," Abstracts of Sin World Congress on Industrial Process Tomography, Bergen, Norway, Abstract No. P04, p. 88 (Sep. 6, 2007).

Alme et al., "3D Reconstruction of 10000 Particle Trajectories in Real-time" Abstracts of Sth World Congress on Industrial Process Tomography, Bergen, Norway, Abstract No. VIAOS, p. 91 (Sep. 6, 2007).

AZom.com, AZO Materials Particle Size—US Sieve Series and Tyler Mesh Size Equivalents, obtained from the internet at http://www.azom.com/Details.asp?ArticleID=1417 on Jan. 21, 2011; Date added: May 15, 2002.

Banasiak et al., "Application of Charge Simulation Method (CSM) for ECT Imaging in Forward Problem and Sensitivity Matrix Calculation" Abstracts of Sth World Congress on Industrial Process Tomography, Bergen, No~ay, Abstract No. VIA02, p. 89 (Sep. 6, 2007).

Janaszewski et al., Adaptive 3D Algorithm to Detect Bridging Ligaments during Intergranular Stress Corrosion Cracking of Stainless Steel Abstracts of Sth World Congress on Industrial Process Tomography, Bergen, Norway, Abstract No. VIA03, p. 90 (Sep. 6, 2007).

Li et al., "Updating Sensitivity Maps in Landweber Iteration for Electrical Capacitance Tomography" Abstracts of Sth World Congress on Industrial Process Tomography, Bergen, Norway, Abstract No. VIA04, p. 90 (Sep. 6, 2007).

Lin et al., "Characterization and Analysis of Porous, Brittle Solid Structures by Micro CT" Abstracts of Sth World Congress on Industrial Process Tomography, Bergen, Norway, Paper No. VIA07, p. 92 (Sep. 6, 2007).

Maad et al., "Comparing Analysis of Image Visualisation Accuracy of Electrical Capacitance Tomography and Gamma Tomography" Abstracts of S World Congress on Industrial Process Tomography, Bergen, Norway, Abstract No. VIA01, p. 89 (Sep. 6, 2007).

Ship et al., "Thermophysical Characterization of Type X Special Fire Resistant Gypsum Board", Proceedings of the Fire and Materials 2011 Conference, San Francisco, Jan. 31- Feb. 2, 2011, Interscience Communications Ltr., London, UK, p. 417-426.

Standard Test Methods for Physical Testing of Gypsum Panel Products, Annual Book of ASTM Standards, Designations: C473-97, vol. 04.01 1998, pp. 253-264.

Ullmann's Encyclopedia of Industrial Chemistry, 5th Edition, vol. A4, "Calcium Sulfate" Wirsching, Franz, pp. 1, 15 (Dec. 20, 1985).

Videla, et al., "Watershed Functions Applied to a 3D Segmentation Problem for the Analysis of Packed Particle Beds", Part. Part. Syst. Charact. 23 (2006) 237-245, . DOI:10.1002/ppsc.200601055, Weinheim.

Xiong et al., "Wavelet Enhanced Visualisation and Solids Distribution in the Top of Circulating Fluidized Beds" Abstracts of Sth World Congress on Industrial Process Tomography, Bergen, Norway, Abstract No. VIA06, p. 91 (Sep. 6, 2007).

U.S. Appl. No. 60/688,839, filed Jun. 9, 2005.

U.S. Appl. No. 11/445,906, filed Jun. 2, 2006.
U.S. Appl. No. 11/449,177, filed Jun. 7, 2006.
U.S. Appl. No. 12/795,125, filed Jun. 7, 2010.
U.S. Appl. No. 11/592,481, filed Nov. 2, 2006.
U.S. Appl. No. 11/537,395, filed Sep. 29, 2006.
U.S. Appl. No. 11/906,479, filed Oct. 2, 2007.
U.S. Appl. No. 11/932,211, filed Oct. 31, 2007.
U.S. Appl. No. 13/035,800, filed Feb. 25, 2011.
U.S. Appl. No. 61/446,941, filed Feb. 25, 2011.
U.S. Appl. No. 13/493,941, filed Jun. 11, 2012.
U.S. Appl. No. 12/709,159, filed Feb. 19, 2010.
U.S. Appl. No. 13/400,010, filed Feb. 17, 2012.
Dilofo® GW Products Bulletin, "Polynaphthalene Sulfonate, Sodium Salt", GEO Speciality Chemicals, Horsham, PA (Nov. 1999).
Hyonic® PFM33 Products Bulletin, "Zero VOC Foaming Agent for Gypsum Wallboard", GEO Speciality Chemicals, Horsham, PA (Jul. 2000).
U.S. Appl. No. 11/592,481, filed Nov. 2, 2006, Yu et al.

* cited by examiner

COMPOSITE LIGHT WEIGHT GYPSUM WALLBOARD

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This application is a continuation-in-part of U.S. patent application Ser. No. 11/449,177, filed Jun. 7, 2006 *now U.S. Pat. No. 7,731,794*, and is a continuation-in-part of U.S. patent application Ser. No. 11/445,906, filed Jun. 2, 2006 *now abandoned*, each one of which claims the benefit of U.S. Provisional Application No. 60/688,839, filed Jun. 9, 2005. The entire disclosures of each of the foregoing patent applications are hereby incorporated by reference.

FIELD OF THE INVENTION

This invention pertains to unique light weight composite gypsum boards having high strength. It also pertains to a method of making such light weight composite gypsum boards using a unique gypsum-containing slurry to form a foamed low density set gypsum core and non-foamed (or reduced-foamed) bonding high density layers that bond the top and bottom cover sheets to the core.

BACKGROUND OF THE INVENTION

Certain properties of gypsum (calcium sulfate dihydrate) make it very popular for use in making industrial and building products, such as gypsum wallboard. Gypsum is a plentiful and generally inexpensive raw material which, through a process of dehydration and rehydration, can be cast, molded or otherwise formed into useful shapes. The base material from which gypsum wallboard and other gypsum products are manufactured is the hemihydrate form of calcium sulfate ($CaSO_4.½H_2O$), commonly termed "stucco," which is produced by heat conversion of the dihydrate form of calcium sulfate ($CaSO_4.2H_2O$), from which 1-½ water molecules been removed.

Conventional gypsum-containing products such as gypsum wallboard have many advantages, such as low cost and easy workability. Various improvements have been achieved in making gypsum-containing products using starches as ingredients in the slurries used to make such products. Pregelatinized starch, for example, can increase flexural strength and compressive strength of gypsum-containing products including gypsum wallboard. Known gypsum wall board contains board starch at levels of less than about 10 lbs/MSF.

It is also necessary to use substantial amounts of water in gypsum slurries containing pregelatinized starch in order ensure proper flowability of the slurry. Unfortunately, most of this water must eventually be driven off by drying, which is expensive due to the high cost of the fuels used in the drying process. The drying step is also time-consuming. It has been found that the use of naphthalenesulfonate dispersants can increase the fluidity of the slurries, thus overcoming the water demand problem. In addition, it has also been found that the naphthalenesulfonate dispersants, if the usage level is high enough, can cross-link to the pregelatinized starch to bind the gypsum crystals together after drying, thus increasing dry strength of the gypsum composite. Trimetaphosphate salts have not in the past been recognized to affect gypsum slurry water requirements. However, the present inventors have discovered that increasing the level of the trimetaphosphate salt to hitherto unknown levels in the presence of a specific disperant makes it possible to achieve proper slurry flowability with unexpectedly reduced amounts of water, even in the presence of high starch levels. This, of course, is highly desirable because it in turn reduces fuel usage for drying as well as the process time associated with subsequent water removal process steps. Thus the present inventors have also discovered that the dry strength of gypsum board can be increased by using a naphthalenesulfonate disperant in combination with pregelatinized starch in the slurry used to make the wallboard.

