DANIEL FRANCISCO PATIÑO SÁNCHEZ

Calle 19B # 81B-30, Bogotá, Colombia

+573214497681

danielpatino742@gmail.com

Magíster en Geotecnia
Especialista en Interventoría y Supervisión de Obras de Construcción
Especialista en Diseño de Vías Urbanas, Tránsito y Transporte
Ingeniero Civil
Tecnólogo en Construcciones Civiles

SOBRE MÍ

Gestor y Director de Proyectos de Consultoría en Geotecnia, Diseño de Pavimentos, Diseño de Vías, Estudios de Suelos, Diseño y Análisis de Cimentaciones, Taludes, Muros de Conteción, Modelación Numérica.

Amplia experiencia Cómo Interventor de contratos de Consultoría y Construcción de Obras Viales, Geotécnicas, de Alcantarillado, Escenarios deportivos, Edificaciones, entre otras

Ejecuctor de Importantes Proyectos de Mejoramiento de Suelos Mediante Inyecciones Sólidas Jet Grouting.

Docente en el Área de Pavimentos, Carreteras, Materiales de Construcción, En la Universidad Distrital Francisco José de Caldas.

Líneas de Investigación en Análisis y Evaluación del Riesgo en Geotecnia

EXPERIENCIA LABORAL

DIRECTOR
ene. 2017 - ene.2023

MEJORAMIENTO DE SUELOS - INYECCIONES SÓLIDAS, JET GRUOTING

- Estabilizamos los asentamientos críticos que se presentaban en el edificio Atika de más de 7 pisos en Bogotá garantizando la seguridad estructural y la seguridad de los habitantes.
-Mejoramos con éxito las propiedades del suelo de el Parque Empresarial Tecnológico, que presentaba asentamientos debido a sus condiciones geotécnicas y de alto tráfico de cargas logrando que no se presentaran más asentamientos.
-Mitiguamos los asentamientos en el sótano del conjunto residencial Brisas de Sotavento ubicado en Bogotá, brindando condiciones de seguridad para la estructura.

DIRECTOR
COLOMBIA
ago. 2017 - Dic 2024

CONSULTOR EN GEOTECNIA Y CARRETERAS

- Estudios de Suelos - Geotécnicos para Edificaciones y Carreteras.
- Diseño Geométrico de Carreteras
- Estudios de Tránsito
- Diseño de Estructuras de Pavimentos.
- Dirección general de Consultorías.
- Gestión de Proyectos.
- Experiencia en diseño de más de 30 proyectos viales

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
BOGOTÁ
ene. 2022 - Actualidad

DOCENTE UNIVERSITARIO

- Docente Universitario en las Áreas de Carreteras, Materiales de Construcción, Pavimentos para el Programa de Ingeniería Civil.

INSTITUTO DE EXTENSIÓN UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
GACHALÁ, CUND.
ago. 2022 - ago. 2023

ESPECIALISTA EN DISEÑO GEOMÉTRICO Y TRÁNSITO

Realizar los Siguientes Diseños para 19 tramos de vías urbanas :
- 19 Levantamientos Topográficos
- 19 Estudios de Tránsito
- 19 Estudios de Suelos
- 19 Diseños Geométricos
- 19 Diseños de Pavimentos

CONSORCIO MAJUY
COTA
may. 2019 - ago. 2022

DIRECTOR DE INTERVENTORÍA CARRETERAS

GESTIÓN, DIRECCIÓN Y EJECUCIÓN GENERAL DEL PROYECTO DE CARRETERAS URBANAS:
"Interventoría Técnica, Administrativa, Legal Y Ambiental Para Realizar El Control Y Seguimiento A La Ejecución De Las Siguientes Obras: Apertura Y Construcción De Las Vías El Sector Sur Occidental Del Municipio De Cota Incluye Obras Alcantarillado Pluvial, Sanitario, Acueducto, Iluminación, Señalización Vial Y Otro"

CONSORCIO VILLA NOHORA
Supatá, Cundinamarca
ago. 2016 - jun. 2017

DIRECTOR DE INTERVENTORÍA

Director de interventoría Técnica, Administrativa, Ambiental, Legal y Financiera para la construcción del Polideportivo Villa Nohora, Supatá, Cundinamarca.

Como política de gestión deportiva para un impacto en una comunidad de 5.000 habitantes.

EDUCACIÓN

ESCUELA COLOMBIANA DE INGENIERÍA JULIO GARAVITO
BOGOTÁ

MAGÍSTER **GEOTECNIA**

MAGÍSTER EN INGENIERÍA CIVIL CON ÉNFASIS EN GEOTECNIA

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
BOGOTÁ
2022

ESPECIALISTA EN INTERVENTORÍA Y SUPERVISIÓN DE OBRAS DE CONSTRUCCIÓN

Posgrado en Interventoría y Supervisión de Obras.

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
BOGOTÁ
2018

ESPECIALISTA EN DISEÑO DE VÍAS URBANAS, TRÁNSITO Y TRANSPORTE

Posgrado en Diseño de Carreteras

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
BOGOTÁ
2016

INGENIERO CIVIL

Título de pregrado, Ingeniero Civil

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
BOGOTÁ
2013

TECNÓLOGO EN CONSTRUCCIONES CIVILES

HABILIDADES

- CONSULTOR EN DISEÑO DE PAVIMENTOS
- GESTIÓN Y SUPERVISIÓN DE PROYECTOS
- CONSULTOR EN DISEÑO DE CARRETERAS
- DIRECTOR INTERVENTORÍA

PUBLICACIONES

JOURNAL OF MATERIALS IN CIVIL ENGINEERING DOI: 10.1061/(ASCE) MT.1943-5533.0002409. © 2018 AMERICAN SOCIETY OF CIVIL ENGINEERS.
may. 2018

Blast Furnace Slag as a Substitute for the Fine Fraction of Aggregates in an Asphalt Mixture

REVISTA INGENIERÍA Y CONSTRUCCIÓN DE CHILE
oct. 2018

Characterization of Blast Furnace slag for Road Projects

DANIEL FRANCISCO PATIÑO SÁNCHEZ

Magíster en Ingeniería Civil Con Énfasis en Geotecnia
Especialista en Interventoría y Supervisión de Obras de Construcción
Especialista en Diseño de Vías Urbanas, Tránsito y Transporte
Ingeniero Civil
Tecnólogo en Construcciones Civiles

PERFIL

Soy **Magíster en Ingeniería Civil con Énfasis en Geotecnia** de la Escuela Colombiana de Ingeniería Julio Garavito, con especializaciones en **Diseño de Vías Urbanas, Tránsito y Transporte**, así como en **Interventoría y Supervisión de Obras de Construcción**. Además, soy **Ingeniero Civil** y **Tecnólogo en Construcciones Civiles** de la Universidad Distrital Francisco José de Caldas.Cuento con una sólida experiencia en el manejo de software especializada en geotecnia, tales como MIDAS GTS NX, Autocad Civil 3D, Slide, GEO5, entre otros.
Mi formación y experiencia me han permitido desarrollar un profundo conocimiento en exploración geotécnica, Mejoramiento de suelos, control de asentamientos, instrumentación geotécnica, copmortamiento de suelos blandos, análisis y evaluación del riesgo en geotecnia, estabiliadad de taludes, diseño de muros de contención, diseño de cimentaciones, diseño geométrico de vías, estudios de tránsito, diseño de pavimentos, interventoría a proyectos viales, a obras de abastecimiento de servicios públicos, alcantarillados, a escenarios deportivosl, entre otras interventorías de diferentes características.Me considero una persona proactiva, con la capacidad de asumir retos y transformarlos en oportunidades de aprendizaje y crecimiento profesional. Tengo habilidades destacadas para trabajar en equipo, gestionar proyectos y establecer relaciones interpersonales saludables en ambientes colaborativos.

PUBLICACIÓN DE ARTÍCULOS CIENTÍFICOS EN REVISTAS INDEXADAS:

1. **REVISTA:**
JOURNAL OF MATERIALS IN CIVIL ENGINEERING
TÍTULO:
“USE OF BLAST FURNACE SLAG AS A SUBSTITUTE FOR THE FINE FRACTION OF AGGREGATES IN AN ASPHALT MIXTURE”
AUTORES:
Hugo Alexander Rondon Quintana, Civil Eng., M. Sc., Ph. D; Juan Carlos Ruge, Civil Eng., M. Sc., Ph. D.; **Daniel Francisco Patiño, Civil Eng**.; Hermes Ariel Vacca, Civil Eng., M. Sc.; Fredy Alberto Reyes, Civil Eng., M. Sc., Ph. D.; Marcio Muniz de Farias, Civil Eng., M. Sc.,

2. **REVISTA:**
INGENIERÍA DE CONSTRUCCIÓN
TÍTULO:
“CHARACTERIZATION OF BLAST FURNACE SLAG FOR ROAD PROJECTS”
AUTORES:
*H. Rondón, W. Fernández, **D. Patiño**, J. Ruge, H. Vacca, F. Reyes*
DATOS DE PUBLICACIÓN:
Volumen 33, No1. 2018

FORMACIÓN ACADÉMICA

- Escuela Colombiana de Ingeniería Julio Garavito
  Carrera**: Maestría en Ingeniería Civil con énfasis en Geotecnia**
  Año de Finalización: 12/2024

- Universidad Distrital Francisco José de Caldas
  Carrera**: Especialización en Interventoría y Supervisión de Obras de Construcción**
  Año de Finalización: 02/2022

- Universidad Distrital Francisco José de Caldas
  Carrera**: Especialización en Diseño De Vías Urbanas, Tránsito y Transporte**
  Año de Finalización: 06/2018

- Universidad Distrital Francisco José de Caldas
  Carrera**: Ingeniería Civil**
  Año de Finalización: 2016

- Universidad Distrital Francisco José de Caldas
  Carrera**: Tecnología en Construcciones Civiles**
  Año de Finalización: 2013

EDUCACIÓN BÁSICA SECUNDARIA:

Escuela Normal Superior Nuestra Señora de la Paz
Título: Bachiller Académico con Profundización en Educación
Año de Finalización: 2008

EXPERIENCIA LABORAL

- **UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS**
  Bogotá D.C
  Cargo ocupado: DOCENTE PROGRAMA INGENIERÍA CIVIL
  Duración: Enero 2022 - Actual

- **UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS**
  Bogotá D.C
  Cargo ocupado: Consultor Diseño de Vías y Pavimentos
  Duración: agosto 2022 - Diciembre 2023

- **UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS**
  Bogotá D.C
  Cargo ocupado: Laboratorio de Suelos, Concretos y Pavimentos
  Duración: Enero 2016 - Diciembre 2016

- **PRS INGENIERÍA SAS -**
  BOGOTÁ
  Cargo ocupado: Director de Proyectos
  Duración: diciembre 2016 – 2020
  Descripción:
  Encargado de la ejecución de diferentes proyectos de Consultoría, construcción e interventoría, en proyectos viales, construcción vertical, mitigación de riesgo entre otros.

CONSULTOR EN ESTUDIOS Y DISEÑOS:

- **DISEÑO GEOMÉTRICO, DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Supatá, Cundinamarca
  Cargo ocupado: Diseñador

  Descripción:
  Diseño Geométrico, Diseño De Pavimento Y Estudio Geotécnico Para La **Carrera 8 Entre Calle 5 Y Calle 6, Y Calle 6 Entre Carrera 7 Y Carrera 8,** Ubicada En El Municipio De Supatá, Cundinamarca.

- **DISEÑO GEOMÉTRICO, DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Supatá, Cundinamarca
  Cargo ocupado: Diseñador

  Descripción:
  Diseño Geométrico, Diseño De Pavimento Y Estudio Geotécnico Para La **Calle 4 Entre Carrera 9 Y Perímetro Urbano,** Ubicada En El Municipio De Supatá, Cundinamarca.

- **DISEÑO GEOMÉTRICO, DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Supatá, Cundinamarca
  Cargo ocupado: Diseñador

  Descripción:
  Diseño Geométrico, Diseño De Pavimento Y Estudio Geotécnico Para La **Carrera 6 Entre Calle 1 Y 2, Calle 1 Entre Carrera 5 Y 6,** Ubicada En El Municipio De Supatá, Cundinamarca.

- **DISEÑO GEOMÉTRICO, DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Supatá, Cundinamarca
  Cargo ocupado: Diseñador

  Descripción:
  Diseño Geométrico, Diseño De Pavimento Y Estudio Geotécnico Para La **Carrera 4 Entre Calle 1 Y 1A,** Ubicada En El Municipio De Supatá,

Cundinamarca.

- **DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Guaduas, Cundinamarca
  Cargo ocupado: Diseñador

  Descripción:
  Diseño De Pavimento En Concreto Hidráulico, Para La **Estación PF2** Patio De Maniobras Descargadero, Pacific Rubiales Energy, Ubicado En El Municipio De Guaduas, Cundinamarca.

- **DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Madrid, Cundinamarca
  Cargo ocupado: Diseñador

  Descripción:
  Diseño De Pavimento En Concreto Hidráulico, Para El Patio De Maniobras De La Empresa Ercol Ltda, Ubicada En El Municipio De Madrid, Cundinamarca.

- **DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Tierralta, Córdoba.
  Cargo ocupado: Diseñador

  Descripción:
  Diseño De Pavimento Para El Patio De Maniobras De La Construcción Industrial De Una Empacadora De Papaya Ubicado En El Municipio De Tierralta, Córdoba.

- **DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Junín, Cundinamarca.
  Cargo ocupado: Diseñador

  Descripción:
  Diseño De La Estructura De Pavimento Para Los Fallos Presentados En La Vía Ramal – Junín Municipio De Junín, Cundinamarca.

- **DISEÑO DE PAVIMENTO Y ESTUDIO GEOTÉCNICO**
  Guatavita, Cundinamarca.
  Cargo ocupado: Diseñador
  Descripción:
  Diseño De La Estructura De Pavimento Para La Construcción De Una Pista De Patinaje En El Casco Urbano Del Municipio De Guatavita, Cundinamarca.

- **ESTUDIOS Y DISEÑOS DE UNA PLAZOLETA DE EVENTOS**
  Supatá, Cundinamarca.
  Cargo ocupado: Coordinador de Diseños

  Descripción:
  Estudios y diseños para una plazoleta de eventos “La Morenita”, en el

municipio de Supatá, Cundinamarca. Diseño Arquitectonico, Estructural, Hidráuilico y Sanitario, Estudio de Suelos, PMT, Estudio de impacto Ambiental, Diseño de Pavimentos.

Gerente y Director de Proyectos

- **CONSORCIO VILLA NOHORA**
  Supatá, Cundinamarca
  Cargo ocupado: INTERVENTOR
  Duración: Abril 2017 – Enero 2018
  Descripción:
  Representante legal - Director de la interventoría a la construcción de la cubierta del polideportivo Villa Nohora en estructura metálica, ubicado en el municipio de Supatá, Cundinamarca.

- **CONSORCIO SAN FRANCISCO**
  Supatá, Cundinamarca
  Cargo ocupado: INTERVENTOR
  Duración: Octubre 2017 – Enero 2018
  Descripción:
  Representante legal - Director de la interventoría al mejoramiento de la vía que comunica el casco urbano con la vereda el Imparal, en el municipio de Supatá, Cundinamarca.

- **CONSORCIO SAN JOSÉ 051**
  Tenjo, Cundinamarca
  Cargo ocupado: INTERVENTOR
  Duración: Agosto 2017 – Diciembre 2017
  Descripción:
  Representante legal - Director de la interventoría a la construcción de una cicloruta y alcantarillado veredal en el municipio de Tenjo, Cundinamarca

- **CONSORCIO SAN NICOLAS**
  Tenjo, Cundinamarca
  Cargo ocupado: INTERVENTOR
  Duración: Diciembre 2017 – Noviembre 2018
  Descripción:
  Representante legal - Director de la interventoría a la pavimentación y construcción de alcantarillado de vías locales en el casco urbano del municipio de Tenjo, Cundinamarca.

- **CONSORCIO INTERVENTORES 2019**
  Supatá, Cundinamarca
  Cargo ocupado: INTERVENTOR
  Duración: enero 2019 – diciembre 2019
  Descripción:
  Representante legal - Director de la interventoría a la construcción de la plazoleta de eventos “laMorenita” ubicada en el municipio de Supatá, Cundinamarca.

- **CONSORCIO MAJUY**

  Cota, Cundinamarca

  Cargo ocupado: INTERVENTOR

  Duración: Mayo 2019 – enero 2022

  Descripción:

  Representante legal - Director de la interventoría a la Apertura y construcción de las vías el sector sur occidental del municipio de cota incluye obras alcantarillado pluvial, sanitario, acueducto, iluminación, señalización vial y otros.

- **PRS INGENIERÍA SAS**

  Zipauirá, Cundinamarca

  Cargo ocupado: DIRECTOR INTERVENTOR

  Duración: Agosto 2019 – enero 2022

  Descripción:

  Representante legal - Director de la interventoría a la *INTERVENTORÍA TÉCNICA AL PROYECTO CONSTRUCCIÓN CALLE SÉPTIMA del proyecto denominado INFRAESTRUCTURA VIAL LA QUINTA ubicado en Zipaquirá - Cundinamarca*

- **SIGMA INGENIERÍA Y PROYECTOS SAS**

  Bogotá, Cundinamarca

  Cargo ocupado: GERENTE Y DIRECTOR PROYECTOS

  Duración: Diciembre 2021 – Noviembre 2024

  Descripción:

  - Estudios geotécnicos

  - Diseños de cimentaciones

  - Muros de contención

  - Interventoría a sistemas de abastecimiento

  - interventoría a la construcción de carreteras

  - interventoría a escenarios deportivos

  - interventoría a obras geotécnicas.

  - Construcción de Soluciones geotécnicas

  - Mejoramiento de suelos blandos mediante inyecciones sólidas en el suelo

	Dirección de los Siguientes Proyectos
1	**EJECUCIÓN D**E OBRAS DE ELIMINACIÓN DE ASENTAMIENTOS DE SUELO DE FUNDACIÓN COSTADO FRONTAL EDIFICIO ATIKA, MEDIANTE INYECCIONES SÓLIDAS EN EL SUELO.
2	**EJECUCIÓN** CONSTRUCCIÓN DE OBRAS PARA LA MITIGACIÓN DE ASENTAMIENTOS PRESENTADOS EN EL EJE CENTRAL DE LAS BODEGAS MPS, NEXSYS, DEL PARQUE EMPRESARIAL TECNOLÓGICO PH; AUTOPISTA MEDELLÍN (CALLE 80) KM. 2
3	**EJECUCIÓN** OBRAS DE MITIGACIÓN DE ASENTAMIENTOS EN COSTADO NOROCCIDENTAL DEL CONJUNTO BRISAS DE SOTAVENTO, MEDIANTE INYECCIONES SÓLIDAS EN EL SUELO.
4	**EJECUCIÓN** DE LAS OBRAS DE LA MITIGACIÓN DE LA INFILTRACIÓN EN LA CORONA DEL MURO DE CONTENCIÓN DEL CONJUNTO RESIDENCIAL BRISAS DE SOTAVENTO.
5	CONSULTORÍA PARA LA EJECUCIÓN DE LOS ESTUDIOS Y DISEÑOS DE 19 VÍAS EN EL MUNICIPIO DE GACHALÁ, CUNDINAMARCA. ESTUDIO DE SUELOS, TOPOGRAFÍA, DISEÑO DE PAVIMENTOS, DISEÑO GEOMÉTRICO, ESTUDIOS DE TRÁNSITO ENTRE OTROS.
6	**INTERVENTORÍA** TÉCNICA, SOCIO -AMBIENTAL, ADMINISTRATIVA, JURÍDICA Y FINANCIERA DE LA OBRA QUE TIENE POR OBJETO LA CONSTRUCCIÓN DE LA CICLORUTA Y ALCANTARILLADO EN EL ACCESO CENTRO POBLADO LA VEREDA JUAICA PARALELOS A LA VÍA TENJO - TABIO. MUNICIPIO DE TENJO CUNDINAMARCA
7	**INTERVENTORÍA** TÉCNICA, ADMINISTRATIVA Y FINANCIERA AL CONTRATO QUE TIENE POR OBJETO PAVIMENTACIÓN Y CONSTRUCCIÓN DE ALCANTARILLADO DE LAS VÍAS LOCALES DEL CASCO URBANO CARRERA 1G ENTRE CALLES 6 Y 7, CALLE 7 ENTE CARRERAS 1G Y 2 G Y CARRERA 7 ENTRE CALLE 6 Y7, MANTENIMIENTO PREVENTIVO VÍAS CARRERA 8 Y 9 ENTRE 1 E Y 1 B PROYECTADA, CALLE 1C ENTRE 7 Y9 DEL MUNICIPIO DE TENJO
8	**INTERVENTORIA** TECNICA, ADMINISTRATIVA, FINANCIERA, LEGAL Y AMBIENTAL PARA REALIZAR EL CONTROL Y SEGUIMIENTO A LA EJECUCIÓN DE LAS SIGUIENTES OBRAS: APERTURA Y CONSTRUCCIÓN DE LAS VÍAS EL SECTOR SUR OCCIDENTAL DEL MUNICIPIO DE COTA INCLUYE OBRAS ALCANTARILLADO PLUVIAL, SANITARIO, ACUEDUCTO, ILUMINACIÓN SEÑALIZACIÓN VIAL Y OTROS
9	**INTERVENTORÍA** TECNICA ESPECILIZADA AL PROYECTO CONSTRUCCIÓN CALLE SEPTIMA DEL PROYECTO INFRAESTRUCTURA VIAL LA QUINTA
10	**INTERVENTORIA**, TECNICA, ADMINISTRATIVA Y FINANCIERA DE LAS OBRAS DE CONTRUCCION DE SOLUCIONES DE VIVIENDA (TIPO MEJORAMIENTOS Y CASAS), EN EL MUNICIPIO DE JERUSALEN CUNDINAMARCA
11	**CONSULTORÍA** SERVICIOS PROFESIONALES DE APOYO A LA SECRETARIA DEGOBIERNO PARA ACTUALIZACIÓN DEL PLAN DE GESTIÓN DELRIESGO DEL MUNICIPIO DE OTANCHE - BOYACÁ 2020
12	**CONSULTORÍA** CONTRATAR LOS ESTUDIOS Y DISEÑOS PARA LA CONSTRUCCIÓN DE LA VÍA LOCALIZADA EN LA VEREDA EL CAMPIN COMPRENDIDA DESDE LA ENTRADA BOMBEROS ANTIGUO BATALLÓN HASTA EL CRUCE HACIA EL BARRIO EL PALMAR EN EL MUNICIPIO DE CAQUEZA DEPARTAMENTO DE CUNDINAMARCA.

13	**CONSULTORÍA** ESTUDIOS Y DISEÑOS PARA ADECUACION Y MEJORAMIENTO DE LA INFRAESTRUCTURA DEPORTIVA Y RECREATIVA, DE LA VILLA OLÍMPICA DEL MUNICIPIO DE OTANCHE BOYACÁ 2020”
14	**CONSULTORÍA** CONTRATAR LA ELABORACIÓN DE LOS ESTUDIOS Y DISEÑOS DE LA ESTRUCTURA DE PROTECCIÓN POR INUNDACIÓN A LA INSTITUCIÓN EDUCATIVA DEPARTAMENTAL RURAL CUNE, DEL MUNICIPIO DE VILLETA, CUNDINAMARCA. EN EL MARCO DEL CUMPLIMIENTO DEL PLAN DE DESARROLLO MUNICIPAL, VIA, EN EL MARCO DEL CUMPLIMIENTO DE PLAN DE DESARROLLO, VILLETA COMPETITIVA CON GESTIÓN TRANSPARENTE 2020 – 2024.
15	**CONSULTORÍA** CONTRATAR LA ELABORACIÓN DE LOS ESTUDIOS Y DISEÑOS DE LA ESTRUCTURA DE CONTENCIÓN Y PROTECCIÓN DEL TALUD, DE LA VÍA QUE DEL CASCO URBANO CONDUCE AL CENTRO POBLADO BAGAZAL, ESPECÍFICAMENTE EN EL SECTOR CONOCIDO COMO VILLA LUISA, DEL MUNICIPIO DE VILLETA, CUNDINAMARCA. EN EL MARCO DEL CUMPLIMIENTO DEL PLAN DE DESARROLLO MUNICIPAL, VILLETA COMPETITIVA CON GESTIÓN TRANSPARENTE 2020 - 2024.
16	**CONSULTORÍA** ESTUDIOS Y DISEÑOS PARA DETERMINAR Y CUANTIFICAR LAS OBRAS A REALIZAR PARA EL TRASLADO DEL VERTIMIENTO DE AGUA RESIDUAL No. 3 AL VERTIMIENTO DE AGUA RESIDUAL No. 4 UBICADO EN EL BARRIO SAN CAYETANO, SECTOR PALMANOVA, DEL MUNICIPIO DE VILLETA,
17	“CONTRATO DE INTERVENTORÍA TÉCNICA, ADMINISTRATIVA, FINANCIERA Y AMBIENTAL A LOS CONTRATOS DE OBRAS DE CONSTRUCCIÓN Y/O REPOSICIÓN DE REDES DE ALCANTARILLADO SANITARIO EN LA VEREDA PORVENIR SEGUNDA FASE, CONSTRUCCIÓN Y/O REHABILITACIÓN DE REDES DE ALCANTARILLADO EN LA VEREDA VERGANZO Y REPARACIÓN E INSTALACIÓN DE REDES DE ACUEDUCTO EN EL MUNICIPIO DE
18	REALIZAR LA INTERVENTORÍA INTEGRAL QUE INCLUYE PERO NO SE LIMITA A LA INTERVENTORÍA TÉCNICA, ADMINISTRATIVA, FINANCIERA, LEGAL, Y AMBIENTAL DEL CONTRATO DE OBRA RESULTANTE DEL PROCESO DE LICITACIÓN PUBLICA LP No. 06 DEL 2021, CUYO OBJETO ES: “REALIZAR LOS ESTUDIOS Y DISEÑOS, Y LA CONSTRUCCIÓN DEL PROYECTO SACÚDETE AL PARQUE TIPO 2 OPCIÓN 4, EN EL MUNICIPIO DE VILLETA CUNDINAMARCA, EN EL MARCO DEL CUMPLIMIENTO DEL CONVENIO 988 DEL 2021, FIRMADO ENTRE EL MINISTERIO DEL INTERIOR Y EL FONDO
19	**INTERVENTORÍA** TÉCNICA ADMINISTRATIVA FINANCIERA Y AMBIENTAL DEL CONTRATO DE OBRA PÚLICA No. 024 - 2015 CUYO OBJETO ES LA CONSTRUCCIÓN DE LA PRIMERA ETAPA DE LA URBANIZACIÓN SAN ANTONIO MUNICIPIO DE SUPATÁ CUNDINAMARCA
20	**INTERVENTORÍA** TÉCNICA ADMINISTRATIVA FINANCIERA Y AMBIENTAL DEL CONTRATO DE OBRA PÚLICA No. 023 - 2015 CUYO OBJETO ES LA CONSTRUCCIÓN DE LA CUBIERTA POLIDEPORTIVO VILLA NOHORA MUNICIPIO DE SUPATÁ CUNDINAMARCA
21	**INTERVENTORÍA** TÉCNICA ADMINISTRATIVA FINANCIERA Y AMBIENTAL DEL CONTRATO DE OBRA PÚLICA No. 014 - 2017 CUYO OBJETO ES EL MEJORAMIENTO DE LA VIA QUE COMUNICA EL CASCO URBANO CON LA VEREDA IMPARAL, EN EL SECTOR LA ESPERANZA DEL MUNICIPIO DE SUPATÁ CUNDINAMARCA

22	**INTERVENTORÍA** TÉCNICA, ADMINISTRATIVA, AMBIENTAL Y FINANCIERA DEL CONTRATO DE OBRA PÚBLICA 017-2018 CUYO OBJETO ES CONSTRUCCIÓN DE PAVIMENTO RÍGIDO EN CARRERA 8, ENTRE CALLES 5 Y CALLE 6, Y CALLE 6 ENTRE CARRERA 7 Y CARRERA 8 DEL CASCO URBANO DEL MUNICIPIO DE SUPATÁ, CUNDINAMARCA.
23	**INTERVENTORÍA** TECNICA, ADMINISTRATIVA, AMBIENTAL Y FINANCIERA DEL CONTRATO DE OBRA PUBLICA 001-2019 CUYO OBJETO ES LA CONSTRUCCIÓN DE LA PLAZOLETA DE EVENTOS "LA MORENITA" EN EL MUNICIPIO DE SUPATÁ CUNDINAMARCA.
24	**INTERVENTORÍA** TECNICA ADMINISTRATIVA, FINANCIERA Y AMBIENTAL DEL CONTRATO DE OBRA PUBLICA N° 002-2019 CUYO OBJETO ES: DEMARCACION Y SEÑALIZACION DE LA ZONA RURAL Y URANA DEL MUNICIPIO DE SUPATA CUNDINAMARCA
25	**CONSULTORÍA** PARA LA ELABORACIÓN DE LOS ESTUDIOS Y DISEÑOS DEL PROYECTO DE VIVIENDA DE OTANCHE - BOYACÁ 2020

CERTIFICACIONES Y REGISTROS ACADÉMICOS

República de Colombia

ESCUELA
COLOMBIANA
DE INGENIERÍA
JULIO GARAVITO

UNIVERSIDAD

La Universidad Escuela Colombiana de Ingeniería Julio Garavito

con personería jurídica concedida por el Ministerio de Justicia según Resolución N.° 086 del 19 de enero de 1973

otorgó a

Daniel Francisco Patiño Sánchez

C.C. 1.023.919.687

El título de

Magíster en Ingeniería Civil

En testimonio de ello se expide el presente diploma.
Bogotá, D.C., 4 de marzo de 2025

Presidente del Consejo Directivo | *Rector* | *Secretario General*

Acta de grado N.° 5717 | *Registro N.° 020517* | *Libro de Diplomas N.° 01* | *Folio N.° 10259*

ESCUELA
COLOMBIANA
DE INGENIERÍA
JULIO GARAVITO

UNIVERSIDAD

La Universidad Escuela Colombiana de Ingeniería Julio Garavito

con Personería Jurídica concedida por el Ministerio de Justicia, según Resolución N.° 086 del 19 de enero de 1973,

certifica que

Daniel Francisco Patiño Sánchez

C.C. 1.023.919.687

obtuvo el título de

Magíster en Ingeniería Civil, en la modalidad de profundización,
con énfasis en **Geotecnia**.

En testimonio de lo anterior, se expide a los cuatro (4) días del mes de marzo de 2025.

Myriam Astrid Angarita Gómez
Rectora

Patricia Salazar Perdomo
Secretaria General

Germán Ricardo Santos Granados
Director de la Maestría

ESCUELA COLOMBIANA DE INGENIERÍA JULIO GARAVITO
UNIVERSIDAD

REPÚBLICA DE COLOMBIA
MINISTERIO DE EDUCACIÓN NACIONAL Y EN SU NOMBRE

LA UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS

CONFIERE EL TÍTULO DE

Especialista en Interventoría y Supervisión de Obras de Construcción

A

Daniel Francisco Patiño Sánchez

Con C. C. No. 1.023.919.687 de Bogotá D.C.

QUIEN CUMPLIÓ CON LAS CONDICIONES ACADÉMICAS REQUERIDAS. EN TESTIMONIO DE ELLO OTORGA EL PRESENTE

DIPLOMA

EN LA CIUDAD DE BOGOTÁ D. C., A LOS 4 DÍAS DEL MES DE MARZO DE 2022

RECTOR | SECRETARIO GENERAL | DECANO DE LA FACULTAD | SECRETARIO ACADÉMICO

No. 54013

Registro No. FT19551 Folio No. 3 Libro No. 23

REPÚBLICA DE COLOMBIA
MINISTERIO DE EDUCACIÓN NACIONAL Y EN SU NOMBRE

LA UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS

CONFIERE EL TÍTULO DE

Especialista en Diseño de Vías Urbanas, Tránsito y Transporte

A

Daniel Francisco Patiño Sanchez

Con C. C. No. 1023919687 de BOGOTÁ D.C.

QUIEN CUMPLIÓ CON LAS CONDICIONES ACADÉMICAS REQUERIDAS. EN TESTIMONIO DE ELLO OTORGA EL PRESENTE

DIPLOMA

EN LA CIUDAD DE BOGOTÁ D. C., A LOS 5 DÍAS DEL MES DE OCTUBRE DE 2018

RECTOR | SECRETARIO GENERAL | DECANO DE LA FACULTAD | SECRETARIO ACADÉMICO

No. 40261

Registro No. 12585 Folio No. 130 Libro No. 1

REPÚBLICA DE COLOMBIA
MINISTERIO DE EDUCACIÓN NACIONAL Y EN SU NOMBRE

LA UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS

CONFIERE EL TÍTULO DE

Ingeniero Civil

A

Daniel Francisco Patiño Sánchez

Con C. C. No. 1.023.919.687 de Bogotá D.C.

QUIEN CUMPLIÓ CON LAS CONDICIONES ACADÉMICAS REQUERIDAS. EN TESTIMONIO DE ELLO OTORGA EL PRESENTE

DIPLOMA

EN LA CIUDAD DE BOGOTÁ D. C., A LOS 4 DÍAS DEL MES DE AGOSTO DE 2017

RECTOR | SECRETARIO GENERAL | DECANO DE LA FACULTAD | SECRETARIO ACADÉMICO

No. 33739 | Registro No. FT14836 | Folio No. 79 Libro No. 18

REPÚBLICA DE COLOMBIA
MINISTERIO DE EDUCACIÓN NACIONAL Y EN SU NOMBRE

LA UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS

CONFIERE EL TÍTULO DE

Tecnólogo en Construcciones Civiles

A

Daniel Francisco Patiño Sánchez

Con C.C.No. 1.023.919.687 de Bogotá D.C.

QUIEN CUMPLIÓ CON LAS CONDICIONES ACADÉMICAS REQUERIDAS.
EN TESTIMONIO DE ELLO OTORGA EL PRESENTE

DIPLOMA

EN LA CIUDAD DE BOGOTÁ D.C., A LOS 26 DÍAS DEL MES DE Abril DE 2.013

RECTOR | *SECRETARIO GENERAL* | *DECANO DE LA FACULTAD* | *SECRETARIO ACADÉMICO*

Registro No FT9092 *Folio No.* 3 *Libro No.* 14

No. 12085

CERTIFICACIONES Y REGISTROS LABORALES

OFICINA DE EXTENSIÓN –IDEXUD- UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
NIT: 899.999.230.7

CERTIFICA

Que revisadas las bases de datos que reposan en los archivos del **IDEXUD**, se encuentra que el señor **DANIEL FRANCISCO PATIÑO SANCHEZ,** identificado con cédula de ciudadanía **No. 1.023.919.687 de Bogotá DC.,** suscribió con esta entidad las Órdenes y/o Contratos de Prestación de Servicios, que a continuación se relacionan:

CONTRATO DE PRESTACIÓN DE SERVICIOS:	**346 I -2023**
EN DESARROLLO DEL CONTRATO INTERADMINISTRATIVO:	**001-2022**
FECHA DE SUSCRIPCIÓN:	09 de febrero de 2023
FECHA ACTA DE INICIO:	17 de febrero de 2023
VALOR CONTRATADO:	$13.500.000.oo M/cte.
DURACIÓN:	Once (11) días
FECHA DE TERMINACIÓN:	27 de febrero de 2024

OBJETO: Prestar servicios de manera autónoma e independiente como Especialista en vías, tránsito y transporte dentro del marco del contrato interadministrativo 001-2022 suscrito entre la Alcaldía de Gachalá y la Universidad Distrital Francisco José de Caldas cuyo objeto es “Fase I. estudios y diseños para la pavimentación de vías, señalización, y mejoramiento, rehabilitación y/o adecuación de andenes en el casco urbano del Municipio de Gachala, Departamento de Cundinamarca.

ACTIVIDADES:

1. Diseño geométrico detallado de 19 vías, incluídas memorias de cálculo con descripción, planos y documentos complementarios.
2. Evaluación del tránsito vehicular a partir del desarrollo de aforos y conteos vehiculares o (estaciones maestras y secundarias) localizadas de forma planeada y búsqueda de información secundaria de la zona.
3. Diseño de la señalización y seguridad vial de más de 30 segmentos viales coordinado con el diseño geométrico del proyecto y las respectivas memorias de cálculo y planos.
4. Atender las demás actividades que le sean asignadas por el supervisor

La presente se expide en Bogotá D.C., a los veintitrés (23) días del mes de diciembre de 2024.

ROBERTO FERRO ESCOBAR
Jefe Oficina de Extensión-IDEXUD

	NOMBRE	CARGO	FIRMA
Proyectó:	Cindy Viviana Cruz	CPS OFEX	
Aprobó:	Andrés Valencia Ramírez	CPS OFEX	
Los arriba firmantes declaramos que hemos revisado el presente documento y lo encontramos ajustado a la norma y disposiciones legales y/o técnicas y por lo tanto bajo nuestra responsabilidad lo presentamos para la firma del remitente.			