Conventional gypsum wallboards have adequate strength for working, and meet standard test requirements such as nail pull (77 lb) and core hardness (11 lb). However, conventional wallboards are heavy, typically weighing up to 1600-1700 lb/MSF. If a way could be fund to produce a high strength gypsum wall board in which board weight (and density) is significantly reduced, without adversely affecting nail pull and hardness characteristics, this would represent a useful contribution to the art.

It is also known in making gypsum wallboard that bonding layers can be used to promote adherence or bonding of the paper cover sheets to the set gypsum core. Typically, these bonding layers are relatively thick, ranging from about 7 mils to about 25 mils, even up to 50 mils. Thinner bonding layers would be expected to be more difficult to apply and to present other drawbacks. Unfortunately, the use of these thick bonding layers can decrease the core hardness in the finished wallboard. Finished densities in these dried bonding layers range from greater than about 70 pcf to about 90 pcf. The term "pcf" is defined as pounds per cubic foot (lb/ft^3). If a way could be found to make a low density set gypsum board using thinner, lighter bonding layers, without sacrificing core hardness or other important board properties, this would represent a useful contribution to the art.

BRIEF SUMMARY OF THE INVENTION

The invention generally comprises a light weight gypsum composite board including a foamed low density set gypsum core having a top surface and a bottom surface, the foamed low density set gypsum core made using a gypsum-containing slurry comprising stucco, and based on the weight of stucco, pregelatinized starch in an amount of about 0.5-10% by weight, a naphthalenesulfonate dispersant in an amount of about 0.1-3.0% by weight and sodium trimetaphosphate in an amount of about 0.12-0.4% by weight, the light weight gypsum composite board also including a top non-foamed (or reduced-foamed) bonding high density layer covering the top surface of the foamed low density set gypsum core, a bottom non-foamed (or reduced-foamed) bonding high density layer covering the bottom surface of the foamed low density set gypsum core, a top cover sheet, and a bottom cover sheet, wherein the top cover sheet is bonded to the foamed low density set gypsum core by the top non-foamed (or reduced-foamed) bonding high density layer, and the bottom cover sheet is bonded to the foamed low density set gypsum core by the bottom non-foamed (or reduced-foamed) bonding high density layer.

The top and bottom non-foamed (or reduced-foamed) bonding high density layers of the light weight gypsum composite board comprise from about 10% by weight to about 16% by weight of the total amount of the gypsum-containing slurry. In a preferred embodiment, the top non-foamed (or reduced-foamed) bonding high density layer covering the top surface of the foamed low density set gypsum core comprises about 6%-9% by weight of the total amount of the gypsum-containing slurry, and the bottom non-foamed (or reduced-foamed) bonding high density layer covering the bottom surface of the foamed low density set gypsum core comprising about 4%-6% by weight of the total amount of the gypsum-containing slurry.

DETAILED DESCRIPTION OF THE INVENTION

It has now unexpectedly been found that the preparation of a foamed low density set gypsum core using thinner, lighter top and bottom non-foamed (or reduced-foamed) bonding high density layers to attain good bonding of a heavy top (face) cover sheet and a bottom (back) cover sheet, can provide a composite gypsum board having nail pull resistance, core hardness, and board strength.

The composite gypsum board of the present invention includes a foamed low density set gypsum core having a top surface and a bottom surface, a top non-foamed (or reduced-foamed) bonding high density layer covering the top surface of the foamed low density set gypsum core, a top (or face) cover sheet having a foamed low density set gypsum core-facing surface, the top cover sheet bonded to the foamed low density set gypsum core by the top non-foamed (or reduced-foamed) bonding high density layer, a bottom non-foamed (or reduced-foamed) bonding high density layer covering the bottom surface of the foamed low density set gypsum core, and a bottom (or back) cover sheet having a foamed low density set gypsum core-facing surface, the bottom cover sheet bonded to the foamed low density set gypsum core by the bottom non-foamed (or reduced-foamed) bonding high density layer. Preferably the top cover sheet will be paper having a weight of about 60 lb/MSF (thickness about 18 mils). Additionally, the top (face) cover sheet and bottom (back) cover sheet are substantially parallel with respect to the foamed low density set gypsum core. The foamed low density set gypsum core is made from a foamed gypsum slurry containing stucco, and includes pregelatinized starch, and preferably a naphthalenesulfonate dispersant, and also preferably, sodium trimetaphosphate. The top and bottom non-foamed (or reduced-foamed) bonding high density layers can comprise from about 10% to about 16% of the of the total amount of gypsum slurry.

According to one embodiment of the present invention, there are provided finished composite gypsum board from gypsum-containing slurries containing stucco, pregelatinized starch, a naphthalenesulfonate disperant, and sodium trimetaphosphate. The naphthalenesulfonate disperant is present in an amount of about 0.1%-3.0% by weight based on the weight of dry stucco. The pregelatinized starch is present in an amount of at least about 0.5% by weight up to about 10% by weight based on the weight of dry stucco in the formulation. The sodium trimetaphosphate is present in an amount of about 0.12%-0.4% by weight based on the weight of dry stucco in the formulation. Other ingredients that may be used in the slurry include binders, paper fiber, glass fiber, and accelerators. A soap foam which introduces air voids is added to the newly formulated gypsum-containing slurries to help reduce the density of the foamed low density set gypsum core in the final gypsum-containing product, for example, gypsum wallboard or composite gypsum board.

The combination of from about 0.5% by weight up to about 10% by weight pregelatinized starch, from about 0.1% by weight up to about 3.0% by weight naphthalenesulfonate dispersant, and a minimum of at least about 0.12% by weight up to about 0.4% by weight of trimetaphosphate salt (all based on the weight of dry stucco used in the gypsum slurry) unexpectedly and significantly increases the fluidity of the gypsum slurry. This substantially reduces the amount of water required to produce a gypsum slurry with sufficient flowability to be used in making gypsum-containing products such as gypsum wall board. The level of trimetaphosphate salt, which is at least about twice that of standard formulations (as sodium trimetaphosphate), is believed to boost the dispersant activity of the naphthalenesulfonate dispersant.

The air voids can reduce the bonding strength between a foamed low density set gypsum core and the cover sheets. Since greater than half of the composite gypsum boards by volume may consist of voids due to foam, the foam can interfere with the bond between the foamed low density set gypsum core and the paper cover sheets. This is addressed by providing a non-foamed (or reduced-foamed) bonding high density layer on the gypsum core-contacting surfaces of both the top cover sheet and the bottom cover sheet prior to applying the cover sheets to the core. This non-foamed, or alternatively, reduced-foamed, bonding high density layer formulation typically will be the same as that of the gypsum slurry core formulation, except that either no soap will be added, or a substantially reduced amount of soap (foam) will be added. Optionally, in order to form this bonding layer, foam can be mechanically removed from the core formulation, or a different foam-free formulation can be applied at the foamed low density set gypsum core face paper interface.

Soap foam is required to introduce and to control the air (bubble) void sizes and distribution in the foamed set gypsum core, and to control the density of the foamed set gypsum core. A preferred range of soap in the set gypsum core is from about 0.2 lb/MSF to about 0.7 lb/MSF; a more preferred level of soap is about 0.3 lb/MSF to about 0.5 lb/MSF. Although preferably no soap will be used in the non-foamed bonding high density layers, if soap is used in reduced-foamed bonding high density layers, the amount will be about 5% by weight or less of the amount of soap to make the foamed low density set gypsum core.

The non-foamed or reduced-foamed, that is, high density portion of the gypsum-containing slurry used in the bonding layer will be from about 10-16% by weight of the (wet) slurry used in making the final board. In a preferred embodiment, 6-9% by weight of the slurry can be used as the top non-foamed (or reduced-foamed) bonding high density layer, and 4-7% by weight of the slurry can be used as the bottom non-foamed (or reduced-foamed) bonding high density layer. The presence of the top and bottom non-foamed (or reduced-foamed) bonding high density layers provides an improved bond between the top and bottom cover sheets and the foamed low density set gypsum core. The wet density of the non-foamed bonding high density layer can be about 80-85 pcf. The dry (finished) density of the non-foamed (or reduced-foamed) bonding high density layer can be about 45-70 pcf. Additionally, the thickness of the non-foamed (or reduced-foamed) bonding high density layers of the present invention will range from about 2 mils to less than 7 mils.

Preferred cover sheets may be made of paper as in conventional gypsum wallboard, although other useful cover sheet materials known in the art (e.g. fibrous glass mates) may be used. However, particular heavy paper cover sheets preferably will be used as top (face) cover sheets in the embodiments of the present invention. Useful cover sheet paper include Manila 7-ply and News-Line 5-ply, available from United States Gypsum Corporation, Chicago, Ill.; and Grey-Back 3-ply and Manila Ivory 3-ply, available from Caraustar, Newport, Ind. A preferred bottom cover sheet paper is 5-ply News-Line (e.g. 42-46 lb/MSF). A preferred top cover sheet paper is Manila 7-ply. A particularly preferred top cover sheet paper is heavy Manila paper (60 lb/MSF, thickness 18 mils), available from Caraustar, Newport, Indiana. Other heavy, thick paper will also be preferred, ranging in thickness from about 15-20 mils.

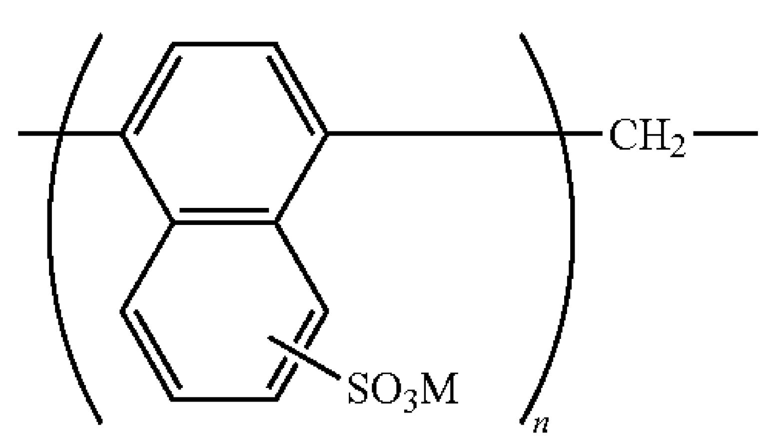
Fibrous mats may also be used as one or both of the cover sheets. Preferably the fibrous mats will be nonwoven glass fiber mats in which filaments of glass fiber are bonded together by an adhesive. Most preferably, the nonwoven glass fiber mats will have a heavy resin coating. For example, Duraglass nonwoven glass fiber mats, available from John-Manville, having a weight of about 1.5 lb/100 ft^2, with about 40-50% of the mat weight coming from the resin coating, could be used.

It is noted here that in manufacturing of conventional gypsum, wallboard, the top or face paper is laid down and moves along the production line first, and so constitutes what is known in the art as the "bottom" of the process, despite contacting and forming the top or face of the wallboard product. Conversely, the bottom or back paper is applied last in the manufacturing process in what is known as the "top" of the process. These same conventions will apply in the formation and preparation of the composite gypsum boards of the present invention. Reference is made to Example 7B below.

It is preferred that a naphthalenesulfonate dispersant by used in gypsum-containing slurries prepared in accordance with the present invention. The naphthalenesulfonate dispersants used in the present invention include polynaphthalenesulfonic acid and its salts (polynaphthalenesulfonates) and derivatives, which are condensation products of naphthalenesulfonic acids and formaldehyde. Particularly desirable polynaphthalenesulfonates include sodium and calcium naphthalenesulfonate. The average molecular weight of the naphthalenesulfonates can range from about 3,000 to 27,000, although it is preferred that the molecular weight be about 8,000 to 22,000, and more preferred that the molecular weight be about 12,000 to 17,000. As a commercial product, a higher molecular weight dispersant has higher viscosity, and lower solids content, than a lower molecular weight dispersant. Useful naphthalenesulfonates include DILOFLO, available from GEO Specialty Chemicals, Cleveland, Ohio; DAXAD, available from Hampshire Chemical Corp., Lexington, Mass.; and LOMAR D, available from GEO Specialty Chemicals, Lafayette, Ind. The naphthalenesulfonates are preferably used as aqueous solutions in the range 35-55% by weight solids content, for example. It is most preferred to use the naphthalenesulfonates in the form of an aqueous solution, for example, in the range of about 40-45% by weight solids content. Alternatively, where appropriate, the naphthalenesulfonates can be used in dry solid or powder form, such as LOMAR D, for example.

The polynaphthalenesulfonates useful in the present invention have the general structure (1):

(I)



wherein n is>2, and wherein M is sodium, potassium, calcium, and the like.

The naphthalenesulfonate dispersant, preferably as an about 45% by weight solution in water, may be used in a range of from about 0.5% to about 3.0% by weight based on the weight of dry stucco used in the gypsum composite formulation. A more preferred range of naphthalenesulfonate dispersant is from about 0.5% to about 2.0% by weight based on the weight of dry stucco, and a most preferred range from about 0.7% to about 2.0% by weight based on the weight of dry stucco. In contrast, known gypsum wallboard contains this dispersant at levels of about 0.4% by weight, or less, based on the weight of dry stucco.

Stated in an another way, the naphthalenesulfonate dispersant, on a dry weight basis, may be used in a range from about 0.1% to about 1.5% by weight based of the weight of dry stucco used in the gypsum composite formulation. A more preferred range of naphthalenesulfonate dispersant, on a dry solids basis, is from about 0.25% to about 0.7% by weight based on the weight of dry stucco, and a most preferred range (on a dry solids basis) from about 0.3% to about 0.7% by weight based on the weight of dry stucco.

The gypsum-containing slurry can optionally contain a trimetaphosphate salt, for example, sodium trimetaphosphate. Any suitable water-soluble metaphosphate or polyphosphate can be used in accordance with the present invention. It is preferred that a trimetaphosphate salt be used, including double salts, that is trimetaphosphate salts having two cations. Particularly useful trimetaphosphate salts include sodium trimetaphosphate, potassium trimetaphosphate, calcium trimetaphosphate, sodium calcium trimetaphosphate, lithium trimetaphosphate, ammonium trimetaphosphate, and the like, or combinations thereof. A preferred trimetaphosphate salt is sodium trimetaphosphate. It is preferred to use the trimetaphosphate salt as an aqueous solution, for example, in the range of about 10-15% by weight solids content. Other cyclic or acyclic polyphosphate can also be used, as described in U.S. Pat. No. 6,409,825 to Yu et al., herein incorporated by reference.

Sodium trimetaphosphate is a known additive in gypsum-containing compositions, although it is generally used in a range of from about 0.05% to about 0.08% by weight based on the weight of dry stucco used in the gypsum slurry. In the embodiments of the present invention, sodium trimetaphosphate (or other water-soluble metaphosphate or polyphosphate) can be present in the range of from about 0.12% to about 0.4% by weight based on the weight of dry stucco used in the gypsum composite formulation. A preferred range of sodium trimetaphosphate (or other water-soluble metaphosphate or polyphosphate) is from about 0.12% to about 0.3% by weight based on the weight of dry stucco used in the gypsum composite formulation.

There are two forms of stucco, alpha and beta. These two types of stucco are produced by different means of calcification. In the present inventions either the beta or the alpha form of stucco may be used.