LA JEFE DE LA OFICINA DE TALENTO HUMANO DE LA UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS NIT 899.999.230-7

C E R T I F I C A

Que el (la) Señor(a) **Daniel Francisco Patiño Sánchez**, identificado(a) con cédula de ciudadanía número **1.023.919.687**, labora en esta Institución en la modalidad de Docente de Vinculación Especial Hora Catedra a Termino Fijo, para los periodos académicos que a continuación se detallan, en el nivel de académico **Asistente,** adscrito a la Facultad Tecnológica en los Proyectos curriculares: Tecnología en Construcciones Civiles e Ingeniería Civil Articulado por Ciclos Propedéuticos con Tecnología en Construcciones Civiles, con la siguiente intensidad horaria:

AÑO	PERIODO	DEDICACIÓN ASIGNATURAS	HORAS SEMANA	NUMERO SEMANAS	TOTAL, HORAS SEMESTRALES
2022	I	MATERIALES DE CONSTRUCCION DISEÑO Y CONSTRUCCION DE PAVIMENTOS MAQUINARIA Y EQUIPOS		DEL 26 DE ABRIL AL 19 DE AGOSTO DE 2022	
2022-I	Totales	Hora Cátedra	16	17	272
2022	III	MATERIALES DE CONSTRUCCION DISEÑO Y CONSTRUCCION DE PAVIMENTOS MAQUINARIA Y EQUIPOS		DEL 29 DE AGOSTO AL 24 DE DICIEMBRE DE 2022	
2022-III	Totales	Hora Cátedra	16	17	272
2023	I	MATERIALES DE CONSTRUCCION DISEÑO Y CONSTRUCCION DE PAVIMENTOS MAQUINARIA Y EQUIPOS		DEL 01 DE FEBRERO AL 10 DE JUNIO DE 2023	
2023-I	Totales	Hora Cátedra	16	18	288
2023	III	MATERIALES DE CONSTRUCCION DISEÑO Y CONSTRUCCION DE PAVIMENTOS MAQUINARIA Y EQUIPOS		DEL 01 DE AGOSTO AL 09 DE DICIEMBRE DE 2023	
2023-III	Totales	Hora Cátedra	16	19	304
2024	I	MATERIALES DE CONSTRUCCION DISEÑO Y CONSTRUCCION DE PAVIMENTOS MAQUINARIA Y EQUIPOS		DEL 01 DE FEBRERO AL 13 DE JUNIO DEL 2024	
2024-I	Totales	Hora Cátedra	16	18	288
2024	III	MATERIALES DE CONSTRUCCION DISEÑO Y CONSTRUCCION DE PAVIMENTOS MAQUINARIA Y EQUIPOS		DEL 05 DE AGOSTO AL 14 DE DICIEMBRE DE 2024	
2024-III	Totales	Hora Cátedra	16	19	304

2024	III	MATERIALES DE CONSTRUCCION DISEÑO Y CONSTRUCCION DE PAVIMENTOS MAQUINARIA Y EQUIPOS		DEL 13 DE ENERO AL 15 DE FEBRERO DE 2025	
2024-III	Totales	Hora Cátedra	16	5	80

Se expide en Bogotá D.C. a los trece (13) días del mes de febrero del año dos mil veinticuatro (2024) a solicitud del interesado

ANDREA CAROLINA HOSPITAL GORDILLO
Jefe de la Oficina de Talento Humano

	NOMBRE	CARGO	FIRMA
Elaboro	*John Mendoza*	*CPS Oficina de Talento Humano*	John Mendoza

EL JEFE DE LA DIVISION DE RECURSOS HUMANOS DE LA UNIVERSIDAD DISTRITAL FRANCISCO JOSE DE CALDAS NIT 899.999.230-7

C E R T I F I C A

Que el señor, DANIEL FRANCISCO PATIÑO SANCHEZ, identificado con la cédula de ciudadanía número 1.023.919.687 se encuentra Vinculado a esta Institución como Docente de Vinculación Especial Hora Catedra. TERMINO FIJO, para el periodo Académico 2023-1 y vinculado en los periodos académicos que a continuación se relacionan, en el nivel académico Asistente adscrito a la Facultad de TECNOLOGICA en los Proyectos Curriculares: TECNOLOGIA EN CONSTRUCCIONES CIVILES (CICLOS PROPEDEUTICOS), INGENIERIA CIVIL (CICLOS PROPEDEUTICOS), con la siguiente intensidad Horaria

AÑO	PERIODO	DEDICACION ASIGNATURAS	HORAS SEMANA	NUMERO SEMANAS	TOTAL HORAS SEMESTRALES
2022	I	DISEÑO Y CONSTRUCCIÓN DE PAVIMENTOS MAQUINARIA Y EQUIPOS MATERIALES DE CONSTRUCCIÓN		DEL 26 DE ABRIL AL 19DE AGOSTO DE 2022	
2022-I	Totales	Hora Cátedra	16	17	272
2022	III	DISEÑO Y CONSTRUCCIÓN DE PAVIMENTOS MAQUINARIA Y EQUIPOS MATERIALES DE CONSTRUCCIÓN		DEL 29 DE AGOSTO AL 24 DE DICIEMBRE DE 2022	
2022-III	Totales	Hora Cátedra	16	17	272
2023	I	DISEÑO Y CONSTRUCCIÓN DE PAVIMENTOS MAQUINARIA Y EQUIPOS MATERIALES DE CONSTRUCCIÓN		DEL 1 DE FEBRERO AL 9 DE JUNIO DE 2023	
2023-I	Totales	Hora Cátedra	16	18	288

Sueldo mensual……………………………….$2.420.115

Se expide en Bogotá D.C. a los Diez (10) días del mes de abril del año dos mil veintitrés (2023) a solicitud del interesado

JUAN CARLOS AMAYA PICO

Jefe División de Recursos Humanos (E)

	NOMBRES Y APELLIDOS	CARGO	FIRMA
PROYECTÓ	VICTOR ALVAREZ CORTINA	CPS DIVISIÓN DE RECURSOS HUMANOS	

CONSORCIO INTERVIAL 2018

NIT: 901221933-3

CERTIFICACIÓN DE

DANIEL FRANCISCO PATIÑO SANCHEZ

A QUIEN INTERESE

El suscrito, CARLOS ANTONIO VELAZCO, identificado con cédula de ciudadanía No 80.398.771 de Bogotá, Cundinamarca, en mi condición de coordinador de interventoría del Consorcio Intervial 2018, me permito certificar, que el señor **DANIEL FRANCISCO PATIÑO SANCHEZ**, identificado con cédula de ciudadanía No 1.023.919.687 de Bogotá, laboró en nuestra empresa Consorcio Intervial 2018 desde el día doce (12) de Octubre de Dos mil dieciocho (2018) hasta el dieciocho (18) de Abril de 2019, desempeñando el cargo de **DIRECTOR DE INTERVENTORÍA ESPECIALISTA EN TRAZADO DE VÍAS**, en el contrato de interventoría No. 003-2018 firmado con la Alcaldía Municipal del municipio de Supatá, cuyo objeto es ***La Interventoría Técnica, Administrativa, Ambiental Y Financiera Del Contrato De Obra Pública No 017-2018, Cuyo Objeto Es La Construcción De Pavimento Rígido En La Carrera 8, Entre Calle 5 Y Calle 6, Y Calle 6 Entre Carrera 7, Y Carrera 8 Del Casco Urbano Del Municipio De Supatá Cundinamarca. Valor total del contrato: $ 51’168.096.00***

Se expide esta certificación a solicitud del interesado a los 13 días del mes de Mayo de 2019.

Cordialmente,

Carlos Antonio Velazco
Coordinador Interventoría
Consorcio Intervial 2018
Móvil. 311 2418932

A QUIEN INTERESE

WILSON VASQUEZ ROMERO identificado con cédula de ciudadanía No 80.161.326 de Bogotá, Cundinamarca, en mi condición de ASESOR GENERAL de interventoría del Consorcio Interventores 2019, me permito certificar, que el señor **DANIEL FRANCISCO PATIÑO SANCHEZ** identificado con cédula de ciudadanía No 1.023.919.687 de Bogotá, laboró en nuestra empresa Consorcio Interventores 2019 desde el día cinco (05) de Enero de Dos mil diecinueve (2019) hasta el veinte (20) de diciembre de 2019, desempeñando el cargo de **DIRECTOR DE INTERVENTORÍA**, en el contrato de interventoría No. 001-2019 firmado con la Alcaldía Municipal del municipio de Supatá, cuyo objeto es "***La Interventoría Técnica, Administrativa, Ambiental Y Financiera Del Contrato De Obra Pública No 001-2019, Cuyo Objeto Es La Construcción De La Plazoleta De Eventos "La Morenita" En El Municipio De Supatá Cundinamarca."***

Se expide esta certificación a solicitud del interesado a los 22 días del mes enero de

2020. Cordialmente,

____

Wilson Andrés Vásquez
Representante Legal
Consorcio Santa Sofía
Móvil. 311 4552533

CONSORCIO SAN NICOLÁS
NIT: 901.142.138-5

CERTIFICACIÓN LABORAL DE
DANIEL FRANCISCO PATIÑO SANCHEZ

A QUIEN INTERESE

El suscrito, CRISTIAN CAMILO TORRES, identificado con cédula de ciudadanía No 1.014.331.222 de Bogotá, Cundinamarca, en mi condición de coordinador de interventoría del Consorcio San Nicolás, me permito certificar, que el señor **DANIEL FRANCISCO PATIÑO SANCHEZ**, identificado con cédula de ciudadanía No 1.023.919.687 de Bogotá, laboró en nuestra empresa Consorcio San Nicolás desde el día veintinueve (29) de Diciembre de Dos mil diecisiete (2017) hasta el veintinueve (29) de Noviembre de Dos mil dieciocho (2018), desempeñando el cargo de **DIRECTOR DE INTERVENTORÍA**, en el contrato de interventoría No. 358- 2017 firmado con la Alcaldía Municipal del municipio de Tenjo, cuyo objeto ***Es La Interventoría Técnica, Administrativa Y Financiera Al Contrato Que Tiene Por Objeto Pavimentación Y Construcción De Alcantarillado De Las Vías Locales Del Casco Urbano Carrera IG Entre Calle 6 Y 7, Calle 7 Entre Carrera IG Y 2 Y Carrera 7 Entre Calle 6 Y 7, Mantenimiento Preventivo Vías Carrera 8 Y 9 Entre IE Y 1B Proyectada, Calle 1C Entre 7 Y 9 Del Municipio De Tenjo Cundinamarca. Valor total del contrato $ 39’369.000***

Se expide esta certificación a solicitud del interesado a los 16 días del mes de Junio de 2018.

Cordialmente,

Cristian Camilo Torres
Coordinador
Interventoría Consorcio
San Nicolás Móvil.
322 331 4022

CONSORCIO SAN JOSÉ 051

NIT: 901.096.401-0

CERTIFICACIÓN LABORAL DE

DANIEL FRANCISCO PATIÑO SANCHEZ

A QUIEN INTERESE

El suscrito, JOHAN OXIRIS QUITIAN CHILA, identificado con cédula de ciudadanía No 3.190.616 de Bogotá, Cundinamarca, en mi condición de coordinador de interventoría del Consorcio San José 051, me permito certificar, que el señor **DANIEL FRANCISCO PATIÑO SANCHEZ**, identificado con cédula de ciudadanía No 1.023.919.687 de Bogotá, laboró en nuestra empresa Consorcio San José 051 desde el día diecinueve (19) de Julio de 2017 hasta el diecinueve (19) de Noviembre de 2017, desempeñando el cargo de **DIRECTOR DE INTERVENTORÍA**, en el contrato de interventoría No. 254-2017 firmado con la Alcaldía Municipal del municipio de Tenjo, **con valor total de $ 28'298.096** cuyo objeto es ***La Interventoría Técnica, Socio-Ambiental, Administrativa, Jurídica Y Financiera De La Obra Que Tiene Por Objeto La Construcción De La Cicloruta Y Alcantarillado En El Acceso Centro Poblado De La Vereda De Juaica Paralelos A La Vía Tenjo- Tabio Del Municipio De Tenjo Cundinamarca Fase 1.***

Se expide esta certificación a solicitud del interesado a los 29 días del mes de Noviembre de 2017.

Cordialmente,

JHOAN OXIRIS QUITIAN
Coordinador Interventoría
Consorcio San José 051
Móvil. 3138341560

CONSORCIO SAN CAYETANO

Nit: 901.416.225-5

CERTIFICACIÓN LABORAL DE

DANIEL FRANCISCO PATIÑO SANCHEZ

A QUIEN INTERESE

El suscrito, CRISTIAN CAMILO TORRES, identificado con cédula de ciudadanía No 1.014.331.222 de Bogotá, Cundinamarca, en mi condición de coordinador de interventoría del Consorcio San Cayetano, me permito certificar, que el señor DANIEL FRANCISCO PATIÑO SANCHEZ identificado con cédula de ciudadanía No 1.023.919.687 de Bogotá, laboró en nuestra empresa, desde el día ocho (01) de Octubre de Dos mil veinte (2020) hasta el treinta y uno (31) de diciembre de 2021, desempeñando el cargo de DISEÑADOR GEOMETRICO DE VIAS, en el contrato 030-2020 celebrado con la alcaldía de Cáqueza cuyo objeto es "CONTRATAR LOS ESTUDIOES Y DISEÑOS PARA LA CONSTRUCCION DE LA VIA LOCALIZADA EN LA VEREDA EL CAMPIN COMPRENDIDA DESDE LA ENTRADA DE BOMBEROS ANTIGUO BATALLON HASTA EL CRUCE HACIA EL BARRIOEL PALMAR EN EL MUNICIPIO DE CAQUEZA DEPARTAMENTO DE CUNDINAMARCA"

Se expide esta certificación a solicitud del interesado a los 11 días del mes de enero de 2022.

Cordialmente,

____

CRISTIAN TORRES
Coordinador consultoría
Consorcio San Cayetano

CONSORCIO SAN FRANCISCO
NIT: 901.121.127-4

CERTIFICACIÓN LABORAL DE

DANIEL FRANCISCO PATIÑO SANCHEZ

A QUIEN INTERESE

El suscrito, CRISTIAN CAMILO TORRES, identificado con cédula de ciudadanía No 1.014.331.222 de Bogotá, Cundinamarca, en mi condición de coordinador de interventoría del Consorcio San Francisco, me permito certificar, que el señor **DANIEL FRANCISCO PATIÑO SANCHEZ** identificado con cédula de ciudadanía No 1.023.919.687 de Bogotá, laboró en nuestra empresa Consorcio San Francisco desde el día ocho (08) de Octubre de Dos mil diecisiete (2017) hasta el veintiocho (28) de Enero de 2018, desempeñando el cargo de **DIRECTOR DE INTERVENTORÍA**, en el contrato de interventoría No. 004-2017 firmado con la Alcaldía Municipal del municipio de Supatá, cuyo objeto es La Interventoría Técnica, Administrativa Financiera y Ambiental del contrato de obra pública No 014-2017, cuyo objeto es ***El mejoramiento de la Vía que comunica el Casco urbano con la vereda Imparal, en el sector la Esperanza del municipio de Supatá Cundinamarca.***

El valor total del contrato fue de: **$ 19'999.735.00**

Se expide esta certificación a solicitud del interesado a los 15 días del mes de Marzo de 2018.

Cordialmente,

____

CRISTIAN CAMILO TORRES
Coordinador Interventoría

CONSORCIO MAJUY

NIT: 901.276.099-1

CERTIFICACIÓN LABORAL
CONSORCIO MAJUY

El suscrito, EDWIN FERNANDO MARROQUIN , identificado con cédula de ciudadanía No 80.250.114 de Bogotá, Cundinamarca, actuando en calidad de gestor de recursos humanos del Consorcio MAJUY, me permito certificar, que el ingeniero **DANIEL FRANCISCO PATIÑO SANCHEZ** identificado con cédula de ciudadanía No 1.023.919.687 de Bogotá, laboró en nuestra empresa Consorcio MAJUY desde el día ocho (08) de MAYO de Dos mil diecinueve (2019) hasta la fecha, desempeñando el cargo de **DIRECTOR DE INTERVENTORÍA ESPECIALISTA EN TRAZADO DE VÍAS**, en el contrato de interventoría No. 762-2019 firmado con la Alcaldía Municipal del municipio de Cota, cuyo objeto es La Interventoría Técnica, Administrativa Financiera y Ambiental del contrato de obra pública No 760-2019, cuyo objeto es Apertura y construcción de las vías el sector sur occidental del municipio de cota incluye obras alcantarillado pluvial, sanitario, acueducto,iluminación, señalización vial y otros. El valor de dicho contrato fue de $ **820’435.621.00**

Se expide esta certificación a solicitud del interesado a los 14 días del mes de enero de 2022.

Cordialmente,

EDWIN FERNANDO MARROQUIN
GESTOR RECURSOS HUMANOS

ARTÍCULO 1:

JOURNAL OF MATERIALS IN CIVIL ENGINEERING

Blast Furnace Slag as a Substitute for the Fine Fraction of Aggregates in an Asphalt Mixture

Hugo Alexander Rondón-Quintana, Ph.D.[1]; Juan Carlos Ruge-Cárdenas, Ph.D.[2]; Daniel Francisco Patiño-Sánchez[3]; Hermes Ariel Vacca-Gamez[4]; Fredy Alberto Reyes-Lizcano, Ph.D.[5]; and Márcio Muniz de Farias, Ph.D.[6]

Abstract: Blast furnace slags (BFS) have interesting physical properties and chemical compositions for the production of mastics in asphalt mixtures. However, most of the studies conducted on this material and their applications in asphalt mixtures have been as substitutes for the coarse fraction of natural aggregates (NGA). In the present study, an experimental program was devised to evaluate the effect on the resistance of a hot mix asphalt (HMA), due to the replacement of fine fraction of a NGA by a BFS. The mechanical properties investigated were indirect tensile strengths, resilient modulus, permanent deformation, resistance to fatigue, and moisture damage. Analysis of variance (ANOVA) tests were performed to verify or reject the null hypothesis that the results are statically equal to those of the reference mixture. X-ray diffractometry (XRD) and X-ray fluorescence (XRF) tests were carried out on particles of BFS and NGA. Additionally, the samples were subjected to imaging processing in a scanning electron microscope (SEM). Characterization tests (viscosity, softening point, penetration, and indirect tension) were performed on mixtures made of fine particles (NGA and BFS) and asphalt. The BFS used as fine aggregate tends to generate, in conjunction with asphalt, a material with improved properties of resistance under monotonic and dynamic load. **DOI: 10.1061/(ASCE)MT.1943-5533.0002409.** *© 2018 American Society of Civil Engineers.*

Author keywords: Blast furnace slag; Asphalt mixture; Fine aggregate fraction; Resistance under monotonic and cyclic loads; Resistance to moisture damage.

Introduction

Background

Slags can be classified into three categories: ferrous blast furnace slag, nonferrous slag, and incineration slag (Shen and Forssberg 2003). According to Das et al. (2007), blast furnace slags (BFS) are inorganic materials whose typical composition is silica (30–35%), calcium oxide (28–35%), magnesium oxide (1–6%), and Al_2O_3/Fe_2O_3 (18–25%). This material is formed when iron ore, coke, and flux (either limestone or dolomite) are melted together in a furnace. When the metallurgic casting process is complete, the lime in the flow has been chemically combined with the aluminates and silicates of mineral ash and coke, generating the BFS (FHWA 2008; Marriaga and Claisse 2011). According to the NSA (2006), the slag from the blast furnaces is slowly cooled outdoors [air-cooled blast furnace slag (ACBFS)] or quickly cooled by applying jets of cold water (expanded slag). ACBFS is used in the construction mainly as aggregate (concrete and fillers, among others), while expanded slag is generally used in cement production. Expanded slag, because of its increased porosity and reduced weight compared to ACBFS, is also used in the manufacture of concretes and light masonry (Van Oss 2003).

According to Okumura (2013), Proctor et al. (2000), and Airey et al. (2004), the annual production of BFS in the United States, Japan, and the UK is 13, 24.3, and 4 million tons, respectively. For each ton of iron produced, an amount of BFS between 220 and 370 kg (Proctor et al. 2000) or 340 and 421 kg (Das et al. 2007) is generated. In Colombia, the iron production was estimated at 710,047 tons for 2013 (UPME 2014) and increased to 901,736 tons during 2015 (HERALDO 2016), from which an annual production of approximately 2×10^5 tons of BFS can be estimated. The conventional method of slag disposal is transporting and depositing the material in open heaps and landfills. This generates an environmental problem because they occupy spaces in landfills, besides wasting a material that can be reused. According to Nouvion et al. (2009), using BFS could generate the following benefits: (1) reducing the use of natural aggregates, preventing additionally the release of pollutants into the air, water, and soil during the processing of such materials, and (2) reducing energy consumption from the exploitation of natural aggregates.