Starches, including pregelatinized starch in particular, must be used in gypsum-containing slurries prepared in accordance with the present invention. A preferred pregelatinized starch is pregelatinized corn starch, for example pregelatinized corn flour available from Bunge Milling, St. Louis, Mo., having the following typical analysis: moisture 7.5%, protein 8.0%, oil 0.5%, crude fiber 0.5%, ash 0.3%; having a green strength of 0.48 psi; and having a loose bulk density of 35.0 lb/ft^3. Pregelatinized corn starch should be used in an amount of at least about 0.5% by weight up to about 10% by weight, based on the weight of dry stucco used in the gypsum-containing slurry.

The present inventors have further discovered that an unexpected increase in dry strength (particularly in wallboard) can be obtained by using at least about 0.5% by weight up to about

10% by weight pregelatinized starch (preferably pregelatinized corn starch) in the presence of about 0.1% by weight to 3.0% by weight naphthalenesulfonate dispersant (starch and naphthalenesulfonate levels based on the weight of dry stucco present in the formulation). This unexpected result can be obtained whether or not water-soluble metaphosphate or polyphosphate is present.

In addition, it has unexpectedly been found that pregelatinized starch can be used at levels of at least about 10 lb/MSF, or more, in the dried gypsum wallboard made in accordance with the present invention, yet high strength and low weight can be achieved. Levels as high as 35-45 lb/MSF pregelatinized starch in the gypsum wallboard have been shown to be effective. As an example, Formulation B, as shown in Tables 1 and 2 below, includes 45 lb/MSF, yet produced a board weight of 1042 lb/MSF having excellent strength. In this example (Formulation B), a naphthalenesulfonate dispersant as a 45% by weight solution in water, was used at a level of 1.28% by weight.

A further unexpected result may be achieved with the present invention when the naphthalenesulfonate dispersant trimetaphosphate salt combination is combined with pregelatinized corn starch, and optionally, paper fiber or glass fiber. Gypsum wallboard made from formulations containing these three ingredients have increased strength and reduced weight, and are more economically desirable due to the reduced water requirements in their manufacture.

Accelerators can be used in the gypsum-containing compositions of the present invention, as described in U.S. Pat. No. 6,409,825 to Yu et al., herein incorporated by reference. One desirable heat resistant accelerator (HRA) can be made from the dry grinding of landplaster (calcium sulfate dihydrate). Small amounts of additives (normally about 5% by weight) such as sugar, dextrose, boric acid, and starch can be used to make this HRA. Sugar, or dextrose, is currently preferred. Another useful accelerator is “climate stabilized accelerator” or “climate stable accelerator,” (CSA) as described in U.S. Pat. No. 3,573,947, herein incorporated by reference.

Water/stucco (w/s) ratio is an important parameter, since excess water must eventually be driven off by heating. In the embodiments of the present invention, a generally preferred w/s ratio is from about 0.7 to about 1.3. A more preferred w/s ratio in the main gypsum slurry formulations should be in the range from 0.8-1.2.

Other gypsum slurry additives can include accelerators, binders, waterproofing agents, paper or glass fibers and other known constituents.

The following examples further illustrate the invention. They should not be construed as in any way limiting the scope of the invention.

EXAMPLE 1

Sample Gypsum Slurry Formulations

Gypsum slurry formulations are shown in Table 1 below. All values in Table 1 are expressed as weight percent based on the weight of dry stucco. Values in parentheses are dry weight in pounds (lb/MSF).

TABLE 1

Component	Formulation A	Formulation B
Stucco (lb/MSF)	(732)	(704)
sodium trimetaphosphate	0.20 (1.50)	0.30 (2.14)
Dispersant (naphthalenesulfonate)	0.18 (1.35)	0.58[1] (4.05)

TABLE 1-continued

Component	Formulation A	Formulation B
Pregelatinized starch (dry powder)	2.7 (20)	6.4 (45)
Board starch	0.41 (3.0)	0
Heat resistant accelerator (HRA)	(15)	(15)
Glass fiber	0.27 (2.0)	0.28 (2.0)
Paper fiber	0	0.99 (7.0)
Soap*	0.03 (0.192)	0.03 (0.192)
Total Water (lb.)	805	852
Water/Stucco ratio	1.10	1.21

*Used to pregenerate foam

[1]1.28% by weight as a 45% aqueous solution.

EXAMPLE 2

Preparation of Wallboards

Sample gypsum wallboards wee prepared in accordance with U.S. Pat. No. 6,342,284, to Yu et al. and U.S. Pat. No. 6,632,550 to Yu et al., herein incorporated by reference. This includes the separate generation of foam and introduction of the foam into the slurry of all of the other ingredients as described in Example 5 of these patents.

Test results for gypsum wallboards made using the Formulation A and B of Example 1, and a normal control board are shown in Table 2 below. As in this example and other examples below, nail pull resistance, core hardness, and flexural strength tests were performed according to ASTM C-473. Additionally, it is noted that typical gypsum wallboard is approximately ½ inch thick and has a weight of between about 1600 to 1800 pounds per 1,000 square feet of material, or lb/MSF. (“MSF” is a standard abbreviation in the art for a thousand square feet; it is an area measurement for boxes, corrugated media and wallboard.)

TABLE 2

Lab test result	Control Board	Formulation A Board	Formulation B Board
Board weight (lb/MSF)	1587	1066	1042
Nail pull resistance (lb)	81.7	50.2	72.8
Core hardness (lb)	16.3	5.2	11.6
Humidified bond load (lb)	17.3	20.3	15.1
Humidified bond failure (%)	0.6	5	11.1
Flexural strength, face-up (MD) (lb)	47	47.2	52.6
Flexural strength, face-down (MD) (lb)	51.5	66.7	78.8
Flexural strength, face-up (XMD) (lb)	150	135.9	173.1
Flexural strength, face-down (XMD) (lb)	144.4	125.5	165.4

MD: machine direction

XMD: across machine direction

As illustrated in Table 2, gypsum wallboards prepared using the Formulation A and B slurries have significant reductions in weight compared to the control board. With reference again to Table 1, the comparisons of the Formulation A board to the Formulation B board are most striking. The water/stucco (w/s) ratios are similar in Formulation A and Formulation B. A significantly higher level of naphthalenesulfonate dispersant is also used in Formulation B. Also, in Formulation B substantially more pregelatinized starch was used, about 6% by weight, a greater than 100% increase over Formulation A accompanied by marked strength increases. Even so, the water demand to produce the required flowability remained low in the Formulation B slurry, the difference being about 10% in comparison to Formulation A. The low water demand in both Formulations is attributed to the synergistic effect of the combination of naphthalenesulfonate dispersant and sodium trimetaphosphate in the gypsum slurry, which increases the fluidity of the gypsum slurry, even in the presence of a substantially higher level of pregelatinized starch.

As illustrated in Table 2, the wallboard prepared using the Formulation B slurry has substantially increased strength compared with the wallboard prepared using the Formulation A slurry. By incorporating increased amounts of pregelatinized starch in combination with increased amounts of naphthalenesulfonate dispersant and sodium trimetaphosphate, nail pull resistance in the Formulation B board improved by 45% over the Formulation A board. Substantial increases in flexural strength were also observed in the Formulation B board as compared to the Formulation A board.

EXAMPLE 3

½ Inch Gypsum Wallboard Weight Reduction Trials

Further gypsum wallboard examples (Boards C, D and E), including slurry formulations and test results are shown in Table 3 below. The slurry formulations of Table 3 include the major components of the slurries. Values in parentheses are expressed as weight percent based on the weight of dry stucco.

TABLE 3

	Control Board	Formulation C Board	Formulation D Board	Formulation E Board
Trial formulation component/parameter				
Dry stucco (lb/MSF)	1300	1281	1196	1070
Accelerator (lb/MSF)	9.2	9.2	9.2	9.2
DILOFLO[1] (lb/MSF)	4.1 (0.32%)	8.1 (0.63%)	8.1 (0.68%)	8.1 (0.76%)
Regular starch (lb/MSF)	5.6 (0.43%)	0	0	0
Pregelatinized corn starch (lb/MSF)	0	10 (0.78%)	10 (0.84%)	10 (0.93%)
Sodium trimetaphosphate (lb/MSF)	0.7 (0.05%)	1.6 (0.12%)	1.6 (0.13%)	1.6 (0.15%)
Total water/stucco ratio (w/s)	0.82	0.82	0.82	0.84
Trial formulation test results				
Dry board weight (lb/MSF)	1611	1570	1451	1320
Nail pull resistance (lb)	77.3†	85.5	77.2	65.2

†ASTM standard: 77 lb

[1]DILOFLO is a 45% Naphthalensulfonate solution in water

As illustrated in Table 3, Boards C, D, and E were made from a slurry having substantially increased amounts of starch, DILOFLO dispersant, and sodium trimetaphosphate in comparison with the control board (about a two-fold increase on a percentage basis for the starch an disperant, and a two- or three-fold increase for the trimetaphosphate), while maintaining the w/s ratio constant. Nevertheless, board weight was significantly reduced and strength as measured by nail pull resistance was not dramatically affected. Therefore, in this example of an embodiment of the invention, the new formulation (such as, for example, Board D) can provide increased starch formulated in a usable, flowable slurry, while maintaining the same w/s ratio and adequate strength.

EXAMPLE 4

Wet Gypsum Cube Strength Test

The wet cube strength tests were carried out by using Southard CKS board stucco, available from United States Gypsum Corp., Chicago, Ill. and tap water in the laboratory to determine their wet compressive strength. The following lab test procedure was used.

Stucco (1000 g), CSA (2 g), and tap water (1200 cc) at about 70° F. were used for each wet gypsum cube cast. Pregelatinized corn starch (20 g, 2.0% based on stucco wt.) and CSA (2 g, 0.2% based on stucco wt.) were thoroughly dry mixed first in a plastic bag with the stucco prior to mixing with a tap water solution containing both naphthalenesulfonate dispersant and sodium trimetaphosphate. The dispersant used was DILOFLO dispersant (1.0-2.0%, as indicated in Table 4). Varying amounts of sodium trimetaphosphate were used also as indicated in Table 4.

The dry ingredients and aqueous solution were initially combined in a laboratory Warning blender, the mixture produced allowed to soak for 10 sec, and then the mixture was mixed at low speed for 10 sec in order to make the slurry. The slurries thus formed were cast into three 2"×2"×2" cube molds. The cast cubes were then removed from the molds, weighted, and sealed inside plastic bags to prevent moisture loss before the compressive strength test was performed. The compressive strength of the wet cubes was measured using an ATS machine and recorded as an average in pounds per square inch (psi). The results obtained were as follows:

TABLE 4

Test Sample No.	Sodium trimetaphosphate, grams (wt % based on dry stucco)	DILOFLO[1] (wt % based on dry stucco)	Wet cube weight (2" × 2" × 2"), g	Wet cube compressive strength, psi
1	0	1.5	183.57	321
2	0.5 (0.05)	1.5	183.11	357
3	1 (0.1)	1.5	183.19	360
4	2 (0.2)	1.5	183.51	361
5	4 (0.4)	1.5	183.65	381
6	10 (1.0)	1.5	183.47	369
7	0	1.0	184.02	345
8	0.5 (0.05)	1.0	183.66	349
9	1 (0.1)	1.0	183.93	356
10	2 (0.2)	1.0	182.67	366
11	4 (0.4)	1.0	183.53	365
12	10 (1.0)	1.0	183.48	341
13	0	2.0	183.33	345
14	0.5 (0.05)	2.0	184.06	356
15	1 (0.1)	2.0	184.3	363

TABLE 4-continued

Test Sample No.	Sodium trimetaphosphate, grams (wt % based on dry stucco)	DILOFLO[1] (wt % based on dry stucco)	Wet cube weight (2" × 2" × 2"), g	Wet cube compressive strength, psi
16	2 (0.2)	2.0	184.02	363
17	4 (0.4)	2.0	183.5	368
18	10 (1.0)	2.0	182.68	339

[1]DILOFLO is a 45% Naphthalensulfonate solution in water

As illustrated in Table 4, Samples 4-5, 10-11, and 17, having levels of sodium trimetaphosphate in the about 0.12-0.4% range of the present invention generally provided superior wet cube compressive strength as compared to samples with sodium trimetaphosphate outside this range.

EXAMPLE 5

½ Inch Light Weight Gypsum Wallboard Plant Production Trials

Further trials were performed (Trial Boards 1 and 2), including slurry formulations and test results are shown in Table 5 below. The slurry formulations of Table 5 include the major components of the slurries. Values in parentheses are expressed as weight percent based on the weight of dry stucco.

TABLE 5

	Control Board 1	Plant Formulation Trial Board 1	Control Board 2	Plant Formulation Trial Board 2
Trial formulation component/parameter				
Dry stucco (lb/MSF)	1308	1160	1212	1120
DILOFLO[1] (lb/MSF)	5.98 (0.457%)	7.98 (0.688%)	7.18 (0.592%)	8.99 (0.803%)
Regular starch (lb/MSF)	5.0 (0.38%)	0	4.6 (0.38%)	0
Pregelatinized corn starch (lb/MSF)	2.0 (0.15%)	10 (0.86%)	2.5 (0.21%)	9.0 (0.80%)
Sodium trimetaphosphate (lb/MSF)	0.7 (0.05%)	2.0 (0.17%)	0.6 (0.05%)	1.6 (0.14%)
Total water/stucco ratio (w/s)	0.79	0.77	0.86	0.84
Trial formulation test results				
Dry board weight (lb/MSF)	1619	1456	1553	1443
Nail pull resistance (lb)	81.5†	82.4	80.7	80.4
Flexural strength, average (MD) (lb)	41.7	43.7	44.8	46.9
Flexural strength, average (XMD) (lb)	134.1	135.5	146	137.2
Humidified bond[2] load, average (lb)	19.2	17.7	20.9	19.1
Humidified bond[2,3] failure (%)	1.6	0.1	0.5	0

†ASTM standard: 77 lb
MD: machine direction
XMD: across machine direction
[1]DILOFLO is a 45% Naphthalensulfonate solution in water
[2]90° F./90% Relative Humidity
[3]It is well understood that under these test conditions, percentage failure rates <50% are acceptable

As illustrated in Table 5, Trial Boards 1 and 2 were made from a slurry having substantially increased amounts of starch, DILOFLO dispersant, and sodium trimetaphosphate, while slightly decreasing the w/s ratio, in comparison with the control boards. Nevertheless, strength as measured by nail pull resistance and flexural testing was maintained or improved, and board weight was significantly reduced. Therefore, in this example of an embodiment of the invention, the new formulation (such as, for example, Trial Boards 1 and 2) can provide increased trimetaphosphate and starch formulated in a usable, flowable slurry, while maintaining substantially the same w/s ratio and adequate strength.

EXAMPLE 6

½ Inch Ultra-Light Weight Gypsum Wallboard Plant Production Trials

Further trials were performed (Trial Boards 3 and 4) using Formulation B (Example 1) as in Example 2, except that the pregelatinized corn starch was prepared with water at 10% concentration (wet starch preparation) and a blend of HYONIC 25 AS and PFM 33 soaps (available from GEO Specialty Chemicals, Lafayette, Ind.) was used. For example, Trial Board 3 was prepared with a blend of HYONIC 25 AS and PFM 33 ranging from 65-70% by weight of 25AS, and the balance PFM 33. For example, Trial Board 4 was prepared with a 70/30 wt./wt. blend of HYONIC 25AS/HYONIC PFM 33. The trial results are shown in Table 6 below.