BFS have been used widely in the world for over a century as fertilizers (Geiseler 1996), in road construction (Houben et al. 2010),

[1]Full Professor, Faculty of Environment and Natural Resources, Universidad Distrital Francisco José de Caldas, Avenida Circunvalar sede Vivero UD, Bogotá, DC 110131, Colombia (corresponding author). Email: harondonq@udistrital.edu.co; harondon2012@hormail.com

[2]Full Professor, Civil Engineering Program, Faculty of Engineering, Universidad Piloto de Colombia, Carrera 9 No. 45A-44, Bogotá, DC 110231, Colombia. Email: juan-ruge@unipiloto.edu.co

[3]Assistant Professor, Technology Faculty, Universidad Distrital Francisco José de Caldas, Cl. 68D Bis A Sur N° 49F - 70, Universidad Distrital, Bogotá, DC 111931, Colombia. Email: dfpatinos@correo.udistrital.edu.co

[4]Associate Professor, Dept. of Civil Engineering, Faculty of Engineering, Pontificia Universidad Javeriana, Carrera 7 No. 40-62, Bogotá, DC 110231, Colombia. Email: vacca@javeriana.edu.co

[5]Full Professor, Dept. of Civil Engineering, Faculty of Engineering, Pontificia Universidad Javeriana, Carrera 7 No. 40-62, Bogotá, DC 110231, Colombia. Email: fredy.reyes@javeriana.edu.co

[6]Full Professor, Faculty of Technology, Universidade de Brasília, Campus Universitário Darcy Ribeiro, 70910-900, Brasília-DF, Brazil. Email: muniz@unb.br

Note. This manuscript was submitted on July 24, 2017; approved on March 2, 2018; published online on July 12, 2018. Discussion period open until December 12, 2018; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Materials in Civil Engineering***, © ASCE, ISSN 0899-1561.

in soil remediation, and in the preparation of materials such as glass ceramic, silica gel, and bricks, among others (Das et al. 2007). However, perhaps its best use is in the production of cement (Shi 2004; Das et al. 2007; Abu-Eishah et al. 2012; Sorlini et al. 2012), because this type of slag (Das et al. 2007) (1) contains little iron, has a high content of calcium oxide, and is similar composition to clinker; (2) is a material that can be used safely together with clinker and gypsum; (3) can be used safely in the production of cement as a result of its low content of iron, ; (4) helps developing properties in cement such as low heat hydration, good long-term resistance, and acid resistance; and (5) allows cost reduction in the cement industries. Additionally, Shi (2004) mentions that BFS exhibits cementitious properties. Regarding the use of BFS in construction projects, there are few environmental concerns, since slag's components are tightly bonded to its matrix and would not leach so easily.

Airey et al. (2004) report that BFS produces an aggregate with a rough surface texture and relatively high porosity (typical absorption between 3 and 7%) that results in good adhesion with bituminous binders. However, these properties imply greater consumption of bitumen to produce an asphalt mixture (Airey et al. 2004; FHWA 2008), resulting in an increase of costs. Nevertheless, this higher cost could be offset by the higher productivity (volume by mass) of BFS as aggregate due to the lower unit weight (Noureldin and McDaniel 1990; Zarei and Reza 2015) of the mixture. Some conclusions reported by the FHWA (2008) are the following: (1) The surface layers using BFS as aggregates have good resistance to friction [because of its angular form, they generate a high friction angle between 40 and 45° (Van Oss 2003; Noureldin and McDaniel 1990)], good resistance against stripping, and high stability. However, the impact resistance is not very high, and the material can be crushed under heavy traffic conditions [Los Angeles abrasion is between 35 and 45% (Noureldin and McDaniel 1990)]. Therefore, these materials are more suitable as aggregates to be applied in the surface courses of low-traffic pavement (ASA 2002). (2) The variability in the production process of iron may lead to high dispersion in the physical properties (gradation, specific gravity, absorption, and angularity). (3) Although resistance to abrasive wear and tear of BFS in the Los Angeles machine is not particularly favorable (as sharp edges break), the field performance has been satisfactory. For this reason, this test has been removed from some standard specifications to characterize BFS. (4) BFS have good compatibility with asphalt, which helps developing good adherence. (5) Being a porous material compared with conventional natural aggregates, it may require longer drying time in production plants of asphalt mixtures.

Problem Statement

The mastic in asphalt mixtures is responsible for providing stiffness, cohesion, adhesion between the binder and the stone aggregate, shear strength, resistance to aging, and resistance to moisture damage (Liao and Chen 2011; Yiqiu et al. 2012; Dan et al. 2014; Davis and Castorena 2015; Kuity and Das 2015; Tenza-Abril et al. 2015; Veytskin et al. 2015). BFS have interesting physical properties for the production of mastics in asphalt mixtures, among which the following characteristics are emphasized: porosity and good compatibility with asphalt to improve adhesion, low specific weigh, rough surface texture and angular form, and chemical composition with high contents of CaO and SiO_2 (similar to the composition of clinker and cement). Most of the studies conducted on this material and their applications in asphalt mixtures have been as substitutes for the coarse fraction of natural granular aggregates (NGA), perhaps because the size of BFS particles is predominantly coarse, among others. However, the BFS are used widely in the production of cement, and for such reason, large quantities of them are obtained in very fine particles, while the filler obtained from NGA requires large energy consumption during its exploitation and production procedures. Therefore, another possible practical application of the BFS would be as filler in HMA. Few studies have been performed to evaluate the potential use of BFS as filler or fine granular aggregate of asphalt mixtures. Some of them have been performed in the analysis of cold asphalt mixtures and have blended the BFS with other types of fillers (e.g., Nassar et al. 2016; Al-Hdabi and Al Nageim 2017). Other studies have used steel slags (SS) for this purpose (e.g., Li et al. 2017).

Objective

The objective of the present study was to evaluate the effects of using blast furnace slag (BFS) as substitutes of the fine particles of a natural aggregate (NGA) in the manufacture of hot mix asphalts (HMA), to determine if such replacement produces statistically significant improvements in the resistance of the mixture against moisture damage, permanent deformation, and fatigue, under cyclic loadings.

General Methodology

Initially a series of tests were carried out for the characterization of the granular materials (BFS and NGA) and the asphalt binder, followed by the design of asphalt mixtures with partial substitution of NGA by BFS. Asphalt cements with penetration grades CA 60-70 and PG 58-22 were used as binders for the manufacture of the mixes. The grain size distribution of the aggregates follows the prescription of INVIAS (2013) for asphalt concrete HMA-19 (maximum nominal size particle of 19 mm) due to the fact that these are the asphalt and the mixture types most commonly used in Colombia for the construction of asphalt layers.

The resistance of these mixtures was evaluated under monotonic loading using the Marshall test [AASHTO T245 (AASHTO 2015a)] and indirect tension test [ASTM D6931 (ASTM 2017b)] in samples in which the fine fraction of the NGA was replaced by BFS. These initial experiments were carried out to define the mixture with best performance under monotonic load, to later investigate its properties under cyclic loading (resilient modulus—EN 12697-26 (BSI 2005b), resistance to permanent deformation—EN 12697-25 (BSI 2000), and fatigue—EN 12697-24 (BSI 2005a) and moisture damage (ASTM D6931). In addition, viscosity [ASTM D4402 (ASTM 2015)], softening point [ASTM D36 (ASTM 2006)], penetration [ASTM D5 (ASTM 2013)], and indirect tensile (ASTM D6931) tests were performed on mastics produced using NGA and BFS as fillers.

To evaluate whether the NGA substitution by BFS produced statistically significant effects on the HMA mix properties, an analysis of variance (ANOVA) with F-test was performed with a confidence level of 95%.

Materials and Methods

Material Characterization

Slags are highly heterogeneous materials as to forms and particle sizes, chemical composition, texture, specific gravity, wear and tear resistance, and porosity among others, which implies complex characteristics and properties (Akbarnejad et al. 2014). This is illustrated in Fig. 1, which shows some particles that prevail in the BFS used in this study. Some of them have a shiny black surface, and they are the ones that are present in greater amounts in the BFS (approximately 65% with respect to the total number of particles); when

Fig. 1. Slag particles (size between 19 and 25.4 mm diameter). (Images by authors.)

crushed, the particles show an internal grayish color. Additionally, they have a rigid, hard, and bulk consistency similar to that of natural aggregates (NGA), although they are much more porous (for example, on average, BFS and NGA particles of 25.4 mm (1-in.) diameter have an average mass of 32 and 35 g, respectively). On the contrary, the other types of particles have a light green surface color and they are easy to abrade (even with the hands), are lightweight, have a light green hue, and float in the water (a particle with a 25.4 mm (1-in.) diameter has a mass of about 9 g on average).

Table 1 [AASHTO T84 (AASHTO 2000); AASHTO T85 (AASHTO 1991b); UNE 14613 (AENOR 2000)] and Table 2 [AASHTO T228 (AASHTO 2004); AASHTO T316 (AASHTO 2013); ASTM D-36 (ASTM 1995); ASTM D-113 (ASTM 1999); ASTM D2872-12e1 (ASTM 2012); NLT 181 (Normas NLT 1988)] present the values obtained from the characterization tests performed on the aggregates (NGA and BFS) and on AC 60–70 asphalt, respectively. The BFS used was of ACBFS type produced by Acerías Paz del Río (Nobsa, Boyacá, Colombia). This company produces monthly 28,000 tons of pig iron and 22,000 tons of BFS and steel slags (Ucrós 2009). The NGA used is a limestone-type mineral aggregate.

It is observed in Table 1 that by decreasing the particle size of BFS, the specific gravity increases while absorption decreases. This is due to its heterogeneous nature and because part of the voids are excluded during the mechanical fracturing process executed on coarse particles to obtain the fine particles. Based on the results of Micro-Deval [AASHTO T327 (AASHTO 2005)] and 10% of fines [DNER-ME 096 (DNER 1998)], it is concluded that this BFS presents good resistance to abrasion by friction between particles and to crushing under a monotonic load, respectively. However, as reported in the reference literature, BFS are materials that generally have low resistance to wear and tear by impact abrasion on the Los Angeles machine [AASHTO T96 (AASHTO 1991a)]. It is also observed that the material has particles with ideal shapes (rounded angular faces fractured with very little content of elongated and flattened particles) [ASTM D5821 (ASTM 2001); NLT 354 (NLT 1991)]. This should help to develop a good granular skeleton after the compaction processes of asphalt mixtures, as well as to resist static, dynamic, or impact loads. The fine particles have no clay content, organic matter, or dust that could generate decreased adhesion between the aggregate and the asphalt, and reduced strength and durability of the mixture by excess of fines or contaminants [AASHTO T176 (AASHTO 2002); ASTM D4318 (ASTM 2000); AASHTO T21 (AASHTO 2015b); T220 RMS 12.495 (Transport Roads and Maritime Services 2012)].

On the other hand, screening tests based on X-ray diffractometry (XRD) and X-ray fluorescence (XRF) were performed on the fine fractions of the BFS and NGA to obtain their mineralogical and chemical compositions. The detailed description of the execution of these tests can be found in Zhang et al. (2003), Chipera and Bish (2001), Moore and Reynolds (1997), and Beckhoff et al. (2006). Particles of both materials were also subject to observation in the scanning electron microscope (SEM) to determine the predominance and diameter of macropores and micropores in the samples [details in Reed (2005)]. Table 3 presents the mineralogical composition of the samples analyzed (NGA and BFS) and the chemical compositions of BFS reported by several researchers. It is observed that the predominant mineral in both samples is quartz [silica (SiO_2)]. This result is consistent with that obtained in the XRF test (Table 4) in which the predominant chemical component is silica (SiO_2). However, the main difference lies in the greater amount of CaO in the BFS and the presence of some clay minerals in the NGA. It is further concluded that the analyzed BFS sample is composed mainly of silica, calcium oxide (CaO), and aluminum oxide (Al_2O_3, 92.76%), while the NGA sample is composed mainly of silica and Al_2O_3 (86.86%). Oxides SiO_2 and Al_2O_3 are pozzolanic compounds, which in very fine particle sizes can

Table 1. NGA and BFS characterization

Test	Method	NGA	BFS
Specific gravity/absorption [19 mm (¾ in.)]	AASHTO T84-00	2.51/1.66%	1.91/3.75%
Specific gravity/absorption [9.5 mm (⅜ in.)]	AASHTO T85-91	2.49/1.70%	1.97/3.33%
Specific gravity/absorption (No. 4)		—	2.11/2.73%
Specific gravity/absorption (No. 40)		—	2.26/2.65%
Specific gravity/absorption (No. 80)		—	2.36/2.25%
Specific gravity/absorption (No. 200)		—	2.51/1.90%
Specific gravity of sands and fines/adsorption	—	2.50/1.50%	—
Abrasion in Los Angeles machine, 500 revolutions	AASHTO T96-02	24.6%	49.2%
Micro-Deval	AASHTO T327-05	22.3%	29.2%
10% of fines (dry resistance)	DNER-ME 096-98	115 kN	123 kN
Fractured particles: 1 face	ASTM D5821-01	87%	92%
Fractured particles: 2 faces		80%	88%
Impurities content	UNE 14613: 2000	0%	0%
Plasticity index	ASTM D4318-00	No plastic	No plastic
Flattening index	NLT 354-91	9.5%	5.62%
Elongation index		9.5%	10.62%
Sand equivalent test	AASHTO T176-02	76%	—
Iron unsoundness	T220 (RMS 12.495)	—	Free

Table 2. General properties of AC 60-70

Test	Method	Unit	Value
Tests on the original AC			
Penetration (25°C, 100 g, 5 s)	ASTM D5	0.1 mm	62.5
Penetration index	NLT 181/88	—	–0.7
Softening point	ASTM D36-95	°C	52.5
Absolute viscosity (60°C)	ASTM D4402	Poises	1,750
Specific gravity	AASHTO T228-04	—	1.012
Viscosity to 135°C	AASHTO T316	Pa-s	0.36
Ductility (25°C, 5 cm/min)	ASTM D113	cm	>105
Tests on the residue of AC after the RTFOT			
Mass loss	ASTM D2872	%	0.47
Penetration (25°C, 100 g, 5 s) of the original penetration	ASTM D5	%	72
Increase on the softening point	ASTM D36-95	°C	5

Table 3. Chemical composition of BFS and NGA

			Others BFS					
Component	BFS	NGA	Emery (1982)	Jones (1982)	León et al. (2009)	WSDOT (2015)	Al-Hdabi and Al Nageim (2017)	Nassar et al. (2016)
CaO (%)	30.83	1.09	36–45	40	43.3	32–45	40.37	41.42
SiO_2 (%)	52.03	79.00	33–42	36.8	25.5	32–42	37.47	35.65
Al_2O_3 (%)	9.90	7.86	10–16	16	17	7–16	4.76	11.21
P (%)	—	—	—	—	2.3	—	—	—
MgO (%)	0.82	2.34	3–16	5.4	1.45	5–15	3.65	6.89
Na_2O (%)	0.65	1.82	—	—	1.4	—	2.55	0.28
SO_3 (%)	0.48	—	1–3	0.4	1	0.4–2	—	2.43
FeO (%)	—	—	0.3–0.2	0.2	—	—	—	—
Fe (%)	—	—	—	—	0.5	—	—	—
Fe_2O_3 (%)	1.52	3.70	—	—	0.71	0.1–0.75	0.15	0.26
MnO (%)	1.26	—	0.2–1.5	0.5	—	0.2–0.8	—	0.60
TiO_2 (%)	0.98	0.44	—	0.3	—	—	—	0.63
K_2O (%)	0.86	1.17	—	0.4	0.14	—	0.62	0.64
Ba (%)	0.21	—	—	—	—	—	—	—
P_2O_5 (%)	0.06	0.11	—	—	—	—	—	—
Cr (%)	0.12	—	—	—	—	—	—	—
Others (%)	0.24	—	—	—	—	—	—	—

develop self-hardening properties and do not need to be activated with water or lime (Misra et al. 2005). This pozzolanic property can increase the resistance to moisture damage of asphalt mixtures (Nassar et al. 2016). Also, these two oxides can improve asphalt-aggregate surface adhesion and internal cohesion in the asphalt mixture (Modarres and Rahmanzadeh 2014). In addition, the presence of high content of quartz in the BFS suggests that it can develop high strength and interlocking in the mineral skeleton. This is an important aspect to be taken into account, since the BFS used in the study presents a higher content of quartz compared to those studied previously (Table 3). According to Modarres and Rahmanzadeh (2014), Anderson and Goetz (1973), and Muniandy et al. (2013), the CaO is alkaline, which contributes to increase the aggregate-asphalt adhesion, and improves the resistance to moisture damage and stripping. Muniandy et al. (2013) reported that SiO_2 is a material of high hardness and mechanical strength, and that Al_2O_3 can improve adhesion between aggregate and asphalt (mainly because of the great affinity of this chemical component with the oil fractions of asphalt), increasing the resistance of the mixtures to rutting. Guo et al. (2016), using molecular dynamics (MD) simulation, found that the interfacial energy and work of adhesion of the four asphalt components (saturates, aromatics, resins, and asphaltenes) with mineral aggregates is greater when these are composed mainly of CaO. A similar conclusion was obtained by Li et al. (2016), also using MD simulation; however, in this study, the interaction capability and interfacial energy ranking of oxides evaluated with the asphaltenes was as follows: MgO > CaO > Al_2O_3 > SiO_2.

Table 4. Mineral percentages in the BFS and NGA samples (XRD test)

Sample	Mineral	Mass (%)
BFS	Quartz	58.9
	Cristobalite	18.1
	Boehmite	12.8
	Calcite	4.8
	Natrolite	5.3
NGA	Quartz	61.00
	Albite	25.05
	Illita	5.28
	Chlorite	8.67

The preparation of samples of BFS and NGA for the SEM observation was preceded by the selection of different particles, to obtain a statistically reliable result. In the case of the BFS, the selected particles were five of green coloration, three of black coloration, and one of white coloration (because the white coloration was scarcer

Table 5. Porosities calculated values

Particle type	Porosity (%)	Pore diameter (μm)
	NGA	
G1	0.6	6.0
G2	20.8	27.1
G3	13.9	10.4
G4	6.5	36.4
G5	2.3	11.0
G6	0.98	7.9
G7	0.86	7.8
	BFS	
Green	63	82.6
Black	9	27.5
White	50	30.3

in the analyzed population). NGA particles were chosen in seven groups (G1–G7, see Table 5), which had different lithological characteristics and did not share characteristics of size, color, and/or sphericity. Observations were performed using a Field Emission Scanning Electron Microscope (FESEM) JEOL JSM 6700F (JEOL, Tokyo, Japan) SEM with an acceleration voltage of 20 kV in high vacuum at a working distance of approximately of 15 mm. The micrographs were taken with a backscattered electron detector (BSE). Several images of each grain were taken with a 30x magnification. Fig. 2 shows an example of the surface porosity of the NGA and BFS particles, and Table 5 shows the average porosity and the average pore diameter measured in the samples. Based on Fig. 2, BFS particles exhibit different morphology compared to NGA. High amounts of large pores can be distinguished clearly on the surface of the BFS. It is observed that the analyzed BFS particles have higher porosity and pore diameter than the particles of NGA, which explains why BFS can absorb a greater amount of asphalt. Additionally, the relationship between the particle size of BFS and the absorption of asphalt should be directly proportional, since the higher porosity and pore dimensions obtained in the test would generate a coarse aggregate with lower specific gravity, higher absorption (as reported in Table 1), and higher fracture probability under mechanical load.

Marshall Tests

To evaluate the reproducibility of the results, five Marshall samples (101.6 mm in diameter and 63.5 mm in height) were compacted applying 75 blows per face for each asphalt percentages of 4.5, 5.0, 5.5, and 6.0%, using the grain-size distribution presented in Fig. 3 and NGA as aggregate. Prior to the mixture and compaction procedures of the samples, the aggregate was dried in the oven for 24 h at a temperature of 105°C and then hot bitumen was added. The temperatures of the samples for compaction and for mixing in the laboratory were 140 and 150°C, respectively. These values were obtained based on the criteria established by the ASTM D6925 (ASTM 2009) specification, in which the viscosity required to obtain mix and compaction temperatures of HMA mixtures are 85 ± 15 Saybolt Furol (SSF) [0.17 Pa · s (170 cP)] and 140 ± 15 SSF [0.28 Pa · s (280 cP)], respectively. Bulk specific gravities and volumetric composition were calculated in accordance with ASTM D2726 (ASTM 2017a). Marshall tests (AASHTO T245) were performed on these samples (HMA-19 of control, BFS = 0%) to obtain their volumetric indices (mainly, air voids in volume – Va) and resistance under monotonic load (stability – S, flow – F, and S/F ratio). This test was performed additionally on samples made with asphalt contents of 5.0, 5.5, 6.0, and 6.5%, and using BFS as follows (five samples were tested for each replacement of NGA by BFS and asphalt content):

1. BFS = 6%, replacing only the material on the bottom.
2. BFS = 12.5%, replacing the bottom and the sieve No. 200.
3. BFS = 19.5%, replacing the bottom and sieves No. 80 and No. 200.
4. BFS = 31%, replacing sieves No. 40, No. 80, and No. 200.
5. BFS = 37.5%, replacing the bottom and sieves No. 40, No. 80, and No. 200.