TABLE 6

Lab test result	Trial Board 3 (Formulation B plus HYONIC soap blend 65/35) (n = 12)	Trial Board 4 (Formulation B plus HYONIC soap blend 70/30) (n = 34)*
Board weight (lb/MSF)	1106	1013
Nail pull resistance[a] (lb)	85.5	80.3
Core hardness[b] (lb)	>15	12.4
Flexural strength, average[c] (MD) (lb)	55.6	60.3[1]
Flexural strength, average[d] (XMD) (lb)	140.1	142.3[1]

*Except as marked,
[1]n = 4
MD: machine direction
XMD: across machine direction
[a]ASTM standard: 77 lb
[b]ASTM standard: 11 lb
[c]ASTM standard: 36 lb
[d]ASTM standard: 107 lb

As illustrated in Table 6, strength characteristics as measured by nail pull and core hardness were above the ASTM standard. Flexural strength was also measured to be above the ASTM standard. Again, in this example of an embodiment of the invention, the new formulation (such as, for example, Trial Boards 3 and 4) can provide increased trimetaphosphate and starch formulated in a usable, flow slurry, while maintaining adequate strength.

EXAMPLE 7

½ Inch Ultra-Light Weight Composite Gypsum Board.

A. Slurry Formulation

A representative gypsum slurry formulation for producing gypsum composite board is shown in Table 7, below. All values in Table 7 are expressed as weight percent based on the weight of dry stucco. Values in parentheses are dry weight in pounds (lb/MSF).

TABLE 7

Component	Formulation C
Stucco (lb/MSF)	(714)
sodium trimetaphophate	0.315 (2.25)
Dispersant (naphthalenesulfonate)	0.630[1] (4.50)
Pregelatinized starch[2]	6.30 (45.0)
Heat resistant accelerator (HRA)	(15)
Glass fiber	0.560 (4.00)
Paper fiber	1.12 (8.00)
Soap*	0.03 (0.192)
Total Water (lb)	931
Water/Stucco ratio	1.30

*Used to pregenerate foam.
Note:
10-14% by weight of slurry was not treated with soap foam.
[1]1.40% by weight as a 45% aqueous solution.
[2]Pregel starch can be added as a dry powder, or alternatively, as 10% pre-dispersed starch in water (wet starch preparation).

B. Preparation of Composite Boards with Dry Pregelatinized Starch

The composite boards were prepared as in Example 2, using Formulation C above, with the following exceptions. Dry powder pregelatinized corn starch was used to prepare the slurry. Heavy Manila paper (60 lb/MSF, caliper 0.018 in.) was used as the top (face) cover sheet, to which was applied 6-8% by weight of the non-foamed high density gypsum slurry having a wet density of 80 pcf across the entire surface of the paper. After application of the main foamed slurry, the bottom (back) cover sheet was applied, (News-Line paper—42 lb/MSF, caliper 0.0125 in.) which included on its gypsum core-facing surface 4-6% by weight of the non-foamed high density gypsum slurry having a wet density of 80-85 pcf, across the entire surface of the paper.

C. Preparation of Composite Boards with Wet Pregelatinized Starch

Composite boards were prepared as set forth above, except that the pregelatinized corn starch was prepared in solution with water at 10% concentration (wet starch preparation).

EXAMPLE 8

Testing of ½ Inch Ultra-Light Weight Composite Gypsum Board

Test results for composite gypsum boards prepared in Examples 7B and 7C are shown in Table 8 below. As in this example and other examples, nail pull resistance, core hardness, and flexural strength tests were performed according to ASTM C-473. 2 ft.×4 ft. trial board samples were tested after conditioning at 70° F./50% R.H.

TABLE 8

Lab test result	Ex. 7B. Composite Board (Dry Starch) (n = 8)	Ex. 7C. Composite Board (Wet Starch) (n = 8)
Board weight (lb/MSF)	1041	1070
Nail pull resistance (lb)	69.6	83.1
Core hardness (lb)	9.4	10.9
Paper-to-core Bond (face/back)	Good/ok	Good/ok

As illustrated in Table 8, the Example 7C, composite board exceeds the ASTM standard for nail pull resistance, and essentially meets the core hardness standard (see Table 6). This demonstrates that the use of strong, heavy face paper and regular back paper, both adhered to a low density core using a non-foamed high density bonding layer, can provide a board having light weight, and increased strength.

The use of the terms “a” and “an” and “the” an similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless other wise indicated herein or clearly contradicted by context. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. It should be understood that the illustrated embodiments are exemplary only, and should not be taken as limiting the scope of the invention.

What is claimed is:

1. A composite light weight gypsum composite board comprising:

a foamed low density set gypsum core having a top surface and a bottom surface, the foamed low density set gypsum core made using a gypsum-containing slurry including stucco, from about 0.5% by weight to about 10% by weight pregelatinized starch *based on the weight of stucco*, and foam,

a top non-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the top surface of the foamed low density set gypsum core,

a bottom non-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the bottom surface of the foamed low density set gypsum core,

the top and bottom non-foamed high density bonding layers comprising from about 10% by weight to about 16% by weight of the total amount of the gypsum-containing slurry,

a top cover sheet, and

a bottom cover sheet,

wherein the top cover sheet is bonded to the foamed low density set gypsum core by the top non-foamed high density bonding layer, and the bottom cover sheet is bonded to the foamed low density set gypsum core by the bottom non-foamed high density bonding layer, the foamed low density set gypsum core has a density from about 10 pcf to about 27 pcf and the top and bottom non-foamed high density bonding layers have a density from about 60 pcf to about 70 pcf, and wherein the composite board has a dry weight of about 1000 lb/msf or less for a ½ inch thick board, a nail pull resistance of at least about 77 lb**[**/msf**]**, and a core hardness of at least about 11 lb**[**/msf**]**.

2. The composite light weight gypsum board of claim **1** in which the pregelatinized starch is in the form of a pre-dispersion of about 10% by weight in water.

3. The composite light weight gypsum board of claim **1**, wherein the gypsum-containing slurry further comprises a naphthalenesulfonate dispersant present in an amount from about 0.1% by weight to about 3.0% by weight based on the weight of stucco.

4. The composite light weight gypsum board of claim **1**, wherein the gypsum-containing slurry further comprises a naphthalenesulfonate dispersant in the form of an aqueous solution containing from about 40% to about 45% by weight naphthalenesulfonate and the aqueous solution is present in the slurry in an amount from about 0.5% to about 2.5% by weight based on the weight of stucco.

5. The composite light weight gypsum board of claim **1**, wherein the gypsum-containing slurry further comprises sodium trimetaphosphate present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of stucco.

6. The composite light weight gypsum board of claim **1**, wherein the gypsum-containing slurry further comprises glass fiber present in an amount up to about 0.5% by weight based on the weight of stucco.

7. The composite light weight gypsum board of claim **1**, wherein the gypsum-containing slurry further comprises a waterproofing agent.

8. The composite light weight gypsum board of claim **1**, wherein the foam is soap foam, and the soap is present in an amount from about 0.3 lb/msf to about 0.5 lb/msf.

9. The composite light weight gypsum board of claim **1**, wherein the top cover sheet is paper having a weight of about 60 lb/msf.

10. The composite light weight gypsum board of claim **1**, wherein the top cover sheet is a fibrous mat.

11. The composite light weight gypsum board of claim **10**, wherein the fibrous mat is a nonwoven glass fiber mat.

12. The composite light weight gypsum board of claim **1**, wherein the gypsum-containing slurry has a water/stucco ratio from about 0.7 to about 1.3.

13. A composite light weight gypsum composite board comprising:

a foamed low density set gypsum core having a top surface and a bottom surface, the foamed low density set gypsum core made using a gypsum-containing slurry including stucco, pregelatinized starch, and foam,

a top reduced-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the top surface of the foamed low density set gypsum core,

a bottom reduced-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the bottom surface of the foamed low density set gypsum core,

a top cover sheet, and

a bottom cover sheet,

wherein the top cover sheet is bonded to the foamed low density set gypsum core by the top reduced-foamed high density bonding layer, and the bottom cover sheet is bonded to the foamed low density set gypsum core by the bottom reduced-foamed high density bonding layer, the foamed low density set gypsum core has a density from about 10 pcf to about 27 pcf and the top and bottom non-foamed high density bonding layers have a density from about 60 pcf to about 70 pcf, and wherein the composite board has a dry weight of about 1000 lb/msf for a ½ inch thick board, a nail pull resistance of at least about 77 lb**[**/msf**]**, and a core hardness of at least about 11 lb**[**/msf**]**.