Indirect Tensile Strength Tests

Indirect tensile tests [ASTM D4867 (ASTM 2014)] were carried out on the control asphalt mixture (HMA-19, BFS = 0%) and the other two mixtures with substitution of NGA by BFS, which presented the best performance in the Marshall test. Six samples of each mixture were tested, three under a dry condition (D) and three in wet condition (W), with air void percentages ranging from $7 \pm 1\%$ as recommended by the ASTM D4867 specification. With the test results, the resistance to moisture damage parameter TSR was calculated using the ratio of indirect tensile strengths (W/D). The samples to be tested under wet conditions were placed in a saturation vacuum with a pressure of approximately 6.7 kPa during 5 min, and then the specimens were submerged for another

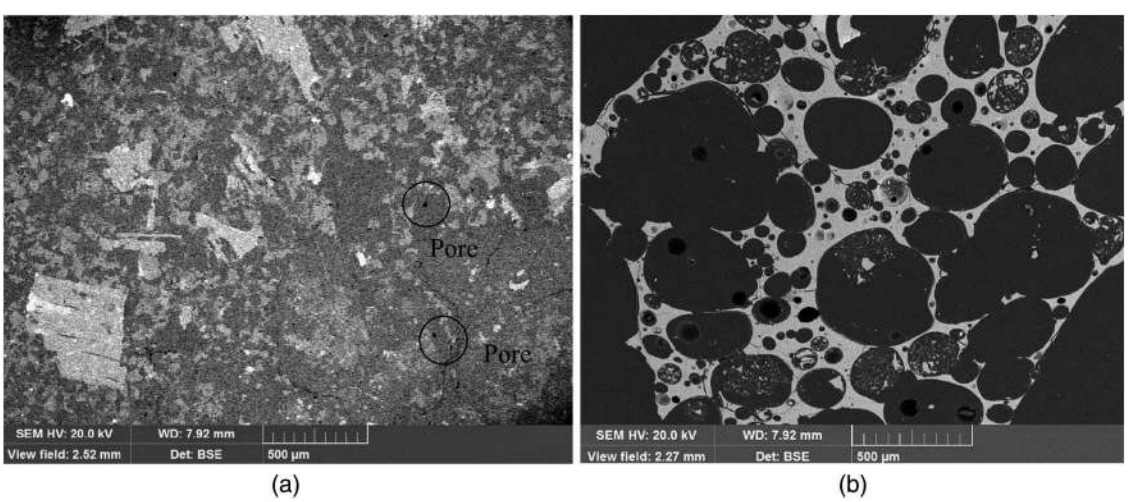

Fig. 2. SEM observation of (a) NGA; and (b) BFS.

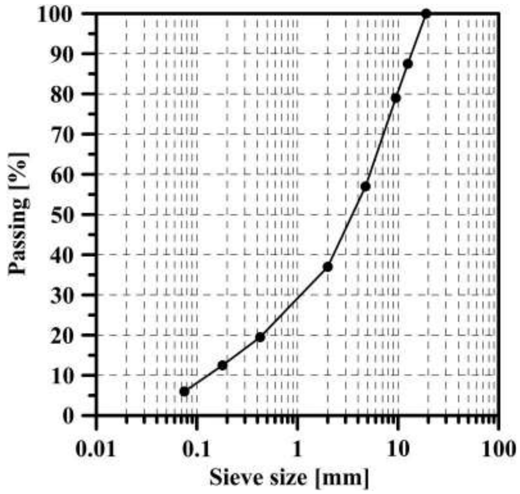

Fig. 3. Particle size distribution of HMA-19.

10 min in a water bath. Thereafter, the samples were submerged in a water bath at 60°C for 24 h. Prior to the indirect tensile tests, the samples were submerged in water at 25°C for 2 h.

Resilient Modulus Tests

On the control asphalt mixture (HMA-19, BFS = 0%) and the mixtures with the substitution of NGA by BFS that presented the best performance in the Marshall test were performed resilient modulus tests (EN 12697-26) under three temperatures (10, 20, and 30°C) and three loading frequencies (2.5, 5.0, and 10.0 Hz). For each test temperature, the Marhall specimens (4 in. in diameter and 2.5 in. in height) were placed in the climatic chamber for 4 h before testing. Resilient modulus tests were performed on nine samples (three for each temperature) using Nottingham asphalt tester (NAT) equipment. The amplitude of the load was controlled to keep a deformation level lower than 50 microstrains in accordance with EN 12697-26 requirements.

Permanent Deformation Tests

Permanent deformation tests (EN 12697-22) under repeated square-wave load with a stress of 100 kPa, test temperature of 40°C, and 3,600 load cycles (N) were performed on the Marshall specimens used in the resilient modulus tests. NAT equipment was used to perform the tests. Prior to the tests, the specimens were preconditioned in the thermostatic chamber at 40°C during 4 h. Then, Marshall samples were preloaded under 10 kPa during 10 min. After the preloading time, the stress of 100 kPa was applied in 3,600 pulses with 1 s of load followed by a rest period of 1 s (frequency of 0.5 Hz).

Fatigue Resistance Tests

Indirect tensile fatigue tests (ITFT), according to UNE-EN 12697-24, controlled stress procedure were conducted on the control mixture and the mix with BFS that presented the best performance under monotonic (Marshall and indirect tensile tests) and dynamic loading conditions (resilient modulus and resistance to permanent deformation). Each fatigue test was performed using 15 samples (three replicates for each of the five constant stress levels applied ranging from 100 to 600 kPa). Prior to testing, the specimens were placed in the thermostatic chamber and exposed to 20°C during 4 h. All fatigue tests were performed under a temperature of 20°C using NAT equipment, Marshall specimens (4 in. in diameter and 2.5 in. in thickness), and repetitive applications of compressive controlled-load in a haversine waveform with load time of 0.1 s and rest time of 0.4 s. The fatigue resistance was determined as the total number of load applications that caused the complete fracture of the specimen (N_f).

Tests Performed on Mixtures of Fine Aggregates and Asphalt

To understand the results from the previous experimental phases, the following tests were performed on two mastics of fine aggregates (only NGA or only BFS) with asphalt: viscosity at 135 and 150°C (Brookfield viscometer was used to measure apparent viscosity, ASTM D4402), softening point (ASTM D36), and penetration (ASTM D5). Both mixtures were produced taking into account the best behavior obtained in the previous experimental phases. Therefore, the composition of the fine aggregate particles was 52 and 48% of material retained in sieves No. 200 and the bottom, respectively. The asphalt content used was 5.0% with respect to total mass of the mixture (ratio between fine aggregate and asphalt of 2.5). A mechanical mixer was used to blend the filler and asphalt binder at the established mixing temperature of 150°C. Prior to mixture with the bitumen, the aggregates were dried in the oven for 24 h at a temperature of 105°C. The mixture was made until a homogeneous distribution between both materials was reached. Five replicate samples were prepared and tested to evaluate each property. Additionally, indirect tensile tests (ASTM D6931) were performed on two samples produced with the same two mixtures and fine aggregate composition mentioned previously. However, to mix adequately the fine aggregate with the asphalt and to perform

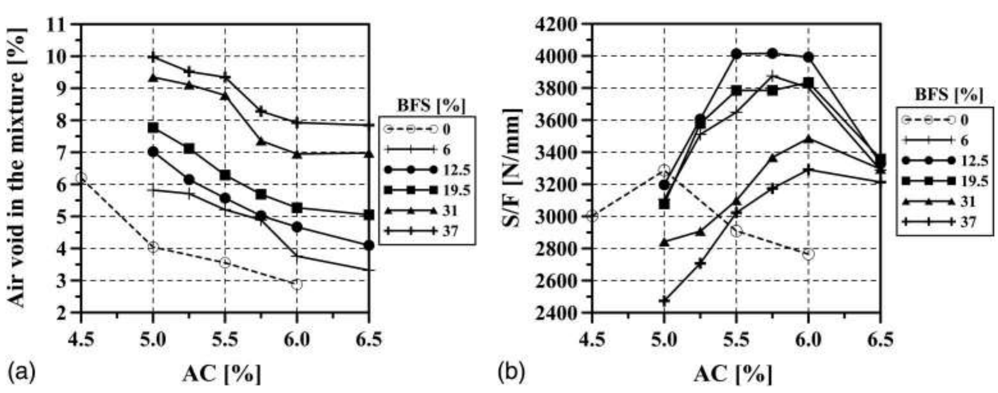

Fig. 4. Marshall test. Substitution of the fine fraction of NGA by BFS: (a) air void; and (b) S/F ratio.

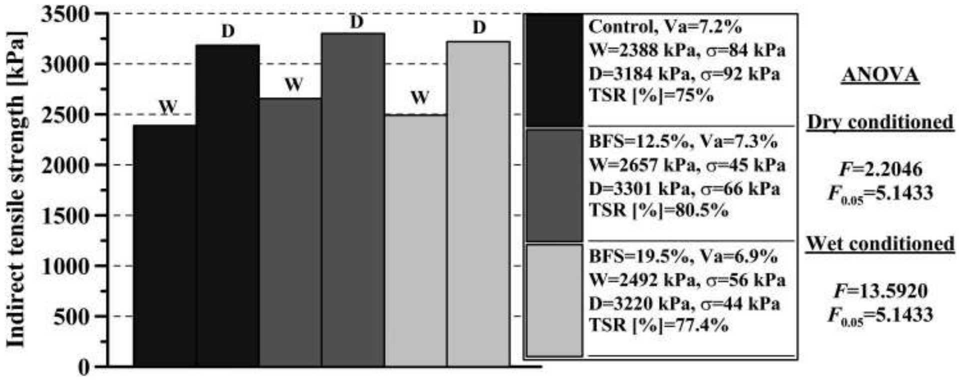

Fig. 5. Indirect tensile test. Va = air void; and σ = standard deviation.

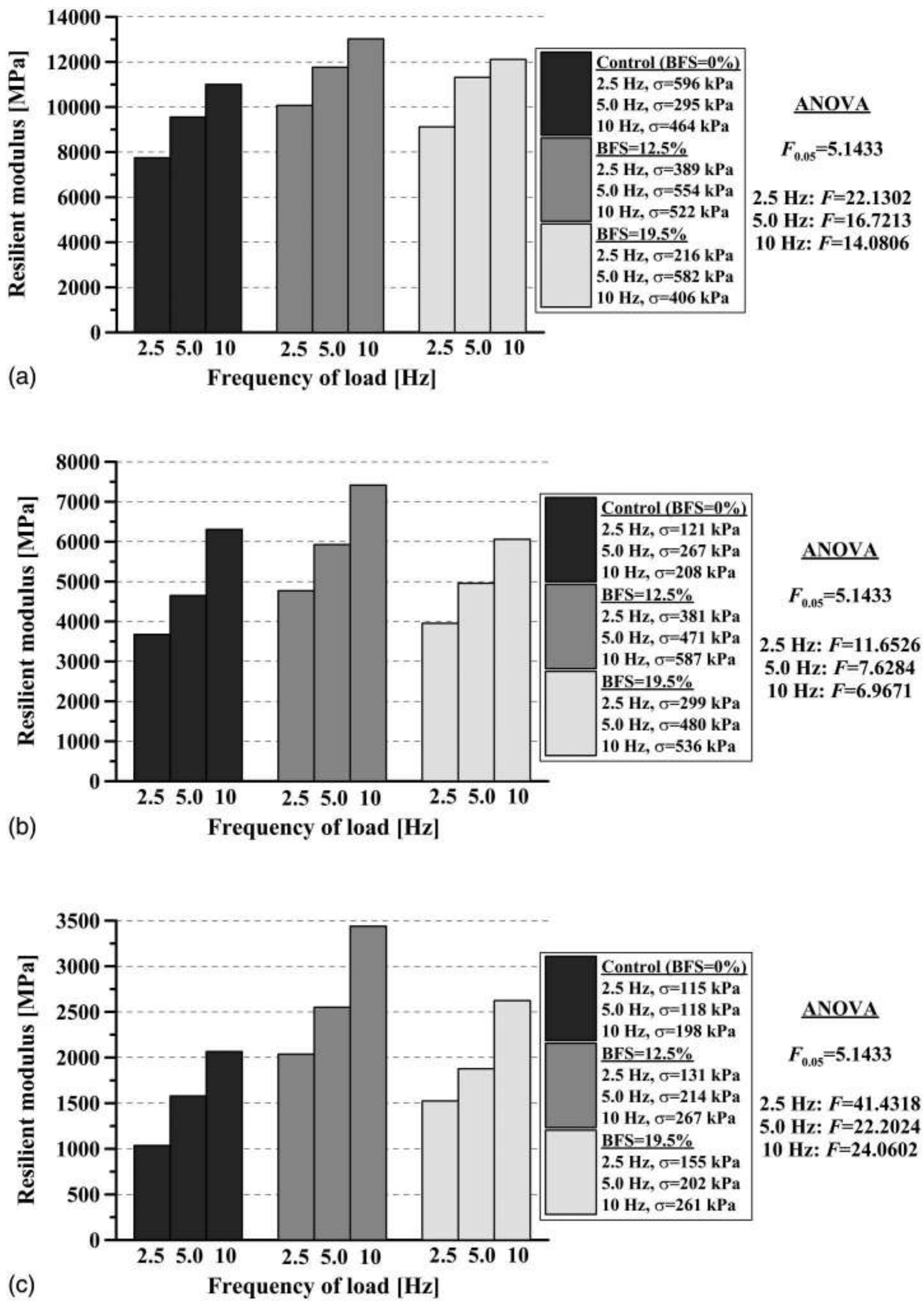

Fig. 6. Resilient modulus: (a) 10°C; (b) 20°C; and (c) 30°C.

Marshall specimens of 1,200 g, it was necessary to increase the amount of bitumen. The asphalt content was 12.5%. Three samples of each mixture were tested under dry conditions (D) and the other three in wet conditions (W).

Results

Resistance under Monotonic Load

Fig. 4 shows the results of the Marshall test executed on the asphalt mixture of control (HMA-19, BFS = 0%) and on the mixtures for which some of the finer fraction of NGA was replaced by BFS. In general terms it was observed that:

1. When replacing the fine fraction of NGA by BFS, the air voids in the mixture increased, and these increments were greater when the BFS content increased [Fig. 4(a)].
2. When the finer particles of NGA were replaced by BFS in proportions BFS = 6, 12.5, and 19.5%, the magnitude of the stability/fluency (S/F) relationship [Fig. 4(b)] was similar to the maximum reached by the mixture of control BFS = 0% (asphalt content of 5%). This was achieved, despite the fact that the mixture with BFS has greater air void content (approximately between 3 and 4% higher). If the asphalt content was increased by 0.25 and 0.5% (asphalt content of 5.25 and 5.5%), the ratio under monotonic loading (S/F) increased in 9.7% (320 N/mm) and 22.1% (726.3 N/mm), respectively, when the fine fraction of NGA was replaced at a ratio of BFS = 12.5%. In the case of substitution at ratios of BFS = 6 and 19.5%, the increments were of 6.9% (225.1 N/mm), 8.9% (292.5 N/mm) and 11% (363 N/mm), 15.2% (498.4 N/mm), respectively.
3. In summary, the best performance of replacement of NGA by BFS was reached when particles with a size of 0.18 mm or less (BFS = 12.5%) were substituted.

Therefore, and taking into account the results presented in Fig. 4, mixtures replacing the fine fraction of NGA by BFS in proportions of BFS = 12.5 and 19.5% were chosen to perform indirect tensile tests and dynamic tests. Also, an asphalt content of 5.25% was chosen for both mixtures (a higher content of asphalt was not chosen to not significantly raise the cost of the mixture). For comparison, the control mixture (HMA-19, BFS = 0%) in these tests will be the one prepared with an asphalt content (AC) of 5%.

Fig. 5 shows the results of the indirect tensile tests. It was observed that the BFS = 12.5 and 19.5% (AC = 5.25%) mixtures developed higher indirect tensile strength under wet conditions and greater moisture damage resistance (TSR) with respect to the control mixture (BFS = 0%, AC = 5%). Besides, ANOVA analysis showed that the BFS had a significant effect on the wet conditioned indirect tensile strength (W) with a confidence level of 95% (see Fig. 5, $F > F_{0.05}$). However, for the case of dry conditioned samples (D), the null hypothesis that the strengths are equal cannot be rejected.

Resilient Modulus, Permanent Deformation, and Resistance to Fatigue

Test results of the resilient modulus are presented in Fig. 6. BFS = 12.5 and 19.5% mixtures tend to have higher stiffness under cyclic loading than the control HMA (BFS = 0%). The highest stiffness is developed by the mixture that substitutes the fine fraction of NGA at a ratio of BFS = 12.5% (particles smaller than 0.18 mm). This mixture shows stiffness on average 24, 25, and 75% higher than that of control for test temperatures of 10, 20, and 30°C, respectively. In the case of the BFS = 19.5% mixture, this average increment in stiffness oscillates between 16, 3, and 31%, respectively. ANOVA analysis shows that the BFS have a significant effect on the resilient modulus for each temperature evaluated (Fig. 6).

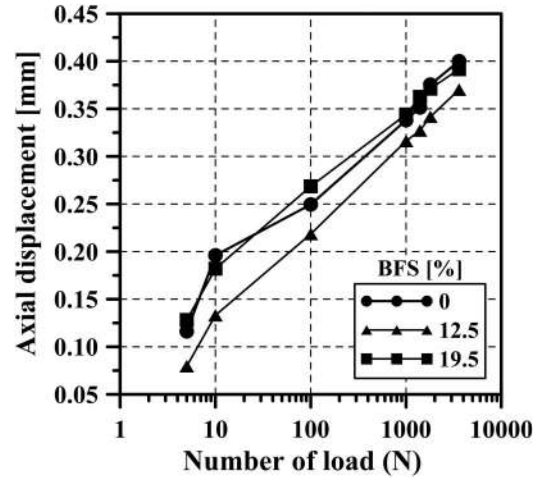

Fig. 7. Permanent deformation.

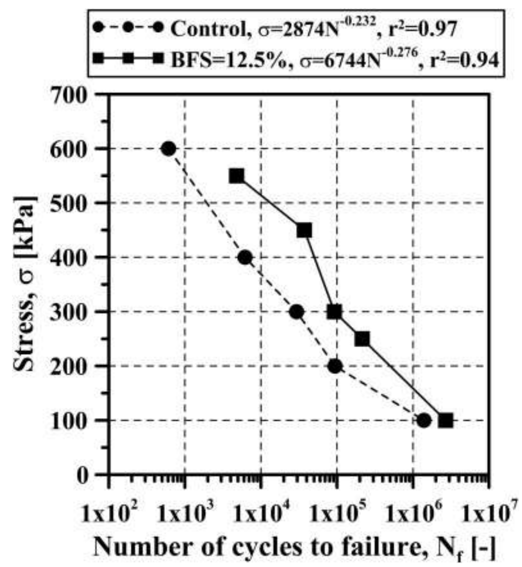

Fig. 8. Fatigue test result.