14. The composite light weight gypsum board of claim **13**, wherein the pregelatinized starch is present in an amount from about 0.5% by weight to about 10% by weight based on the weight of stucco.

15. The composite light weight gypsum board of claim **13** in which the pregelatinized starch is in the form of a pre-dispersion of about 10% by weight in water.

16. The composite light weight gypsum board of claim **13**, wherein the gypsum-containing slurry further comprises a naphthalenesulfonate dispersant present in an amount from about 0.1% by weight to about 3.0% by weight based on the weight of stucco.

17. The composite light weight gypsum board of claim **13**, wherein the gypsum-containing slurry further comprises sodium trimetaphosphate present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of stucco.

18. The composite light weight gypsum board of claim **13**, wherein the foam is soap foam, and the soap is present in an amount from about 0.2 lb/msf to about 0.7 lb/msf.

19. The composite light weight gypsum board of claim **18**, wherein the top and bottom reduced-foamed high density bonding layers include about 5% by weight or less of the amount of soap used to make the foamed low density set gypsum core.

20. The composite light weight gypsum board of claim **13**, wherein the top cover sheet is paper having a weight of about 60 lb/msf.

[**21**. The composite light weight gypsum board of claim **13**, wherein the foamed low density set gypsum core has a density from about 10 pcf to about 27 pcf.]

[**22**. The composite light weight gypsum board of claim **13**, wherein the top and bottom reduced-foamed high density bonding layers have a density from about 45 pcf to about 60 pcf.]

23. A composite light weight gypsum composite board having a dry weight of about 1,000 lb./msf or less for a ½ inch thick board comprising:

a foamed low density set gypsum core having a top surface and a bottom surface, the foamed low density set gypsum core made using a gypsum-containing slurry including stucco from about 0.5% by weight to about 10% by weight pregelatinized starch *based on the weight of stucco*, and foam,

a top non-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the top surface of the foamed low density set gypsum core,

a bottom non-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the bottom surface of the foamed low density set gypsum core,

the top and bottom non-foamed high density bonding layers comprising from about 10% by weight to about 16% by weight of the total amount of the gypsum-containing slurry,

a top fibrous mat cover sheet, and

a bottom cover sheet,

wherein the top cover sheet is bonded to the foamed low density set gypsum core by the top non-foamed high density bonding layer, and the bottom cover sheet is bonded to the foamed low density set gypsum core by the bottom non-foamed high density bonding layer, the foamed low density set gypsum core has a density from about 10 pcf to about 30 pcf and the top and bottom non-foamed high density bonding layers have a density from about 60 pcf to about 70 pcf.

24. The composite light weight gypsum board of claim **23** in which the pregelatinized starch is in the form of a pre-dispersion of about 10% by weight in water.

25. The composite light weight gypsum board of claim **23**, wherein the gypsum-containing slurry further comprises a naphthalenesulfonate dispersant present in an amount from about 0.1% by weight to about 3.0% by weight based on the weight of stucco.

26. The composite light weight gypsum board of claim **23**, wherein the gypsum-containing slurry further comprises sodium trimetaphosphate present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of stucco.

27. The composite light weight gypsum board of claim **23**, wherein the foam is soap foam, and the soap is present in an amount from about 0.2 lb/msf to about 0.7 lb/msf.

28. The composite light weight gypsum board of claim **23**, wherein the board has a dry weight from about 900 lb/msf to about 1100 lb/msf.

29. The composite light weight gypsum board of claim **23**, wherein the fibrous mat cover sheet is a nonwoven glass fiber mat.

30. A method of making composite light weight gypsum board having a dry weight from about 900 lbs./msf to about 1,100 lbs./msf, comprising the steps of:

(a) mixing a non-foamed gypsum-containing slurry having a density from about 80 pcf to about 85 pcf comprising water, stucco, pregelatinized starch, and a naphthalenesulfonate dispersant, wherein the pregelatinized starch is present in an amount from about 0.5% by weight to about 10% by weight based on the weight of stucco, and wherein the naphthalenesulfonate dispersant is present in an amount from about 0.1% to about 3.0% by weight based on the weight of stucco;

(b) depositing from about 6% to about 9% by weight of the total amount of the non-foamed gypsum-containing slurry on a first cover sheet;

(c) adding soap foam to from about 84% to about 90% by weight of the total amount of the non-foamed gypsum-containing slurry to form a foamed gypsum-containing slurry;

(d) depositing the foamed gypsum-containing slurry onto the non-foamed gypsum-containing slurry on the first cover sheet;

(e) depositing from about 4% to about 7% by weight of the total amount of the non-foamed gypsum-containing slurry on a second cover sheet;

(f) placing the non-foamed gypsum-containing slurry-covered surface of the second cover sheet over the deposited foamed gypsum-containing slurry to form a composite light weight gypsum board;

(g) cutting the composite light weight gypsum board after the foamed gypsum-containing slurry has hardened sufficiently for cutting; and

(h) drying the composite light weight gypsum board to provide a foamed low density set gypsum core in the finished composite light weight gypsum board.

31. The method of claim **30** in which the pregelatinized starch is in the form of a pre-dispersion of about 10% by weight in water.

32. The method of claim **30**, wherein the non-foamed gypsum-containing slurry further comprises sodium trimetaphosphate present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of stucco.

33. The method of claim **30**, wherein the non-foamed gypsum-containing slurry further comprises glass fiber present in an amount up to about 0.5% by weight based on the weight of stucco.

34. The method of claim **30**, wherein the non-foamed gypsum-containing slurry further comprises paper fiber present in an amount up to about 1.0% by weight based on the weight of stucco.

35. The method of claim **30**, wherein the soap foam includes soap present in an amount from about 0.3 lb/msf to about 0.5 lb/msf.

36. The method of claim **30**, wherein the first cover sheet and the second cover sheet are made of paper.

37. The method of claim **30**, wherein the first cover sheet is paper having a weight of about 60 lb/msf.

38. The method of claim **30**, wherein the first cover sheet is a fibrous mat.

39. The method of claim **38**, wherein the fibrous mat is a nonwoven glass fiber mat.

40. The method of claim **30**, wherein the foamed gypsum-containing slurry has a water/stucco ratio from about 0.7 to about 1.3.

41. The method of claim **30**, wherein the pregelatinized starch is corn starch.

42. A composite light weight gypsum board, comprising:

a foamed low density set gypsum core having a top surface and a bottom surface, the foamed low density set gypsum core made using a gypsum-containing slurry comprising water, stucco, pregelatinized corn starch present in an amount of about 6% by weight based on the weight of stucco, a 45% by weight aqueous solution of a naphthalenesulfonate dispersant present in an amount of about 1.2% by weight based on the weight of stucco, sodium trimetaphosphate present in an amount of about 0.3% by weight based on the weight of stucco, paper fiber present in an amount of about 1% based on the weight of stucco, and glass fiber present in an amount of about 0.5% based on the weight of stucco, and soap foam,

a top non-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the top surface of the foamed low density set gypsum core,

a bottom non-foamed high density bonding layer having a thickness of about 2 mils to less than about 7 mils covering the bottom surface of the foamed low density set gypsum core,

the top and bottom non-foamed high density bonding layers comprising from about 10% by weight to about 16% by weight of the total amount of the gypsum-containing slurry,

a top paper cover sheet having a weight of about 60 lb/msf, and

a bottom paper cover sheet,

wherein the top cover sheet is bonded to the foamed low density set gypsum core by the top non-foamed high density bonding layer, and the bottom cover sheet is bonded to the foamed low density set gypsum core by the bottom non-foamed high density bonding layer, wherein the foamed low density set gypsum core has a density of about 25 pcf, the top and bottom non-foamed high density bonding layers have a density from about 60 pcf to about 70 pcf and wherein the composite board has a dry weight of about 1000 lb/msf for a ½ inch thick board, a nail pull resistance of at least about 77 lb**[**/msf**]**, and a core hardness of at least about 11 lb**[**/msf**]**.

43. The composite light weight gypsum board of claim **42** in which the pregelatinized corn starch is in the form of a pre-dispersion of about 10% by weight in water.

44. A composite gypsum board comprising:

a set gypsum core having a top surface and a bottom surface, the set gypsum core formed from at least stucco, starch, and foam,

a top bonding layer having a thickness of about 2 mils to less than about 7 mils adjacent the top surface of the set gypsum core,

a bottom bonding layer having a thickness of about 2 mils to less than about 7 mils covering the bottom surface of the set gypsum core,

a top cover sheet, and

a bottom cover sheet,

wherein the top cover sheet is bonded to the set gypsum core by the top bonding layer, and the bottom cover sheet is bonded to the set gypsum core by the bottom bonding layer, the set gypsum core has a density from about 10 pcf to about 27 pcf and less than the density of either the top or bottom bonding layer, and wherein the board, when at a thickness of about ½ inch, has a dry weight of about 1100 lbs/MSF or less and a core hardness of at least about 11 lb as determined in accordance with ASTM C473.

45. The composite gypsum board of claim 44, wherein the starch is present in an amount from about 0.5% by weight to about 10% by weight based on the weight of the stucco.

46. The composite gypsum board of claim 44, wherein the set gypsum core further comprises dispersant present in an amount from about 0.1% bv weight to about 3.0% by weight based on the weight of the stucco.

47. The composite gypsum board of claim 44, wherein the set gypsum core further comprises a trimetaphosphate salt present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of the stucco.

48. The composite gypsum board of claim 44, wherein the top and bottom bonding layers have a density from about 45 pcf to about 70 pcf.

49. A composite gypsum board comprising:

a set gypsum core having a dry density;

the set gypsum core adjacent to a first and a second bonding layer each having a dry density, the set gypsum core dry density being less than each of the first and second bonding layer dry densities by a differential of at least about 10 pcf;

the first and second bonding layers each having a thickness of about 2 mils to less than about 7 mils;

the board, when at a thickness of about ½ inch, having a dry weight of about 1100 lbs/MSF or less; and

the set gypsum core has an average core hardness of at least about 11 pounds as determined in accordance with ASTM C473.

50. The composite gypsum board of claim 49, wherein the first and second bonding layers are formed from one or more slurries, the amount of slurry used to form the first and second bonding layers comprising from about 10% to about 16% by weight of the total amount of slurry used to form the set gypsum core and the first and second bonding layers.

51. The composite gypsum board of claim 49, the set gypsum core formed from a slurry comprising water, stucco, foam, and starch present in an amount from about 0.5% to about 10% by weight based on the weight of the stucco, the starch effective to increase the core hardness of the gypsum board relative to the core hardness of the gypsum board without the starch.

52. The composite gypsum board of claim 49, the set gypsum core formed from a slurry comprising water, stucco, foam, and dispersant present in an amount from about 0.1% to about 3.0% by weight based on the weight of the stucco.

53. The composite gypsum board of claim 49, the set gypsum core formed from a slurry comprising water, stucco, foam, and a trimetaphosphate salt present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of the stucco.

54. The composite gypsum board of claim 49, the set gypsum core having a density from about 10 pcf to about 27 pcf and the top and bottom bonding layers having a density from about 45 pcf to about 70 pcf.

55. The composite gypsum board of claim 54, wherein the board, when at a thickness of about ½ inch, has (a) a nail pull resistance of at least 65 lb and (b) an average flexural strength of at least 36 lb in a machine direction and/or 107 lb in a cross-machine direction, as determined in accordance with ASTM C473.

56. The composite gypsum board of claim 54, the set gypsum core formed from a slurry comprising water, stucco, foam, dispersant, a trimetaphosphate salt and starch present in an amount from about 0.5% to about 10% by weight based on the weight of the stucco, the starch effective to increase the core hardness of the gypsum board relative to the core hardness of the gypsum board without the starch and dispersant present in an amount from about 0.1% to about 3.0% by weight based on the weight of the stucco and a trimetaphosphate salt present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of the stucco.

57. A composite gypsum board comprising:

the set gypsum core adjacent to a first and a second bonding layer, the dry density of the gypsum core being less than each of the dry densities of first and second bonding layer by a differential of at least about 10 pcf;

the first and second bonding layers each having a thickness of about 2 mils to less than about 7 mils;

the board, when at a thickness of about ½ inch, having a dry weight of about 1100 lbs/MSF or less; and

the board has a ratio of dry density (pcf) to average core hardness (lb) of less than about 3.2, wherein the core hardness is determined in accordance with ASTM C473.

58. The composite gypsum board of claim 57, wherein the first and second bonding layers are formed from one or more slurries, the amount of slurry used to form the first and second bonding layers comprising from about 10% to about 16% by weight of the total amount of slurry used to form the set gypsum core and the first and second bonding layers.

59. The composite gypsum board of claim 57, the set gypsum core formed from a slurry comprising water, stucco, foam, and starch present in an amount from about 0.5% to about 10% by weight based on the weight of the stucco, the starch effective to increase the core hardness of the gypsum board relative to the core hardness of the gypsum board without the starch.

60. The composite gypsum board of claim 57, the set gypsum core formed from a slurry comprising water, stucco, foam, and a trimetaphosphate salt present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of the stucco.

61. The composite gypsum board of claim 57, the set gypsum core having a density from about 10 pcf to about 27 pcf and the top and bottom bonding layers having a density from about 45 pcf to about 70 pcf.

62. A composite gypsum board comprising:

a set gypsum core having a dry density;

the set gypsum core adjacent to a first and a second bonding layer each having a dry density, the set gypsum core dry density being less than each of the first and second bonding layer dry densities by a differential of at least about 10 pcf;

the first and second bonding layers each having a thickness of about 2 mils to less than about 7 mils;

the board, when at a thickness of about ½ inch, having a dry weight of about 1100 lbs/MSF or less; and

the board, when at a thickness of about ½ inch (about 1.3 cm), has a nail pull resistance to average core hardness ratio from about 4 to about 8, each as determined in accordance with ASTM C473.

63. The composite gypsum board of claim 62, the set gypsum core formed from a slurry comprising water, stucco, foam, and starch present in an amount from about 0.5% to about 10% by weight based on the weight of the stucco, the starch effective to increase the core hardness of the gypsum board relative to the core hardness of the gypsum board without the starch.

64. The composite gypsum board of claim 62, the set gypsum core formed from a slurry comprising water, stucco, foam, and a trimetaphosphate salt present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of the stucco.

65. The composite gypsum board of claim 62, the set gypsum core having a density from about 10 pcf to about 27 pcf and the top and bottom bonding layers having a density from about 45 pcf to about 70 pcf.

66. The composite gypsum board of claim 65, the set gypsum core has an average core hardness of at least about 11 pounds as determined in accordance with ASTM C473.

67. The composite gypsum board of claim 65, the set gypsum core formed from a slurry comprising water, stucco, foam, and starch present in an amount from about 0.5% to about 10% by weight based on the weight of the stucco, the starch effective to increase the core hardness of the gypsum board relative to the core hardness of the gypsum board without the starch and dispersant present in an amount from about 0.1% to about 3.0% by weight based on the weight of the stucco and a trimetaphosphate salt present in an amount from about 0.12% by weight to about 0.4% by weight based on the weight of the stucco.

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