Table 6. Viscosity values

Material	Viscosity at 135°C (cP)	Viscosity at 150°C (cP)
Asphalt	360	102
Asphalt + NGA	472.5	285.4
Asphalt + BFS	605.7	442.0

Table 7. Penetration and softening point values

Material	Softening point (°C)	Penetration (mm/10)
Asphalt	52.5	62.5
Asphalt + NGA (mix)	58.2	42.2
Asphalt + BFS (mix)	61.7	37.6

J. Mater. Civ. Eng., 2018, 30(10): 04018244

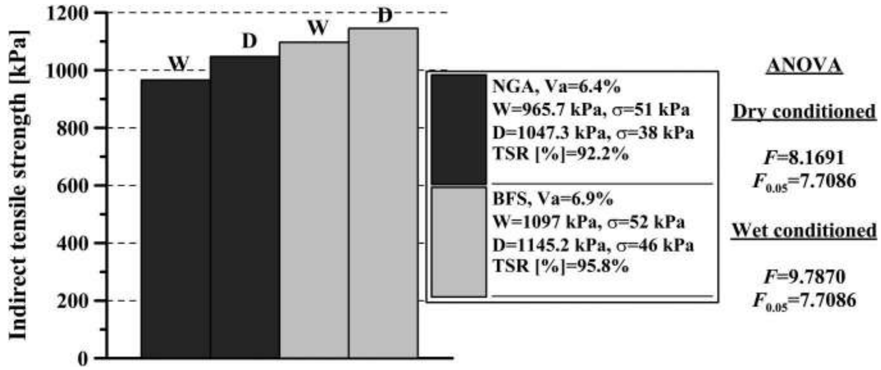

Fig. 9. Indirect tensile test performed on Marshall specimens with fine aggregates of NGA and BFS.

The permanent deformation results are presented in Fig. 7. The greater resistance to permanent deformation under cyclic loading was achieved by the mixture that substituted the fine fraction of NGA at a proportion of BFS = 12.5%. This result is consistent with those obtained in Fig. 6 for the case of the resilient modulus. However, for the case of the BFS = 19.5% mixture, the accumulation of permanent deformation is similar to that of the control mixture (BFS = 0%), mainly because of its greater air void content [Fig. 4(a)]. Therefore, to perform the fatigue tests, the mixture with BFS = 12.5% was chosen. ANOVA analysis for permanent deformation test was calculated at N = 3,600 (final load cycle). It showed that the BFS had a significant effect on the axial displacement measured ($F = 49.9288 > F_{0.05} = 5.1433$).

Fig. 8 shows that HMA with BFS = 12.5% developed higher resistance to fatigue in comparison to control mixture. In this test, the ANOVA analysis was calculated for the stress levels of 100 and 300 kPa, showing that the BFS had a significant effect on the fatigue resistance ($F = 17.4723 > F_{0.05} = 7.7086$ and $F = 78.8449 > F_{0.05} = 5.1433$ for 100 and 300 kPa, respectively).

Tests Performed on Mixtures of Fine Aggregates and Asphalt

Penetration test measures the consistency of the asphalt or asphalt mastics and indirectly is an indicator of stiffness. Viscosity and softening point of asphalt mastic are directly associated with shearing deformation resistance and high temperature stability, respectively (Cheng et al. 2015, 2016). Tables 6 and 7 show the results of viscosity, penetration, and softening point tests performed on the asphalt and the mastics made with the asphalt and fine aggregates of NGA and BFS (asphalt, asphalt + NGA, and asphalt + BFS, respectively). BFS as fine aggregate provided the best behavior for asphalt mastic, since it enhanced the stiffening effect and improved high-temperature susceptibility (lower penetration and greater viscosity and softening point) compared with NGA.

The TSR parameter of indirect tensile test is directly correlated to the susceptibility of the mixes to the action of water. Additionally, the tensile resistance is correlated also with adherence properties between aggregate and asphalt. Fig. 9 shows the results of the indirect tensile tests performed on Marshall specimens produced with fine aggregates (NGA and BFS) and 12.5% of asphalt. It was observed that the asphalt mixtures that contain BFS as fine aggregate developed higher indirect tensile resistance (under dry and wet conditions) and was more resistant to moisture damage (greater TSR) with respect to that made with NGA. ANOVA analysis showed that the BFS had a significant effect on the dry and wet conditioned indirect tensile strength (Fig. 9).

Conclusions

The following conclusions can be taken specifically for the BFS analyzed. Similar studies using other types of BFS must be performed to verify what types of slags can be used to replace the fine fraction of NGA. Based on the results obtained, the following were concluded:

1. The best performance under monotonic and cyclic loads, and best resistance to moisture damage was attained by the mixture for which the finer fractions (smaller than 0.18 mm) of NGA was replaced by BFS in a ratio BFS = 12.5%.
2. When using fine granular aggregate substitution of BFS = 12.5%, the asphalt content in the mixture should be increased by only 0.25% to achieve an increase in the S/F ratio of 320 N/mm and an increase of 117 and 269 kPa in the wet and dry indirect tensile resistance, respectively, with respect to the control mixture. It was also observed an increment of the resilient modulus by 24, 25, and 75% for test temperatures of 10, 20, and 30°, resulting in higher resistance to permanent deformation. Besides, the resistance to fatigue under controlled stress loading also increased.
3. The ANOVA analysis showed that the BFS used as fine aggregate had a significant effect on the dynamic properties (resilient modulus, permanent deformation, and fatigue resistance) of hot mix asphalts and on their indirect tensile strength under wet conditions.
4. When fine particles of BFS analyzed were mixed with the asphalt, it helped to increase the stiffness of the asphalt mixture generating greater resistance to permanent deformation. Besides, it was responsible for providing higher cohesion, associated with the resistance to fatigue, and better adhesion between the binder and the aggregate associate to resistance in indirect tensile tests.
5. Based on the mineralogical and chemical compositions of the BSF, it was supposed that the asphalt that adhered to the fine aggregate fraction composed of BFS generated a material with better adhesion properties, compared to those using the aggregate composed of NGA. Adhesion properties were associated mainly with the content of CaO in the BFS. The content of SiO_2 (material with high mechanical strength and hardness) in the BFS also suggested that it could develop good cohesion properties.

References

AASHTO. 1991a. *Standard method of test for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine*. AASHTO T96. Washington, DC: AASHTO.

AASHTO. 1991b. *Standard method of test for specific gravity and absorption of coarse aggregate*. AASHTO T85. Washington, DC: AASHTO.

AASHTO. 2000. *Standard method of test for specific gravity and absorption of fine aggregate*. AASHTO T84. Washington, DC: AASHTO.

AASHTO. 2002. *Standard method of test for plastic fines in graded aggregates and soils by use of the sand equivalent test*. AASHTO T176. Washington, DC: AASHTO.

AASHTO. 2004. *Standard method of test for specific gravity of semi-solid asphalt materials*. AASHTO T228. Washington, DC: AASHTO.

AASHTO. 2005. *Standard method of test for resistance of coarse aggregate to degradation by abrasion in the Micro-Deval apparatus*. AASHTO T327. Washington, DC: AASHTO.

AASHTO. 2013. *Standard method of test for viscosity determination of asphalt binder using rotational viscometer.* AASHTO T316. Washington, DC: AASHTO.

AASHTO. 2015a. *Standard method of test for resistance to plastic flow of bituminous mixtures using Marshall apparatus*. AASHTO T245. Washington, DC: AASHTO.

AASHTO. 2015b. *Standard test method for organic impurities in fine aggregates for concrete*. AASHTO T21. Washington, DC: AASHTO.

Abu-Eishah, S. I., A. S. El-Dieb, and M. S. Bedir. 2012. "Performance of concrete mixtures made with electric arc furnace (EAF) steel slag aggregate produced in the Arabian Gulf region." *Constr. Build. Mater.* 34: 249–256. https://doi.org/10.1016/j.conbuildmat.2012.02.012.

AENOR (Norma Técnica Española). 2000. "Contenido de impurezas (agregado grueso) [Impurities content (coarse aggregate)]." UNE 14613. Madrid, Spain: AENOR.

Airey, G. D., A. C. Collop, and N. H. Thom. 2004. "Mechanical performance of asphalt mixtures incorporating slag and glass secondary aggregates." In *Proc., 8th Conf. Asphalt Pavements for Southern Africa (CAPSA'04)*. Pretoria, South Africa: CSIR Transportek, Asphalt Academy.

Akbarnejad, S., L. J. M. Houben, and A. A. A. Molenaar. 2014. "Application of aging methods to evaluate the long-term performance of road bases containing blast furnace slag materials." *Road Mater. Pavement Des.* 15 (3): 488–506. https://doi.org/10.1080/14680629.2014.907196.

Al-Hdabi, A., and H. Al Nageim. 2017. "Improving asphalt emulsion mixtures properties containing cementitious filler by adding GGBS." *J. Mater. Civ. Eng.* 29 (5): 04016297. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001859.

Anderson, D. A., and W. H. Goetz. 1973. "Mechanical behavior and reinforcement of mineral filler-asphalt mixtures." *Proc. Assoc. Asphalt Paving Technol.* 42: 37–66.

ASA (Australasian Slag Association). 2002. *A guide to the use of iron and steel slag in roads*. Sydney, Australia: ASA.

ASTM. 1995. *Standard test method for softening point of bitumen (ring-and-ball apparatus)*. ASTM D36. West Conshohocken, PA: ASTM.

ASTM. 1999. *Standard test method for ductility of bituminous materials*. ASTM D-113. West Conshohocken, PA: ASTM.

ASTM. 2000. *Standard test methods for liquid limit, plastic limit, and plasticity index of soils*. ASTM D4318. West Conshohocken, PA: ASTM.

ASTM. 2001. *Standard test method for determining the percentage of fractured particles in coarse aggregate*. ASTM D5821. West Conshohocken, PA: ASTM.

ASTM. 2006. *Standard test method for softening point of bitumen (ring-and-ball apparatus)*. ASTM D36. West Conshohocken, PA: ASTM.

ASTM. 2009. *Standard test method for preparation and determination of the relative density of hot mix asphalt (HMA) specimens by means of the superpave gyratory compactor.* ASTM D6925. West Conshohocken, PA: ASTM.

ASTM. 2012. *Standard test method for effect of heat and air on a moving film of asphalt (rolling thin-film oven test)*. ASTM D2872-12e1. West Conshohocken, PA: ASTM.

ASTM. 2013. *Standard test method for penetration of bituminous materials*. ASTM D5/D5M. West Conshohocken, PA: ASTM.

ASTM. 2014. *Standard test method for effect of moisture on asphalt concrete paving mixtures*. ASTM D4867/D4867M. West Conshohocken, PA: ASTM.

ASTM. 2015. *Standard test method for viscosity determination of asphalt at elevated temperatures using a rotational viscometer.* ASTM D4402/D4402M. West Conshohocken, PA: ASTM.

ASTM. 2017a. *Standard test method for bulk specific gravity and density of non-absorptive compacted asphalt mixtures*. ASTM D2726/D2726M. West Conshohocken, PA: ASTM.

ASTM. 2017b. *Standard test method for indirect tensile (IDT) strength of asphalt mixtures*. ASTM D6931. West Conshohocken, PA: ASTM.

Beckhoff, B., B. Kanngießer, N. Langhoff, R. Wedell, and H. Wolff. 2006. *Handbook of practical X-ray fluorescence analysis*. New York, NY: Springer.

BSI (British Standards Institution). 2000. *Bituminous mixtures test methods for hot mix asphalt. Part 25: Cyclic compression test*. BS EN 12697-25. London: BSI.

BSI (British Standards Institution). 2005a. *Bituminous mixtures test methods for hot mix asphalt. Part 24: Resistance to fatigue*. BS EN 12697-24. London: BSI.

BSI (British Standards Institution). 2005b. *Bituminous mixtures test methods for hot mix asphalt. Part 26: Stiffness*. BS EN 12697-26. London: BSI.

Cheng, Y., J. Tao, Y. Jiao, Q. Guo, and C. Li. 2015. "Influence of diatomite and mineral powder on thermal oxidative ageing properties of asphalt." *Adv. Mater. Sci. Eng.* 2015: 1–10. https://doi.org/10.1155/2015/947834.

Cheng, Y., J. Tao, Y. Jiao, G. Tan, Q. Guo, S. Wang, and P. Ni. 2016. "Influence of the properties of filler on high and medium temperature performances of asphalt mastic." *Constr. Build. Mater.* 118: 268–275. https://doi.org/10.1016/j.conbuildmat.2016.05.041.

Chipera, S., and D. Bish. 2001. "Baseline studies of The Clay Minerals Society source clays: Powder X-ray diffraction analysis." *Clays and Clay Miner.* 49 (5): 398–409. https://doi.org/10.1346/CCMN.2001.0490507.

Dan, L., Z. Chuanfeng, Q. Yong, B. Heng, L. Keyao, and H. Junfei. 2014. "Analysing the effects of the mesoscopic characteristics of mineral powder fillers on the cohesive strength of asphalt mortars at low temperatures." *Constr. Build. Mater.* 65: 330–337. https://doi.org/10.1016/j.conbuildmat.2014.04.123.

Das, B., S. Prakash, P. S. R. Reddy, and V. N. Misra. 2007. "An overview of utilization of slag and sludge from steel industries." *Resour. Conserv. Recycl.* 50 (1): 40–57. https://doi.org/10.1016/j.resconrec.2006.05.008.

Davis, C., and C. Castorena. 2015. "Implications of physico-chemical interactions in asphalt mastics on asphalt microstructure." *Constr. Build. Mater.* 94: 83–89. https://doi.org/10.1016/j.conbuildmat.2015.06.026.

DNER (Departamento Nacional de Estradas de Rodagem). 1998. *Avaliação da resistência mecânica pelo método dos 10% de finos [Evaluation of mechanical resistance to coarse aggregate using 10% method]*. DNER-ME 096. Rio de Janeiro, Brazil: Departamento Nacional de Infraestrutura de Transporte.

Emery, J. J. 1982. "Slag utilization in pavement construction." In *Extending aggregate resources*, 95–118. Philadelphia, PA: ASTM.

FHWA (Federal Highway Administration Research and Technology). 2008. *Coordinating, developing, and delivering highway transportation innovations: User guidelines for waste and byproduct materials in pavement construction*. Rep. Publication Number: FHWA-RD-97-148. Washington, DC: FHWA.

Geiseler, J. 1996. "Use of steelworks slag in Europe." *Waste Manage.* 16 (1–3): 59–63. https://doi.org/10.1016/S0956-053X(96)00070-0.

Guo, M., Y. Tan, A. Bhasin, J. Wei, X. Yang, and Y. Hou. 2016. "Using molecular dynamics to investigate interfacial adhesion between asphalt binder and mineral aggregate." In *Proc., 4th Chinese-European Workshop on Functional Pavement Design (4th CEW 2016)*, edited by S. Erkens, X. Liu, K. Anupam, and Y. Tan, 517–527. Delft, Netherlands: Taylor & Francis Group.

HERALDO. 2016. "Colombia aumentó en 2015 la producción de hierro, oro y esmeraldas [Colombia increased the production of iron, gold and emeralds in 2015]." Accessed November 17, 2017. https://www.elheraldo.co/economia/colombia-aumento-en-2015-la-produccion-de-hierro-oro-y-esmeraldas-243818.

Houben, L. J. M., S. Akbarnejad, and A. A. A. Molenaar. 2010. "Performance of pavements with blast furnace base courses." In *Proc.,*

GeoShanghai 2010 Int. Conf. on Paving Materials and Pavement Analysis Geotechnical*, 476–483. Reston, VA: ASCE.
INVIAS (Instituto Nacional de Vías). 2013. *Especificaciones generales de construcción de carreteras*. Bogotá, Colombia: INVIAS.
Jones, D. E. 1982. "Application of steel plant by-products to roadworks." In *Proc., Conf. Australian Road Research Board*. Melbourne, Australia: ARRB Group Limited.
Kuity, A., and A. Das. 2015. "Homogeneity of filler distribution within asphalt mix – A microscopic study." *Constr. Build. Mater.* 95: 497–505. https://doi.org/10.1016/j.conbuildmat.2015.07.043.
León, N. A., N. R. Rojas, B. U. Suárez, and O. Bustamante. 2009. "Evaluación experimental de unidades sílico-calcáreas a partir de escoria de alto horno y cal hidráulica para mampostería [Experimental evaluation of silicon-calcareous units from blast furnace slag and hydraulic lime for masonry]." *Dyna* 76 (160): 247–254.
Li, C., Z. Chen, S. Wu, B. Li, J. Xie, and Y. Xiao. 2017. "Effects of steel slag fillers on the rheological properties of asphalt mastic." *Constr. Build. Mater.* 145 (1): 383–391. https://doi.org/10.1016/j.conbuildmat.2017.04.034.
Li, R., H. Du, Z. Fan, and J. Pei. 2016. "Molecular dynamics simulation to investigate the interaction of asphaltene and oxide in aggregate." *Adv. Mater. Sci. Eng.* 2016: 1–10. https://doi.org/10.1155/2016/3817123.
Liao, M. C., and J. S. Chen. 2011. "Zero shear viscosity of bitumen-filler mastics." *J. Mater. Civ. Eng.* 23 (12): 1672–1680. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000331.
Marriaga, J. L., and P. Claisse. 2011. "The influence of the blast furnace slag replacement on chloride penetration in concrete." *Ingeniería e Investigación* 31 (2): 38–47.
Misra, A., D. Biswas, and S. Upadhyaya. 2005. "Physico-mechanical behavior of self cementing class C fly ash-clay mixtures." *Fuel* 84 (11): 1410–1422. https://doi.org/10.1016/j.fuel.2004.10.018.
Modarres, A., and M. Rahmanzadeh. 2014. "Application of coal waste powder as filler in hot mix asphalt." *Constr. Build. Mater.* 66: 476–483. https://doi.org/10.1016/j.conbuildmat.2014.06.002.
Moore, D., and R. Reynolds. 1997. *X-Ray diffraction and the identification and analysis of clay minerals*. 2nd ed. New York: Oxford University Press.
Muniandy, R., E. Aburkaba, and L. Mahdi. 2013. "Effect of mineral filler type and particle size on asphalt-filler mastic and stone mastic asphalt laboratory measured properties." *Aust. J. Basic Appl. Sci.* 7 (11): 475–487.
Nassar, A. I., M. K. Mohammed, N. Thom, and T. Parry. 2016. "Mechanical, durability and microstructure properties of cold asphalt emulsion mixtures with different types of filler." *Constr. Build. Mater.* 114: 352–363. https://doi.org/10.1016/j.conbuildmat.2016.03.112.
NLT (Norma Laboratorio de Transporte). 1991. *Standard method for the determination of the flakiness index of the aggregate*. NLT 354. Madrid, Spain: Centro de Estudios y Experimentación de Obras Públicas.
Normas NLT. 1988. *Método para determinar la variación de la consistencia del betún asfáltico con los cambios de temperatura (susceptibilidad) [Method to determine the variation in the consistency of asphalt bitumen with temperature changes (susceptibility)]*. NLT 181. Madrid, Spain: Normas NLT.
Noureldin, A. S., and R. S. McDaniel. 1990. "Evaluation of surface mixtures of steel slag and asphalt." *Transp. Res. Rec.* 1269: 133–149.
Nouvion, S., A. Jullien, M. Sommier, and V. Basuyau. 2009. "Environmental modeling of blast furnace slag aggregate production." *Road Mater. Pavement Des.* 10 (4): 715–745. https://doi.org/10.3166/rmpd.10.715-745.
NSA (National Slag Association). 2006. "Blast furnace slag." Accessed April 11, 2016. http://nationalslag.org/blast-furnace-slag.
Okumura, H. 2013. "Recycling of iron and steelmaking slags in Japan." In *Proc., 1st Int. Conf. on Processing Materials for Properties*, 803–806. Warrendale, PA: Minerals, Metals, and Materials Society (TMS).
Proctor, D. M., K. A. Fehling, E. C. Shay, J. L. Wittenborn, C. Avent, R. D. Bigham, M. Connolly, B. Lee, T. O. Shepker, and M. A. Zak. 2000. "Physical and chemical characteristics of blast furnace, basic oxygen furnace, and electric arc furnace steel industry slags." *Environ. Sci. Technol.* 34 (8): 1576–1582. https://doi.org/10.1021/es9906002.
Reed, S. J. B. 2005. *Electron microprobe analysis and scanning electron microscopy in geology.* Cambridge, UK: Univ. of Cambridge.
Shen, H., and E. Forssberg. 2003. "An overview of recovery of metals from slags." *Waste Manage.* 23 (10): 933–949. https://doi.org/10.1016/S0956-053X(02)00164-2.
Shi, C. 2004. "Steel slag—Its production, processing, characteristics, and cementitious properties." *J. Mater. Civ. Eng.* 16 (3): 230–236. https://doi.org/10.1061/(ASCE)0899-1561(2004)16:3(230).
Sorlini, S., A. Sanzeni, and L. Rondi. 2012. "Reuse of steel slag in bituminous paving mixtures." *J. Hazard. Mater.* 209–210: 84–91. https://doi.org/10.1016/j.jhazmat.2011.12.066.
Tenza-Abril, A. J., J. M. Saval, and A. Cuenca. 2015. "Using sewage-sludge ash as filler in bituminous mixes." *J. Mater. Civ. Eng.* 27 (4): 04014141. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001087.
Transport Roads and Maritime Services. 2012. *Test method T220 Iron unsoundness in metallurgical slag*. T220 (RMS 12.495). Camperdown, NSW, Australia: Transport Roads and Maritime Services.
Ucrós, J. C. 2009. "Propuesta para la implementación de instrumentos de política ambiental en la planta siderúrgica de Acerías Paz del Río S.A. [Proposal for the implementation of environmental policy instruments in the steel plant Acerías Paz del Río S.A.]." M.S. thesis, Pontificia Universidad Javeriana.
UPME (Unidad de Planeación Minero Energética). 2014. *Indicadores de la minería en Colombia [Indicators of mining in Colombia]*. Bogotá, Colombia: UPME.
Van Oss, H. G. 2003. *Slag-iron and steel*, 69.1–69.7. Reston, VA: US Geologycal Survey.
Veytskin, Y., C. Bobko, C. Castorena, and R. Kim. 2015. "Nanoindentation investigation of asphalt binder and mastic cohesion." *Constr. Build. Mater.* 100: 163–171. https://doi.org/10.1016/j.conbuildmat.2015.09.053.
WSDOT (Washington State Department of Transportation). 2015. *Strategies regarding use of steel slag aggregate in pavements. A report to the state legislature in response to 2ESHB 1299*. Olympia, WA: Washington State DOT Construction Division Pavements Office.
Yiqiu, T., L. Xiaolin, and W. Jiantao. 2012. "Internal influence factors of asphalt-aggregate filler interactions based on rheological characteristics." *J. Mater. Civ. Eng.* 24 (12): 1520–1528. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000506.
Zarei, Z., and M. B. Reza. 2015. "Application of iron slag at different pavement layers." *J. Environ. Treat. Technol.* 3 (3): 158–162.
Zhang, G., J. Germaine, M. Torrence, and A. A. Whittle. 2003. "A simple sample-mounting method for random powder X-ray diffraction." *Clays Clay Miner.* 51 (2): 218–225. https://doi.org/10.1346/CCMN.2003.0510212.

ARTÍCULO 2:

Revista Ingeniería de Construcción
CHILE

ENGLISH VERSION..........

Characterization of blast furnace slag for road projects
Caracterización de una escoria de alto horno para proyectos viales

H. Rondón [1]*, W. Fernández *, D. Patiño *, J. Ruge **, H. Vacca ***, F. Reyes ***

* Universidad Distrital Francisco José de Caldas, Bogotá. COLOMBIA
** Universidad Piloto de Colombia, Bogotá. COLOMBIA
*** Pontificia Universidad Javeriana, Bogotá. COLOMBIA

Fecha de Recepción: 07/09/2017
Fecha de Aceptación: 09/03/2018
PAG 83-92

Abstract

The present study evaluated the potential use of Blast Furnace Slag (BFS) as forming material of untreated granular layers in pavement (e.g. base, subbase and subgrade), and as stone aggregate in the manufacture of asphalt mixtures. For that purpose, tests of characterization, X-ray diffractometry (XRD), X-ray fluorescence (XRF) and imaging in a scanning electron microscope (SEM) were executed on the BFS. As a general conclusion is reported that the BFS can be used in the formation of unbound granular layers of subbase. As granular base material, its use would be recommended on roads with low traffic volumes or with thick asphalt layers and as a selected material, in tertiary roads that support light traffic. In the case of HMA is not recommended to use the coarse fraction of the BFS as a stone aggregate. However, the obtained results indicate that the fine fraction shows good characteristics to be used in the production of the mastic of such mixtures.

Keywords: *Blast furnace slag, BFS, granular material, road construction, pavements*

Resumen

El presente estudio evaluó el potencial de uso de una escoria de alto horno (BFS) como material de conformación de capas granulares no tratadas en pavimentos (base, subbase y afirmado), y como agregado pétreo en la fabricación de mezclas asfálticas. Para tal fin, fueron ejecutados sobre la BFS, ensayos de caracterización, difractometría de rayos X (DRX), fluorescencia de rayos X (FRX) e imagenología en un microscopio electrónico de barrido (MEB). Como conclusión general se reporta que la BFS puede ser utilizada en la conformación de capas granulares no tratadas de subbase. Como material para base granular se recomendaría su uso en vías con bajos volúmenes de tráfico o con capas asfálticas gruesas, y como material de afirmado, en vías terciarias que soporten tráfico liviano. Para el caso de mezclas asfálticas no se recomienda utilizar como agregado pétreo la fracción gruesa de la BFS. Sin embargo, los resultados obtenidos indican que la fracción fina presenta buenas características para ser utilizado en la producción del mastic de dichas mezclas.

Palabras clave: Escoria de alto horno, BFS, material granular, construcción vial, pavimentos

1. Introduction

In construction, maintenance and road rehabilitation projects, large quantities of natural granular materials (NGM) are used. This results in a negative environmental impact. In the last two decades, the interest in replacing NGM with alternative materials has been growing in order to conserve natural resources, reduce the space they occupy in the dumps at the end of their useful life and prevent the deterioration of the landscape (Pasetto and Baldo, 2010). However, with regard to the use of alternative materials, various concerns related to the assessment of technical and environmental performance in road projects still exist. These concerns have not been answered in a satisfactory manner (Nouvion et al., 2009).

One of the alternative materials that can be used as NGM substitutes is the Blast Furnace Slag (BFS). This material is formed when iron ore, coke and a flux (either limestone or dolomite) are fused together in a blast furnace (FHWA, 2008; Marriaga and Claisse, 2011). Significant quantities of this material are generated as waste on a daily basis in iron industries. According to Okumura (1993), Proctor et al. (2000) and Airey et al. (2004), the annual production of BSF in the USA, Japan and the UK is 13, 24.3 and 4 million tons respectively. According to Proctor et al. (2000), and Das et al. (2007), for every ton of produced steel, a quantity between 220-370 kg and 340-421 kg of blast furnace slag is produced respectively. The conventional method of eliminating slag is to transport it and deposit it in dumps. This causes an environmental problem since is occupies spaces in the landfills, thus wasting a material that can be reused. According to Nouvion et al. (2009), using blast furnace slag could reduce the energy consumption during the process of NGM extraction, thus reducing the release of pollutants into the air, water and soil.

Some uses of the BFS include fertilizers (Geiseler, 1996), road construction (Houben et al., 2010), soil recovery and preparation of materials such as glass-ceramics, silica gel, bricks, etc. (Das et al., 2007). However, perhaps its broader use is the production of cement (Shi, 2004; Das et al., 2007; Abu-Eishah et al., 2012; Sorlini et al., 2012).

The study group identified as possible uses of BFS for the substitution of MGN in road projects, the formation of granular layers of subgrade, subbase and base, and as stone aggregates for the manufacture of asphalt mixtures. Therefore, in the present study, an experimental phase was performed in order to assess these possible uses. For this purpose, the typical tests conducted on the coarse and fine fractions of NGM for

[1] Corresponding author:

Facultad del Medio Ambiente y Recursos Naturales, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia.
E-mail: harondonq@udistrital.edu.co

their characterization were carried out on the BFS. In contrast to other studies carried out on the BFS, in the present study the mineralogical, chemical and microstructural composition was measured through X-ray diffractometry (XRD), X-ray fluorescence (XRF) and visual recognition techniques in a scanning electron microscope (SEM).

2. Methodology

The BFS used was the type of Air-Cooled Blast Furnace Slag - ACBFS (once the slag is out of the blast furnace, it is slowly cooled in the open air; NSA, 2016), from the company Acerías Paz del Río (Nobsa – Boyacá, Colombia). Figure 1 shows the coarse and fine fractions of the analyzed BFS.

Figure 1. *Slag particles (coarse and fine)*

2.1 Visual characterization

A phase of visual characterization was initially made to help to identify the groups of representative samples that would be tested in XRD, XRF and SEM. This is because the BFS is a highly heterogeneous material (shapes and sizes of particles, chemical constitution, texture, specific gravity, degradation resistance and porosity, etc.) that develops complex characteristics and properties (Akbarnejad et al., 2014). The two types of coarse particles that predominate in the BFS used in the present study are shown in figure 2. The particles of the image on the left are those present in larger quantities within the BFS (on average, approximately 65% with regard to the number of particles), their surface color is shiny black, and when they are ground they internally develop a grayish color. In addition, they have a rigid and hard consistency and a mass similar to the natural stone aggregates (NGM), even though they are much more porous. On the contrary, the particles of the image on the right are easy to degrade through abrasion (even with the hands); they are lightweight, light green and can float in water.

Figure 2. *Slag particles (size between ¾" and 1" in diameter)*

2.2 Typical characterization by specifications

The same tests specified to the NGM were carried out on the BFS in the construction of untreated granular layers in pavements (base, subbase, subgrade, etc.) and the manufacture of asphalt mixtures such as: specific gravity and absorption (AASHTO T 84-00, AASHTO T 85-91), degradation of Los Angeles machine (AASHTO T 96 – 02), Micro-Deval (AASHTO T327-05), 10% of fines (DNER-ME 096-98), impurity content (UNE 14613:2000), plasticity index (ASTM D 4318-00), flat and elongated indices (NLT 354-91), sand equivalent (AASHTO T 176-02) and CBR (AASHTO T 193-99). Every test was conducted five times and no high dispersion was generated in the results. To conduct the CBR test, the grading presented in Table 1 were used (BG, SBG and A refer to the base, subbase and subgrade, respectively). Prior to this test, the samples were compacted through the Proctor test (AASHTO T 180), obtaining maximum dry unit weights and optimum water contents of 16 kN/m3 and 6%, 16.6 kN/m3 and 7.1%, and 16.2 kN/m3 and 7.7% for BG, SBG and A, respectively.

Table 1. *Granulometry used for compaction tests and CBR (INVIAS, 2013)*

Sieve		Percentage that passes (%)		
		BG-25	SBG-38	A-38
1 ½"	37.5 mm	-	100	100
1"	25 mm	100	85	-
¾"	19 mm	85	70	90
3/8"	9.5 mm	65	60	72.5
No. 4	4.75 mm	50	45	52.5
No. 40	2.0 mm	32.5	32.5	40
No. 80	0.425 mm	20	19	21.5
No. 200	0.075 mm	10	8.5	13.5

2.3 Mineralogical characterization

For the mineralogical characterization of the BFS, an analysis based on X-ray diffractometry (XRD) and X-ray fluorescence (XRF) was carried out. In the XRD test, the preparation of the sample began with a pulverizing and sieving phase in order to guarantee a particle size smaller than 75μm. After that, the sample was poured on an aluminum sample holder and with the help of a spatula the excess was removed, thus creating a flat surface on which the analysis was carried out (please refer to the details of the procedure in Moore and Reynolds, 1997; Chipera and Bish, 2001; Zhang et al., 2003 and Reed, 2005).

In the case of the XRF test (Beckhoff et al., 2006), the samples were dried at 105°C for a 12-hour period. Since the grain size of the sample was too coarse and its grading was well graded (heterogeneous), this was reduced in an agate ball mill. The samples were homogenized by agitation and were prepared in the shape of meltedpearls with a sample: flux ratio of 1:10. A mixture of lithium tetraborate and lithium metaborate was used as a flux and lithium iodide was added in order to prevent the samples from sticking. After that, the samples were taken to an induction furnace. In doing so, glass disks of 37 mm in diameter were obtained to be measured in a semi-quantitative or quantitative application. The quantitative analysis was carried out through the SemiQ software, with which 11 scannings were performed in order to detect all the elements present in the sample (H, C, Li, Be, B, N, O are excluded as well as the transuranic elements).

2.4 Microstructure

The microstructure of any material that is a component of a system that will work mechanically, governs part of its operation, especially if this microstructure is susceptible to be invaded by a fluid that conditions its mechanic and hydraulic response. The preparation of the slag samples for an imaging test was conducted through the first selection of different grains in order to obtain a statistically reliable result. The chosen grains were five green grains, three black grains and one white grain. This last grain was scarce in the delivered population; therefore, a single sample was selected. The assembly of the sample consisted in the use of resin and hardener to obtain a sample containing all the grains chosen. After that, the surface of interest was mirror polished (abrasives in disks and cloths) and then a conductive layer was deposited on the surface. The final result of the previous metallization is shown in Figure 3. Finally, the sample was studied by using a scanning electron microscope (SEM) and several photographs were taken of every individual grain at different zooms to be subsequently analyzed. In order to compare the results obtained on the BFS, this test was also conducted on an NGM sample used as a stone aggregate of asphalt mixtures and that has been extensively studied and characterized by the research group (Figure 4).

Figure 3. *Sample assembled with selected grains of BFS*

Figure 4. *Sample assembled with selected grains of NGM*

3. Results

3.1 Typical characterization by specifications

The results of the characterization tests conducted on the BFS are detailed in Table 2.

It is shown in Table 2 that by decreasing the size of the BFS particles, the specific gravity increases and the absorption decreases. This is perhaps due to the fact that during the process of mechanical fracturing performed on the coarse particles to obtain fine particles the latter lose part of their porosity. In addition, the above is an indicator of an increase in porosity with the increase in the size of the particle. Based on the degradation results in Micro-Deval and 10% of fines, the BFS is reported to present a good resistance to abrasion degradation by friction between particles and to the fracturing under monotonic loading, respectively. However, as reported in the reference literature (e.g., Airey et al., 2004; FHWA, 2008), the BFS is a material that experiences low resistance to abrasion degradation by impact in Los Angeles machine. In addition, it can be observed that this material presents particles with ideal shapes (rounded with angular and cracked sides with very little content of elongated and flat particles) to develop a good granular skeleton that helps in the compaction processes, as well as resisting static, dynamic or impact loading. The fine particles do not present any content of clay, organic matter or dust. The CBRs obtained (at 100% of maximum dry density and four-day immersion in water) were 95.3%, 88.7% and 76.1% for BG, SBG and A, respectively. These dimensions are high and, together with the results previously reported in Table 2 and the minimum quality requirements required for BG, SBG and A (Table 3) indicate that the BFS can be used as stone aggregate for the formation of granular layers of subbase, subgrade of pavements. We could even think of its use as material for the granular base of roads with low traffic volumes or with thick asphalt layers, since only it does not comply with the required maximum resistance of 35% of degradation in Los Angeles machine. Additionally, in the case of subgrade, caution is required since this material would be susceptible to fracture (according to the obtained values of degradation in Los Angeles machine and the high porosity of coarse particles) because these layers are subjected to the direct action of traffic in tertiary roads.

Table 2. *BFS characterization*

Test	Method	Value
Specific gravity/absorption (¾")	AASHTO T 84-00 AASHTO T 85-91	1.81/3.75%
Specific gravity/absorption (3/8")		1.97/3.33%
Specific gravity/absorption (No. 4)		2.11/2.73%
Specific gravity/absorption (No. 40)		2.26/2.65%
Specific gravity/absorption (No. 80)		2.36/2.25%
Specific gravity/absorption (No. 200)		2.45/1.95%
Resistance of Los Angeles machine, 500 revolutions	AASHTO T 96 – 02	49.2%
Micro-Deval	AASHTO T327-05	29.2%
10% of fines (dry)	DNER-ME 096-98	123 kN
Cracked sides: 1 side	ASTM D 5821-01	92%
Cracked sides: 2 sides		88%
Flat and elongated particles		1%
Sand equivalent	AASHTO T 176-02	62%
Impurity content	UNE 14613 : 2000	0%
Plasticity index	ASTM D 4318-00	Non plastic
Flattening index	NLT 354-91	5.62%
Elongated index		10.62%

As coarse stone aggregate in the case of asphalt concrete mixtures (DHM – dense hot mix) the high adsorption reported in Table 2 shows the need to require higher contents of asphalt, thus resulting in an increase in cost. Despite the above, in some cases, this higher cost could be compensated with higher performance (volume per mass) of BFS as an aggregate due to the lower unit weight of the mixture. Since this is a porous material in comparison with conventional aggregates, it could be necessary a longer drying period in asphalt mixture production plants. In addition, since the BFS does not comply with most of the minimum quality requirements for DHM (Table 3), the BFS will be more prone to abrasion degradation and particle fracturing since the vehicles are driven directly on the asphalt layer in the pavement. However, the BFS is observed to have desirable properties for being used as an aggregate that can substitute the fine fraction of the stone aggregate (high sand equivalent, non-plastic filler, zero impurity content and adsorption decrease).

Table 3. *Minimum quality requirements of stone aggregates for subgrade (A), subbases (SBG), bases (BG) and asphalt mixtures (DHM) according to INVIAS (2013). High-traffic volume roads*

Test	***Method***	***A***	***SBG***	***BG***	***MDC***
Degradation Los Angeles (500 revolutions), dry	*AASHTO T 96-02*	*50% máx.*	*50% máx.*	*35% máx.*	*25% max.*
Micro-Deval	*AASHTO T327-05*	*NA*	*30% máx.*	*30% máx.*	*20% max.*
10% of fines (dry)	*DNER-ME 096-98*	*NA*	*NA*	*90 kN mín.*	*110 kN min.*
Plasticity index	*ASTM D 4318-00*	*4-9*	*6% máx.*	*0*	*0*
Sand equivalent	*AASHTO T 176-02*	*NA*	*25% mín.*	*30% mín.*	*50% min.*
Impurity content	*UNE 14613 : 2000*	*2% máx.*	*2% máx.*	*2% máx.*	*0.5% max.*
Cracked sides: 1 side	*ASTM D 5821-01*	*NA*	*NA*	*100% mín.*	*85% min.*
Cracked sides: 2 sides	*ASTM D 5821-01*	*NA*	*NA*	*70% mín.*	*70% min.*
Flattening index	*NLT 354-91*	*NA*	*NA*	*35% máx.*	*10% max.*
Elongated index	*NLT 354-91*	*NA*	*NA*	*35% máx.*	*10% max.*
CBR (at 100% of maximum dry density and four-day immersion in water)	*INV. E-148*	*15% mín.*	*30% mín.*	*95% mín.*	*NA*

Note: *NA: Not applicable*

3.2 Mineralogical Characterization – XRD and XRF

In Figure 5, the diffractogram (powder sample) obtained from the XRD is shown. The counts ordinate axis can be observed. This corresponds to the intensities of each diffracted mineral peak and the abscissas show the 2theta angle according to the Bragg law (Equation 1).

$$n\lambda = 2d \text{ sen } \vartheta \qquad (1)$$

Where, n is a positive integer, λ is the wavelength of the incident wave, d is the interplanar spacing, and ϑ is the diffraction angle. Bragg (1910) showed that there is a ratio between the interplanar spacing d in the crystal structure of a mineral or minerals and the sine of the ϑ angle. The intensity of the peak height in the y axis depends on the crystal structure and the quantity of each mineral present in the sample

In other words, the different peaks detected are the plane reflections in each mineral phase, which are compared with a data basis (Brucker). The quantification is carried out with specialized software, which operates under the RIR method. This particular method consists of making a ratio between relative intensities. The function modeling the diffractogram takes into account the scale parameters, which described the background and the shapes of the peaks, instrument contributions and preferred orientations. In Table 4 it is possible to observe the minerals found in the analyzed BFS sample.

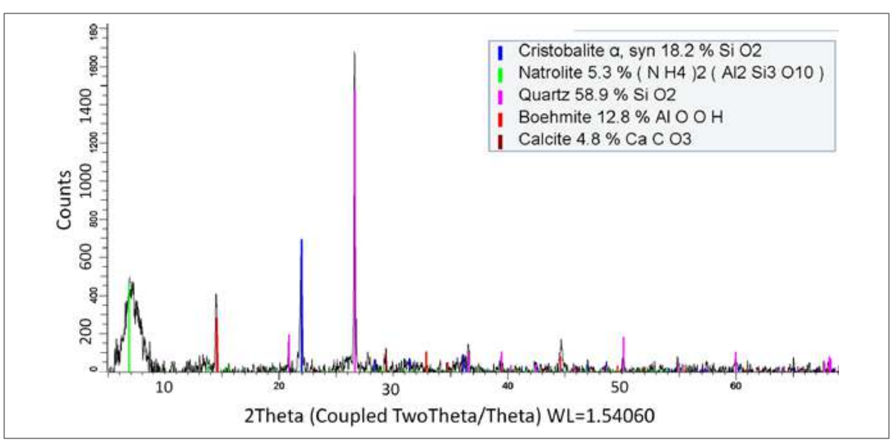

Figure 5. *Powder BFS diffractogram*

Table 4. *Mineral percentages in the sample*

Mineral	***Weight%***
Quartz	*58.9*
Cristobalite	*18.1*
Boehmite	*12.8*
Calcite	*4.8*
Natrolite	*5.3*

It can be observed that the predominant minerals (77%) are quartz (silica - SiO_2) and cristobalite (high-temperature cubic phase of silica - SiO_2). The silica is one of the most abundant oxide materials in nature, where it can exist in an amorphous manner as glass silica or in a wide variety of crystal shapes. This material has good resistance to abrasion (high hardness), high thermal stability and generally acceptable mechanical properties (Table 5), as reported by Muniandy et al. (2013). The presence of silica in all its shapes in BFS samples can possibly generate high interlocking levels, either between its own particles or working in combination with NGM due to its rough texture and compression. The results in XRD are consistent with those reported in the XRF test (Table 6), where the predominant chemical component is silica (SiO_2) in the shape of Quartz and Cristobalite. In addition, the analyzed BFS is reported to be comprised mainly of silica, calcium oxide (CaO) and aluminum oxide (86.76%).

In the case of asphalt mixtures, the Al_2O_3 together with CaO can be used as adhesion improves (Muniandy et al., 2013; Modarres and Rahmanzadeh, 2014; Nassar et al., 2016). Additionally, the SiO_2 and Al_2O_3 are pozzolanic compounds, which in sizes of very fine particles can develop self-cementing properties (Misra et al., 2005). All of the above could result in beneficial effects on the resistance to rutting, moisture damage and stripping.

Table 5. *Physical properties of quartz*

Property	***Quartz***
Density (g/cm3)	*2.65*
Tensile Strength (MPa)	*55*
Compressive Strength (MPa)	*2070*
Elasticity Modulus (GPa)	*70*

Table 6. *XRF results for the sample analyzed in dry base*

Element	SiO_2	***CaO***	Al_2O_3	Fe_2O_3	***MnO***	TiO_2	K_2O	***MgO***	Na_2O	SO_3	***Ba***	***Cr***
Weight % of the Sample	*52.03*	*20.83*	*13.90*	*6.52*	*2.26*	*0.979*	*0.862*	*0.818*	*0.653*	*0.475*	*0.209*	*0.124*

3.3 Microstructure

The difference between the three colors chosen from the beginning in the BFS effectively showed three different populations. Initially, the porosity of the samples was calculated in order to obtain the results shown in Table 7. The green grains have a significant dispersion, but they tend to present dimensions above other populations with regard to porosity. In white grains, the porosity is high, but it is less than in the case of the green population. Finally, the black population stands out for its reduced porosity and minor variation.

Table 7. *Porosity values calculated for different grain populations*

Type	Porosity (%)	Error (%)
Green Grains	63	13
Black Grains	9	3
White Grain	50	4

In order to visually understand the results, it was necessary to conduct SEM tests. Figures 6, 7 and 8 show specific and representative cases of each grain sample chosen. It is possible to demonstrate the difference between the black grain samples and the other types of grains. In the images shown it can be analyzed that the most frequent grain populations in the sample (green and white) have a similar porosity (63% and 50%), revealed by the presence of coarser grains. In contrast, the black grain has a lower porosity as shown in Figure 7. The quantitative values of the pore throats of each population are consistent with the porosity obtained since the lower the percentage of voids content in the sample, the fewer opportunities of interconnection among them. In addition, in the case of black grains, it can be demonstrated that the low porosity present in the sample is translated into a lower value in the proportion and size of the throats (Table 8). The distribution of the pore throats of the black grain population is not well defined due to the low porosity observed in the image, largely controlled by the size of the grain that tends to be smaller than in the other populations. On the other hand, both green and white grains show a distribution that can be visually defined with ease in the images since the connectivity between the pores is clearly shown. Table 8 shows the statistical summary for each population. Again, the variation in the results of green grains is evident by means of a significant deviation. However, it reveals a higher average in the pore throat in comparison with the other grains. Statistically, it can be determined that for green, black and white grains, the pore throat average is 82.6 µm, 27.5 µm and 30.3 µm, respectively.

Based exclusively on the imaging and the pore throat analysis, it is evident that the population of green grains governs the behavior of the whole sample since its grains present matches near 72% of the total population. This result is contrary to that obtained in the visual characterization of coarse particles, where a greater quantity of black and grayish grains was reported. This is perhaps because, during the process of mechanical fracturing to obtain fine particles, the coarse green particles of the BFS are easier to degrade and fracture. The green grains of the BFS present high porosity, which makes us assume a priori that if this material is part of an asphalt mixture, the binding material will adhere more easily to them.

Seven types of grain were selected to conduct the test on the NGM, which represented different lithological characteristics, they did not have shared characteristics, and they were classified according to the size, color and sphericity of the grain. The average porosity and pore throat of the selected grains were 7% and 12 µm, respectively. These average porosity and pore throat dimensions are low in comparison with those previously reported in the BFS.

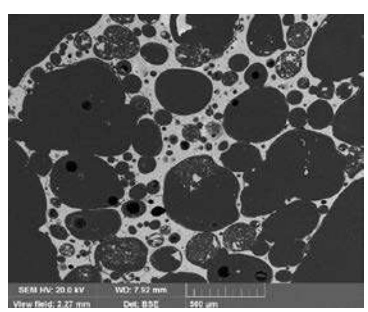

Figure 6. *Representative grain of the green grain population*

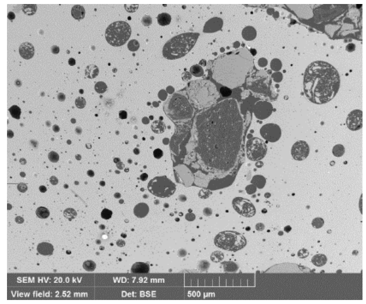

Figure 7. *Representative grain of the black grain population*

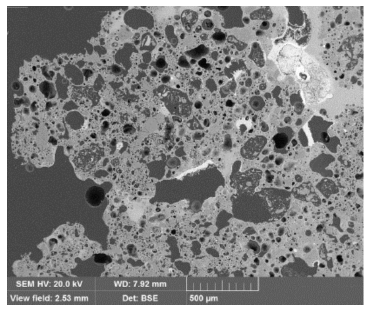

Figure 8. *Representative grain of the white grain population*

Table 8. *Statistical data for each grain population*

Parameter	*Green Grains*	*Black Grains*	*White Grains*
Average (µm)	82.6	27.5	30.3
Deviation (µm)	71.0	25.0	25.4
Median (µm)	60	17.65	20.5
Range (µm)	575.9	99.3	112.7
Maximum (µm)	585.9	104.0	116.6
Minimum (µm)	10.0	4.7	3.9
Counts	255	39	60

4. Conclusions

Based on the results obtained in the case of the use of BFS as a material in the formation of granular layers, we can conclude the following:

Since the analyzed BFS is mainly comprised of Quartz (silica), which is a high hardness material, it shows good resistance to abrasion degradation by friction and fracturing under monotonic loading. In addition, it has other characteristics that are desirable in road projects, such as i) particles predominantly rounded with angular and cracked sides and very little content of elongated and flat particles (indicators of a more compact granular skeleton which is less deformable under mechanical loading). ii) high sand equivalent (an indicator of a material that will not have an excess of fines), iii) the fine particles do not present any content of clay or organic material (these two materials tend to decrease the mechanical response of granular materials in road projects), iv) high shear resistance under controlled humidity and density conditions. However, the high porosity of the particles can lead to fracturing under a mechanical loading. As a result of the aforementioned properties, the BFS can be used with confidence in the formation of subbase granular layers in pavements (since the traffic efforts have dissipated when they act on this layer), as granular base material of roads with low traffic volumes or with thick asphalt layers, and as a subgrade in tertiary roads supporting light traffic (it is not recommended *for heavy traffic since this layer in tertiary roads generally support traffic directly).*

In the case of asphalt mixtures, we can come to the conclusion that the coarse fraction of the BFS cannot be used since this does not meet the minimum quality requirements for the manufacture of these materials according to technical specifications. In addition, the coarse particles present high porosity and thus high adsorption. The latter is an indicator of i) probability of particle fracturing by impact or under the action of heavy traffic and cyclic loading, ii) need of higher contents of asphalt, resulting in cost increase, iii) higher requirements of drying times of BFS particles in the mixture production plants. Despite the above, the fine fraction reports good characteristics to be used in the production of asphalt mix mastic: i) high sand equivalent, ii) zero content of clay or organic material, iii) since the fine fraction is mainly comprised of pozzolanic materials, CaO y Al_2O_3 it can develop self-cementing properties thus increasing the resistance to moisture damage and stripping, improving the superficial asphalt-subgrade adhesion, the inner unity of the mastic, and the resistance of the mixture to rutting, iv) the high content of quartz identified reveals that a high mechanical resistance and interlocking can be developed in the skeleton of the collection of materials.

5. References

Abu-Eishah S. I., El-Dieb A. S., Bedir M. S. (2012), *Performance of concrete mixtures made with electric arc furnace (EAF) steel slag aggregate produced in the Arabian Gulf region. Construction and Building Materials, 34:249-256, http://dx.doi.org/10.1016/j.conbuildmat.2012.02.012.*

Airey G. D., Collop A. C., Thom N. H. (2004), *(12-16 of September). Mechanical performance of asphalt mixtures incorporating slag and glass secondary aggregates. In Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04). Sun City, North West Province, South Africa.*

Akbarnejad S., Houben L.J.M., Molenaar A.A.A. (2014), *Application of aging methods to evaluate the long-term performance of road bases containing blast furnace slag materials. Road Materials and Pavement Design, 15(3):488-506, http://dx.doi.org/10.1080/14680629.2014.907196.*

Beckhoff, B., Kanngießer B., Langhoff N., Wedell R., Wolff H. (2006), *Handbook of Practical X-Ray Fluorescence Analysis, 863 p., Springer.*

Chipera S., Bish D. (2001). *Baseline studies of the clay minerals society source clays: powder x-ray diffraction analysis. Clays and Clay Minerals, 49(5):398-409, DOI: 10.1346/CCMN.2001.0490507.*

Das B., Prakash S., Reddy P. S. R., Misra V. N. (2007), *An overview of utilization of slag and sludge from steel industries. Resources, Conservation and Recycling, 50(1):40-57. http://dx.doi.org/10.1016/j.resconrec.2006.05.008.*

FHWA (2008), *Federal Highway Administration Research and Technology. Coordinating, Developing, and Delivering Highway Transportation Innovations. User Guidelines for Waste and Byproduct Materials in Pavement Construction. Report Publication Number: FHWA-RD-97-148.*

Geiseler J. (1996),. *Use of steelworks slag in Europe. Waste Management, 16(1-3):59-63. doi:10.1016/S0956-053X(96)00070-0.*

Houben L. J. M., Akbarnejad S., Molenaar A. A. A. (2010), *(3-5 of June). Performance of pavements with blast furnace base courses. In GeoShanghai 2010 - International Conference, Paving Materials and Pavement Analysis, Geotechnical Special Publication No. 203 (pp. 476-483). Shanghai, China.*

INVIAS (2013), *Instituto Nacional de Vías –Especificaciones Generales de Construcción de Carreteras. Bogotá D.C., Colombia.*

Marriaga J. L., Claisse P. (2011), *The influence of the blast furnace slag replacement on chloride penetration in concrete. Ingeniería e Investigación, 31(2):38-47.*

Misra A., Biswas D., Upadhyaya S. (2005), *Physico-mechanical behavior of selfcementing class C fly ash–clay mixtures. Fuel, 84(11):1410–1422, http://dx.doi.org/10.1016/j.fuel.2004.10.018.*

Modarres A., Rahmanzadeh M. (2014), *Application of coal waste powder as filler in hot mix asphalt. Construction and Building Materials, 66:476–483, http://dx.doi.org/10.1016/j.conbuildmat.2014.06.002.*

Moore D., Reynolds R. (1997), *X-Ray diffraction and the identification and analysis of clay minerals, p. 378, New York: Oxford University Press, Second Edition.*

Muniandy R., Aburkaba E., Mahdi L. (2013), *Effect of mineral filler type and particle size on asphalt-filler mastic and stone mastic asphalt laboratory measured properties. Australian Journal of Basic and Applied Sciences, 7(11):475-787.*

Nassar A. I., Mohammedb M. K., Thom N., Parry T. (2016), *Mechanical, durability and microstructure properties of Cold Asphalt Emulsion Mixtures with different types of filler. Construction and Building Materials, 114:352–363, http://dx.doi.org/10.1016/j.conbuildmat.2016.03.112.*

Nouvion S., Jullien A., Sommier M., Basuyau V. (2009), *Environmental modeling of blast furnace slag aggregate production. Road Materials and Pavement Design, 10(4):715-745, http://dx.doi.org/10.1080/14680629.2009.9690224*

NSA (2016), *National Slag Association. http://nationalslag.org/blast-furnace-slag, consulted in april of 2016.*

Okumura H. (1993), *Recycling of iron-and steelmaking slags in Japan. In: Proceedings of the 1st International Conference on Processing Materials for Properties, Sponsored by: TMS; MMIJ Publ by Minerals, Metals & Materials Soc (TMS) (pp. 803-806).*

Pasetto M., Baldo N. (2010), *Experimental evaluation of high performance base course and road base asphalt concrete with electric arc furnace steel slags. Journal of Hazardous Materials, 181(1-3):938–948, http://dx.doi.org/10.1016/j.jhazmat.2010.05.104.*

Proctor D. M., Fehling K. A., Shay E. C., Wittenborn J. L., Avent C., Bigham R. D., Connolly M., Lee B., Shepker T. O., Zak M. A. (2000), *Physical and chemical characteristics of blast furnace, basic oxygen furnace, and electric arc furnace steel industry slags. Environmental Science and Technology, 34(8):1576-1582, DOI: 10.1021/es9906002.*

Reed S. J. B. (2005), *Electron Microprobe analysis and Scanning Electron Microscopy in Geology, 190 p., New York: Cambridge University Press.*

Shi C. (2004), *Steel slag—its production, processing, characteristics, and cementitious properties. Journal of Materials in Civil Engineering, 16(3):230-236, http://dx.doi.org/10.1061/(ASCE)0899-1561(2004)16:3(230).*

Sorlini S., Sanzeni A., Rondi L. (2012), *Reuse of steel slag in bituminous paving mixtures. Journal of Hazardous Materials, 209–210:84-91, http://dx.doi.org/10.1016/j.jhazmat.2011.12.066.*

Zhang G., Germaine J., Torrence M., Whittle A. (2003), *A simple sample-mounting method for random powder X-RAY diffraction. Clays and Clay Mineral, 51(2):218-255, DOI: 10.1346/CCMN.2003.0510212.*

REPÚBLICA DE COLOMBIA

COPNIA

Consejo Profesional Nacional de Ingeniería

Matrícula Profesional No.

25202-366143 CND

Fecha de Expedición: **18/08/2017**

Nombre:

DANIEL FRANCISCO

PATIÑO SANCHEZ

Identificación:

C.C. 1023919687

Profesión:

INGENIERO CIVIL

Institución:

UNIVERSIDAD DISTRITAL

FRANCISCO JOSE DE CALDAS

REPÚBLICA DE COLOMBIA
COPNIA
Consejo Profesional Nacional de Ingeniería

Certificado de vigencia y antecedentes disciplinarios
CVAD-2026-4290075

CONSEJO PROFESIONAL NACIONAL DE INGENIERÍA
COPNIA

EL DIRECTOR GENERAL

CERTIFICA:

1. Que DANIEL FRANCISCO PATIÑO SANCHEZ, identificado(a) con CEDULA DE CIUDADANIA 1023919687, se encuentra inscrito(a) en el Registro Profesional Nacional que lleva esta entidad, en la profesión de INGENIERIA CIVIL con MATRICULA PROFESIONAL 25202-366143 desde el 18 de Agosto de 2017, otorgado(a) mediante Resolución Nacional 1137.

2. Que el(la) MATRICULA PROFESIONAL es la autorización que expide el Estado para que el titular ejerza su profesión en todo el territorio de la República de Colombia, de conformidad con lo dispuesto en la Ley 842 de 2003.

3. Que el(la) referido(a) MATRICULA PROFESIONAL se encuentra **VIGENTE**

4. Que el profesional no tiene antecedentes disciplinarios ético-profesionales.

5. Que la presente certificación se expide en Bogotá, D.C., a los dos (02) días del mes de Febrero del año dos mil veintiseis (2026).

Rubén Dario Ochoa Arbeláez

Firmal del titular (*)

(*)Con el fin de verificar que el titular autoriza su participación en procesos estatales de selección de contratistas. La falta de firma del titular no invalida el Certificado
El presente es un documento público expedido electrónicamente con firma digital que garantiza su plena validez jurídica y probatoria según lo establecido en la Ley 527 de 1999. Para verificar la firma digital, consulte las propiedades del documento original en formato .pdf.
Para verificar la integridad e inalterabilidad del presente documento consulte en el sitio web https://tramites.copnia.gov.co/Copnia_Microsite/CertificateOfGoodStanding/CertificateOfGoodStandingStart indicado el número del certificado que se encuentra en la esquina superior derecha de este documento.